KADIR HAS UNIVERSITY
SCHOOL OF GRADUATE STUDIES
INDUSTRIAL ENGINEERING PROGRAM

ENERGY TRANSITION SCENARIO ANALYSIS FOR TURKEY USING LONG-RANGE ENERGY ALTERNATIVES PLANNING (LEAP)

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MASTER'S THESIS

ISTANBUL, AUGUST 2019

DANIEL JULIUS MASSAGA M.S.Thesis 2019

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Submitted to the School of Graduate Studies
in partial fulfillment of the requirements for the degree of
Master of Science
In

INDUSTRIAL ENGINEERING

KADIR HAS UNIVERSITY

AUGUST 2019

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This work entitled ENERGY TRANSITION SCENARIO ANALYSIS FOR TURKEY USING LONG-RANGE ENERGY ALTERNATIVES PLANNING (LEAP) prepared by DANIEL JULIUS MASSAGA has been judged to be successful at the defense exam on 23 August 2019 and accepted by our jury as

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DATE OF APPROVAL: 23/08/2019

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ENERGY TRANSITION SCENARIO ANALYSIS FOR TURKEY USING LONG-RANGE ENERGY ALTERNATIVES PLANNING (LEAP)

ABSTRACT

Fossil fuel thermal power plants constitute a large part of the Turkish electricity generation capacity. The Turkish government has been developing several energy policy documents to evaluate how various renewable energy sources of the country can be utilized optimally in the generation of electricity for the next 30 years. The study considers three scenarios in the transition to renewable energy for Turkey; the business as usual (BAU), energy conservation (EE) and renewable energy (REN) scenarios were modeled with the help of the LEAP (Long-range Energy Alternatives Planning) software. EE scenario considers the use of energy-efficient appliances across all sectors of demand while emphasizing on more efficiency in electricity production activities, whereas REN scenario considers increasing the share of the renewable energy sources as much as possible in the power generation mix. These scenarios were evaluated in terms of cost and environmental impact. The optimized energy efficiency scenario has been shown to be the optimal energy policy option for Turkey in terms of cost and environmental impact.

Keywords: renewable energy, energy transition, energy efficiency, LEAP, scenario analysis

ENERGY TRANSITION SCENARIO ANALYSIS FOR TURKEY USING LONG-RANGE ENERGY ALTERNATIVES PLANNING (LEAP)

ÖZET

Fosil yakıtlı termik santraller, Türkiye'deki elektrik üretim kapasitesinin büyük bir bölümünü oluşturmaktadır. Türk hükümeti, ülkenin çeşitli yenilenebilir enerji kaynaklarının önümüzdeki 30 yıl boyunca elektrik üretiminde en iyi şekilde nasıl kullanılabileceğini değerlendirmek için çeşitli enerji politikası belgeleri geliştirmektedir. Çalışma, Türkiye için yenilenebilir enerjiye geçişte üç senaryo ele alıyor; her zamanki gibi iş (BAU), enerji tasarrufu (EE) ve yenilenebilir enerji (REN) senaryoları LEAP (Long-range Energy Alternatives Planning) yazılımı yardımıyla modellenmiştir. EE senaryosu, tüm elektrik sektörlerinde enerji verimliliği sağlayan cihazların kullanımını ele alırken, elektrik üretim faaliyetlerinde daha fazla verime vurgu yaparken, REN senaryosu, yenilenebilir enerji kaynaklarının elektrik üretim karışımındaki payını mümkün olduğunca arttırmayı düşünmektedir. Bu senaryolar maliyet ve çevresel etki açısından değerlendirildi. Maliyet eniyileme kullanılarak çözülen enerji tasarrufu senaryosunun, maliyet ve çevresel etki açısından Türkiye için en uygun enerji politikası seçeneği olduğu gösterilmiştir.

Anahtar Kelimeler: LEAP, enerji tasarrufu, yenilenebilir enerji, senaryo analizi

ACKNOWLEDGEMENTS

I would like to extend my gratitude to my Supervisor, Assoc. Prof. Dr. Gökhan Kirkil whose expertise, understanding, generous guidance and support made it possible for me to work on a topic that was of great interest to me. I am hugely indebted to Dr. Kirkil for finding the time to reply my e-mails and for being ever so kind and showing interest in my research and for giving his precious, kind and valuable advice regarding my research.

I also would like to express my gratitude to Assoc. Prof Dr. Ahmet Yücekaya and Assist. Prof. Dr. Emre Çelebi for being so generous as to provide me with a copy of his research and for finding time for me in their busy schedule. Words can never be enough to thank you for your kindness.

I would also like to express my gratitude to all my teachers, friends and colleagues who put their faith in me and urged me to do my best.

To my Loving Parents

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ABBREVIATIONS

EMRA	Energy Market Regulatory Authority
TUIK	Turkish Statistical Institute
MENR	Ministry of Energy and Natural Resources
TEIAS	Turkish Electricity Transmission Corporation
EPIAS	Energy Markets Operations Corporation
MTOE	Million tonnes of oil equivalent
NEEAP	National Energy Efficiency Action Plan
NREAP	National Renewable Energy Action Plan
GHG	Green House Gases
IPCC	Intergovernmental Panel on Climatic Change
IEA	International Energy Agency
LEAP	Long Range Energy Alternatives Planning
NPV	Net Present Value
BAU	Business as Usual Scenario
EE	Energy Efficiency Scenario
REN	Renewable Energy Scenario
CO2eq	Carbon Dioxide Equivalent

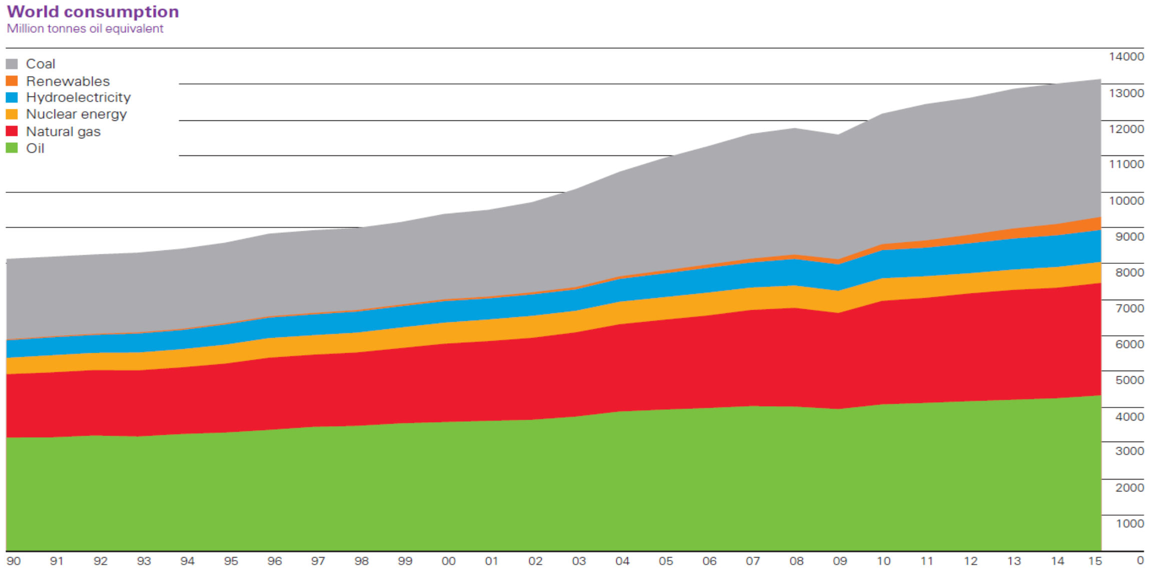
1. INTRODUCTION

1.1. Opening Statement

Energy consumption today, be it in transportation, electricity generation or any other application, is the greatest than any other era of human existence and this is mainly due to worldwide economic and social development. In this modern world, it is almost impossible for a nation to significantly reduce poverty in the absence of massive energy consumption, in fact, according to [Gazzino, et al., 2009], the development of a nation could be expressed in terms of energy consumption per capita, which according to [Akuru, 2009]**,** means countries with high incomes and high human development index tend to have higher energy consumption

Fossil fuels are the most common used source of energy in the world. Coal, fuel oil and natural gas constitute most of the percentage, Figure 1.1 shows the total consumption of primary energy sources in the world. Fossils are known to emit greenhouse gases (GHG) which are harmful to the environment and the society at large. [Kaygusuz, 2007], emphasized that this one of the major reasons that forced policy makers and decision makers to opt for alternative resources in renewable energy sources (RES). RES is a collection of energy producing resources such as hydro, nuclear, solar, wind, geothermal, biofuels and waste which are derived from sources that can be replenished time after time hence sustainable sources of energy.

Turkey is currently one of the fastest growing economies in the world obtaining a Gross Development Product (GDP) of $851.102 Billion in 2017 [World Bank, 2017] and has largest increase in the energy demand among the Organization for Economic Cooperation and Development (OECD) countries. According to World Bank Data, the annual GDP growth rate was 3.18% in 2015 and spiked up to 7.42% in 2016 making Turkey the fastest growing economy among the G20 countries [World Bank Data, 2017]. The GDP growth in Turkey has experienced some fluctuations as illustrated in Figure 1.2, but Turkey’s GDP is generally on the rise. In 2014, Turkey's GDP was $934.186 Billion, which then dropped to $859.797 Billion in 2015.



World primary energy consumption grew by a below-average 1.0% in 2015, the slowest rate of growth since 1998 (other than the decline in the aftermath of the financial crisis). Growth was below average in all regions except Europe & Eurasia. All fuels except oil and nuclear power grew at below-average rates. Oil remains the world's dominant fuel and gained global market share for the first time since 1999, while coal's market share fell to the lowest level since 2005. Renewables in power generation accounted for a record 2.8% of global primary energy consumption.

Figure 1.1 World Total Primary Energy Consumption by fuel type from 1990 up to 2015 (Mtoe) [BP,2016]

Causes of these fluctuations in Turkey's GDP over the recent years could be focused on the widespread street protests that took place in the summer of 2013 against the government, famously known as Gezi Park Protests [Tekinalp, 2016]. In addition to that, in 2015, Turkey held an election to which most citizens found controversial, moreover in the next year Turkey experienced a series of terrorist attacks [Güneyli A., et al, 2017], another reason was the Syrian civil war, it added a social burden on Turkey. The war caused mass migration of Syrian refugees into European countries especially Turkey [Akcapar & Simsek, 2018] and finally, the failed coup attempts in 2016 which caused a state of emergency to be declared for several months in Turkey, all these factors affected the certainty of the Turkish economy.

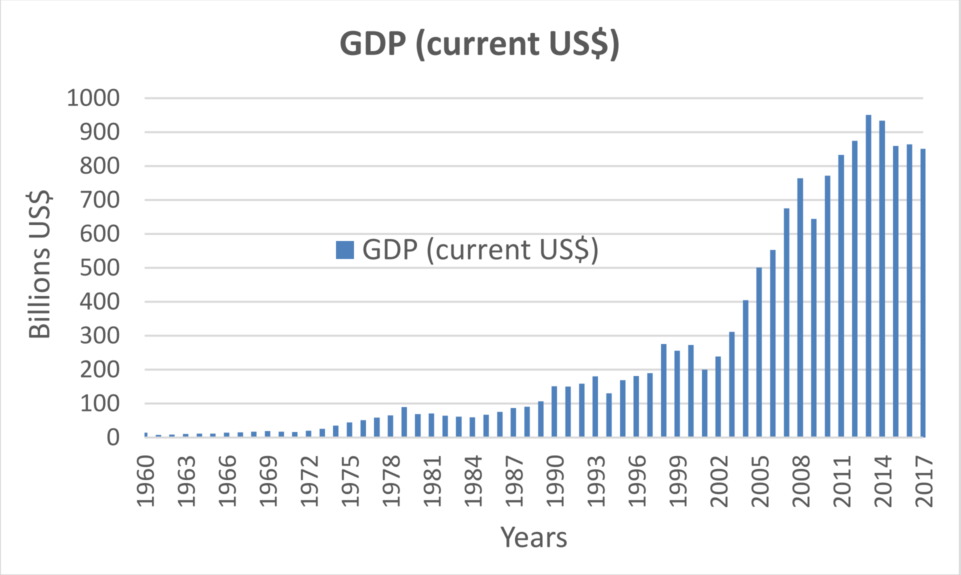


Figure 1.2 Turkey's GDP in Billion US$ from 1960 to 2017(World Bank Data, 2017)

Historically there have been studies that argue on the concept of the relationship between energy consumption and GDP growth but there has never been a direct solution to this concept as conflicting results from different studies emerge to support either side of the argument [Al-mulali & Sab, 2012].

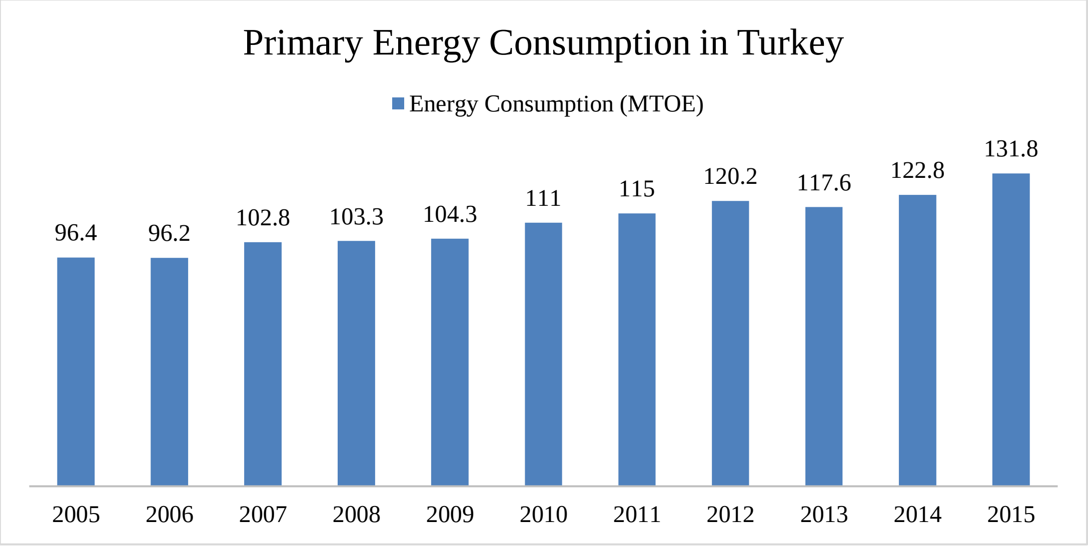


Figure 1.3 Total Primary Energy consumption in Turkey (Mtoe) (BP,2016)

There are some studies that have proven economic growth and energy consumption are highly dependent on each other ([Rezitis & Ahmmad, 2015] and [Liddle & Lung, 2015])**.** In the case of Turkey, this concept is true as illustrated in Figure 1.3, the total energy consumption of Turkey is given from 1965 leading up to 2015 in Million tonnes of oil equivalent (Mtoe), and in Figure 1.4, the annual GDP growth rate of Turkey is given. One can observe the peaks and lows in the same years in both Figures.

1.2. Purpose of The Study

In recent years, Turkey has experienced population, urbanization and industrialization growth, which led to Turkey's significant increase in electricity consumption. According to the IEA report in 2015, Turkey ranked 5th in electricity consumption in Europe [International Energy Agency, 2016]**,** furthermore as result of growth of economic and development indicators, electricity demand in Turkey is expected to continue rising. Fossil fuels in natural gas and coal have for a long period constituted a large part of Turkey's electricity generation mix. Turkey has no natural gas reserves hence Turkey is forced to import natural gas from natural gas rich countries hence making Turkey an energy importing country. Turkey also imports hard coal, heavy fuel oil and electricity. In 2015, the Turkish Statistical Institute (TUIK) reported that between the years 2000 and 2015, the annual expenditure on fuel import increased over 220%, and fuel imports accounted for 20% of total imports in that same period [TUIK, 2018]

Energy importing countries have huge trade deficits, in Turkey's case the Ministry of Trade released a statement through the Turkish Statistical Institute (TUIK), stating that as of July 2018 Turkey's trade deficit was 5.982 Billion USD which indicates a decrease by 32.6% compared to July's 2017 deficit [TUIK, 2018].

This study investigates various pathways for energy transition in Turkey by analyzing the energy transition strategy papers released by Turkish government on Turkey's future energy consumption and generation. These energy plans also aim to promote an energy self-sufficient nation and improve Turkey's energy security mainly by reducing the amount of imported resources used for electricity generation activities and promoting domestic renewable energy resources in Turkey.

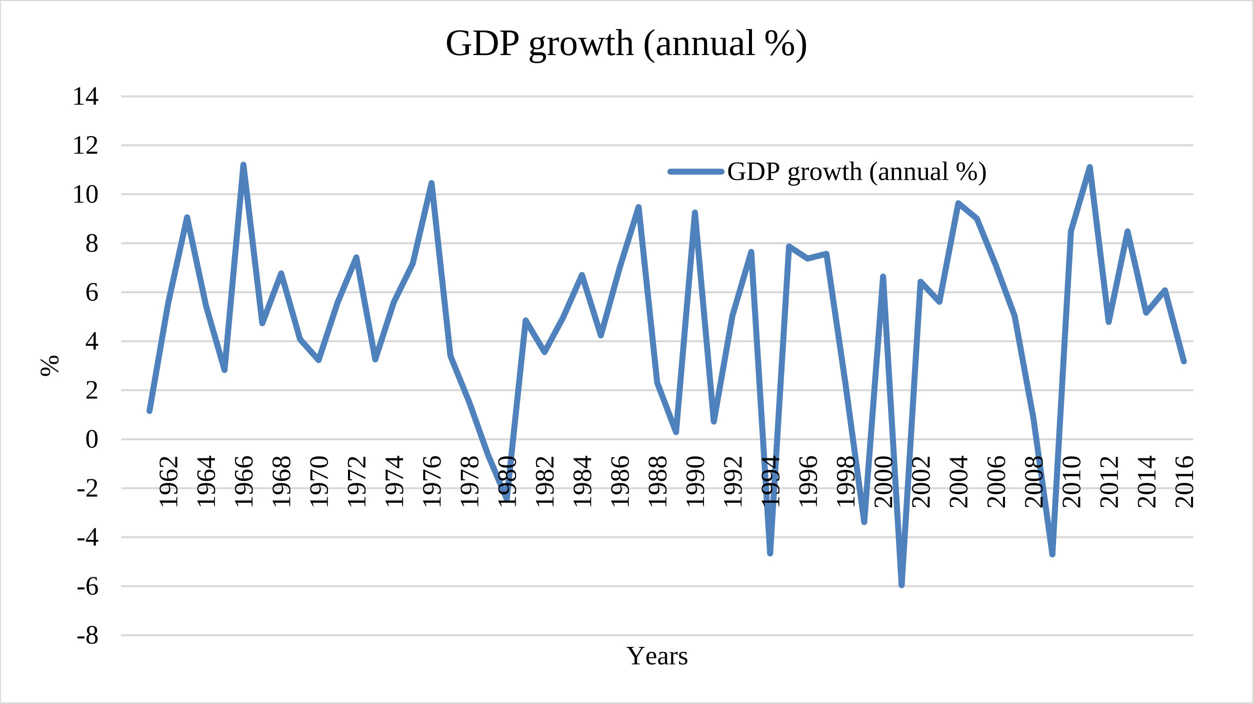


Figure 1.4 Annual GDP Growth in Turkey [World Bank,2017]

In this study, the government's released energy documents on improving energy efficiency [National Energy Efficiency Action Plan (NEEAP) 2017-2023] and renewable energy utilization [National Renewable Energy Action Plan (NREAP) 2017-2023] up to the year 2023, which marks Turkey's 100 years of Independence, will be analyzed and used to create two scenarios that are Renewable Energy (REN) and Energy Efficiency (EE) scenarios. We analyzed each scenario using accounting and optimization models in LEAP to project Turkey's future electricity generation mix. We benchmarked the results with the current trend given it will continue as in the past Business-as-usual scenario (BAU). This study aims to perform an in-depth analysis on how the proposed energy plans by the government fair against the reference scenario (BAU) on aspects such as levels of GHGs emissions, costs of generating electricity, import levels and independence of the Turkish electricity system.

Table 1.1 Energy consumption in Turkey

Years	Population	Electricity Consumption (GWh)
2008	71,517,100	161,948
2009	72,561,312	156,894
2010	73,722,988	172,051
2011	74,724,269	186,100
2012	75,627,384	194,923
2013	76,667,864	198,045
2014	77,695,904	207,375
2015	78,74,1053	217,312
2016	79,814,871	231,204

1.3. Scope of the Study

In chapter 2, an overview of the Turkish electricity sector will be given. Brief information about the history of the Turkish electricity market, the current trends in the electricity market, the behavior of electricity consumption in Turkey and finally the chapter will focus on the historical and current status of RES utilization in Turkey’s electricity generation mix and how well RES related policies and regulations are implemented in the country.

In chapter 3, the methodology used in this study: Long Term Energy Alternatives Planning (LEAP) will be briefly introduced and some special features of the modeling platform will be explained followed up by a detailed introduction of Turkey’s LEAP model. Furthermore, this chapter will formally introduce the summaries of the Ministry of Energy and Natural Resources documents: NREAP and NEEAP, which will be used to create three scenarios in

LEAP. Then finally, introduce the scenarios namely Business as Usual (BAU), Energy Efficiency (EE) and Renewable Energy Resources (REN) scenarios and their properties.

Chapter 4 includes the discussions on the results from the three scenarios. The demand, supply, amount of GHG emissions and costs of each scenario will be displayed and then results of each scenario will be benchmarked against the reference scenario (BAU).

In chapter 5, the study’s shortcomings will be explained and recommendations on future studies will be given.

1.4. Literature Review

Modeling the energy demand and consumption of a region is usually based on the region’s historical energy consumption and the correlation of this energy consumption with other social and economic drivers such as GDP growth, income per capita, growth in population, climate change, price of energy and so on. Over the years there has been a few studies analyzing energy consumption in different counties using different models including various independent drivers. In this section the previous studies on energy forecasting and modelling in Turkey will be discussed.

Energy demand forecasting is very important to policy makers all over the world even more so for developing energy markets such as Turkey [Ediger & Akar, 2007]. In Turkey, government bodies such as the Ministry of Energy and Natural Resources (MENR) are responsible for carrying out energy demand and supply forecasting studies and all other energy related issues [Ediger & Tatlidil, 2002], in fact one of MENR’s objectives is to provide high economic and social contribution to national welfare by utilizing energy and natural resources in the most efficient and environmental-friendly manner [MENR, 2018]. In hand with the MENR, the State’s Planning Organization (SPOs) and the State’s Institute of Statistics (SIS, currently known as TUIK) were also responsible in developing different energy models that forecasted energy demand in Turkey.

In 1984, Turkey’s MENR started using Model for Analysis of Demand (MAED) to forecast medium to long range energy demand and the Ministry used Wien Automatic System Planning (WASP) to calibrate the most favorable future investment and production plans [Ediger and Tatildil, 2002]. The MAED method was then applied six times over a 20 years’ period, from 1986 to 2005 specifically MAED studies were conducted in the years 1986, 1990, 1994, 1997, 2000 and 2005. The demand forecast results from these studies were regarded to be greater than the actual demand figures. For instance, [Ediger and Tatildil, 2002] tested the consistency and accuracy of the MAED models, they considered 1999 as the final year for the conducted studies. The results implied that in MAED’86 model the results of the study forecasted 34% more than the actual demand figures, in the other MAED models leading up to 1999: MAED’90, MAED’94 and MAED’97, they respectively recorded 33%, 9% and 6% higher demand compared to the actual demand. The authors went on to say that, MAED is more accurate when used to forecast medium to short range periods compared to long term periods.

Correspondingly, other methods have been applied in Turkey. In 2002, Ediger and Tatildil (2002) used cycle analysis to forecast future energy demand in Turkey. The model uses energy demand trends in the historical data to forecast better results. In their study, they predicted Turkey’s primary energy demand would reach 135 Million tons of oil equivalent (TOE) in 2010.

In 2004, Ozturk et al predicted Turkey’s energy demand based on economic and demographic drivers such as the amount of imports and exports in Turkey, the gross national product (GNP), and population growth. They used a genetic algorithm approach to estimate future energy demand. And the results of their study were more suitable compared to results of the government model.

In 2006, Sözen et al developed a model to predict the future energy consumption in Turkey using Artificial Neuronal Networks (ANN). In this study, the authors developed equations that were used to forecast Turkey’s future net energy consumption (NEC). Furthermore, according to their results the NEC was well predicted within acceptable errors and the coefficients of determination were 0.999 and 1 for training and test data respectively. They went on to emphasize the importance of ANN approach in finding solutions that allow energy application studies to present viable and attractive results.

In 2007, Ediger & Akar used Autoregressive Integrated Moving Average (ARIMA) and Seasonal Autoregressive Integrated Moving Average to analyze the primary energy demand in Turkey and forecast future demand. In their study, the authors used data from 1950 to 2005 and predicted the future primary energy demand from 2006 to 2020. In their results they suggested that Turkey's primary energy demand will increase at a rate of 3.3%.

Another hot research topic in Turkey is forecasting the future electricity demand, supply and, consumption. In 2010, Altun & Cunkas applied ANN to forecast Turkey's long-term electricity demand using economic data. The authors developed two ANN structures, three-layered back propagation and a recurrent neural network (RNN) in order to forecast the future electricity demand for the years 2008 to 2014. The RNN approach yielded the best results.
In 2011, Kavaklioglu (2011) used Support Vector Regression (SVR) method to forecast electricity consumption in Turkey. In this study, the author modeled the electricity consumption in Turkey as a function of socio-economic drivers such as population, GNP, imports and exports using the ε-SVR format. The author used data from 1975 to 2006 to predict the electricity consumption in Turkey up to the year 2025.

In 2014, Hamzacebi & Anvi Es (2014) proposed an optimized grey model (OGM) to predict total electricity demand in Turkey from 2013 up to 2025. In their model they applied both direct and iterative approaches. The authors also compared their proposed model's results with results from other studies in the literature and showed how their model's results was superior. In addition to that, they also calculated the amount of primary energy resources required to supply the forecasted electricity demand for the years 2015, 2020 and 2025.

In recent years, there has been several studies emphasizing on the importance of utilizing Turkey’s domestic renewable energy resources. In 2011, Melikoglu & Albostan used the government’s “Vision 2023” energy targets to predict how RES can be utilized by Turkey in less than 15 years. In addition to that, the author also states that given the wind, hydropower, geothermal and solar energy potentials in Turkey, these resources can supply the electricity demand predicted in Turkey’s Vision 2023 targets of 530,000 GWh.

In 2012, Toklu & Kaygusuz (2012) studied the potential of utilizing RES in Turkey and came up with a conclusion that, biomass, wind, hydropower, geothermal and solar show huge potential. The author added that RES is more suitable for clean and sustainable energy environment in Turkey because with utilization of RES, emission of greenhouse gases (GHGs) would decrease significantly.

In 2016, Ozcan (2016) spoke about the important role RES play in promoting Turkey’s self-sufficient electricity supply. In the study, the author analyzed the current investments in RES in Turkey and compares them to the government plans “Vision 2023” energy targets, and he concludes that the current pace will not meet the targets, the author goes on to suggest that the government should think of introducing a new energy policy specific for RES activities in Turkey to speed up the pace of RES utilization.

There have been few LEAP applications in Turkey. Ozer et al. (2013) used LEAP to analyze the potential of reducing emissions in Turkish electricity sector using various government policies to create scenarios. They created two scenarios: Baseline Scenario (BAU) and Mitigation scenario, where 2006 was the base year and 2030 the final year. The comparison of the results of the two scenarios over the modeled period showed that carbon dioxide emissions (CO2) will increase significantly in BAU scenario while the Mitigation scenario’s electricity-based CO2 emission grew at an annual rate of 5.8%, which reciprocated a 17.5% mitigation ratio. Furthermore, the results suggested that the cumulative CO2 emission reduction between the two scenarios over the modeled period was 903 Million tons CO2eq.

In 2015, Ates (2015) applied LEAP in assessing the energy efficiency and carbon dioxide mitigation potential in Turkey’s iron and steel industries. The author created four scenarios: Business as Usual (BAU), Accelerated Energy Efficiency Improvement (AEI), Cleaner Production and Technology scenario (CPT) and Slow-speed Energy Efficiency Improvement scenario (SEI), where 2010 was the base year and 2030 the final year. The results of the study suggest that, the energy intensity rate among the four scenarios was lowest in AEI scenario at 51% compared to BAU scenario. The results implemented that, the CPT scenario had the highest economic potential at $1.8 Billion. The CPT scenario also had the least CO2 emissions at 14.5 Million tons of CO2 (MtCO2). The author suggests that, if there are significant measures taken in Turkey, there is a huge potential for decreasing the energy consumption and GHGs emissions from iron and steel industries and the industry sector at large.

Ediger & Çamdali (2007) performed a fossil fuel linear programming optimization analysis or Turkey. The authors performed the analysis using the exergy analysis approach based solely on the concept of the second law of thermodynamics, which considers both the quality and quantity of the energy produced. In their analysis the authors state that inter-fuel substitution between different fossil fuel resources will lead to a better generation mix for Turkey. The results suggested by increasing domestic electricity production from lignite, fuel oil and hard coal would decrease Turkey’s energy imports. Furthermore, result also suggested that imported natural gas will still play a major role in the mix as it will be used to meet the rest of demand. In conclusion, the fossil fuel costs would decrease by 1.67 Billion USD if domestic electricity production from oil, lignite and hard coal are given a chance.

In 2010, (Askar, 2010) aimed to find the least cost set of technologies in Turkey that would meet the demand between the years 2010-2025 mainly by decreasing CO2 emissions. In order to perform the analysis, the author proposed a mathematical programming method with a bottom-up approach model. The model was represented as a simple version of the energy system as a flow chart in three different modules: the primary energy suppliers, energy conversion technologies and the final energy demand module. Results from this study showed that most of the electricity demand through the modelled period was particularly met by renewable energy resources such as hydro, geothermal, solar and wind.

In 2017, (Sulukan, Sağlam, & Uyar, 2017) established a model for Turkey using MARKAL energy system model and use the model to conduct an analysis of alternative technological pathways that the country may pursue over the 2005-2020 period. Based on their model's results, the country would decrease dependence on imported fuels if firstly, domestic renewable energy resources are greatly promoted but more importantly the whole energy system should be improved parallel to the country's national energy strategies. The results also suggest that energy efficiency measures should be applied in all energy technologies and all main sectors of demand and in transmission and distribution activities and finally, the county should try to increase cogeneration practices so as to minimize both the demand and the costs.

There are studies in Turkey that focus on optimization energy models to forecast either the future energy generation mix, or future electricity demand. This study will act as the pioneer LEAP optimization and accounting study for Turkey. The results from the accounting model will be compared to the results from the optimization model.

2. OVERVIEW OF TURKISH ELECTRICITY SECTOR

2.1. The Turkish Electricity Market

The history of the Turkish electricity market dates to 1970, the year that marked the inauguration of the Turkish Electricity Authority famously known amongst the locals as Türkiye Elektrik Kurumu (TEK). TEK, a state-owned institution ran all market activities and it was also responsible for generation, transmission and distribution activities too. This created a monopoly in the state's electricity market meaning no private investments were allowed in the market. Later in the years 1980s leading up to the mid-1990s, the Turkish government started pursuing privatization of electricity generation. Liberalization of the market was due to the increasing demand for electricity during the 1980s, especially by power hungry industries such steel production, automotive and mining. TEK controlled the electricity prices, the prices went up meanwhile the supply couldn't meet the demand which eventually led to recurring power outages across the country. Another major reason that led to electricity market liberalization in Turkey was lack of public funds to invest in state owned companies. Boycotting TEK was initiated by the energy sector seeing that a monopoly system doesn't fit the country, the sector and the state at large opted for Public Private Partnership (PPP) models of electricity generation.

Turkey was one of the first countries that managed to establish its own legislation on PPP. In 1984, the state chose to abandon the monopoly of the vertically integrated TEK by enacting the law numbered 3096 which allowed private companies involvement in the energy sector specifically for electricity generation projects. With the introduction of this law, existing generation and distribution companies practiced privatization through Transfer of Operating Rights (TOOR) contracts, while on the other hand, new generation facilities were subjected to Build-Operate-Transfer (BOT) contracts and some companies could produce their own electricity in the auto-producer system.

In attempt to ease and facilitate the nation's privatization procedures, TEK was restructured into two departments in 1993. One department was responsible for electricity generation (TEAŞ -Turkish Electricity Generation and Transmission Company) while the other department dealt with distribution of electricity (TEDAŞ – Turkish Electricity Distribution Company). TEDAŞ and TEAŞ were responsible for attracting private companies to sign whether BOT, TOOR or BOO contracts.

The BOT model was officially introduced in June 08, 1994 under Law No 3996 famously known as "BOT Law". Under BOT contracts, private investors were given the right to build a generation facility, have control over all operations activities concerning the facility for a certain period, sell the produced electricity to the state within the agreed period and then transfer the facility to the state the end of the period at no cost.

Under TOOR contracts, state owned generation, transmission and distribution facilities were transferred to private investors for a given amount of time. As the name of the model states, only the operation facility activities were transferred for a period of time to the private investors not ownership and furthermore any investments made by the private investor be it to increase efficiency of the facilities or speed up operations during the agreed period were assumed to be owned by the state-owned facility.

Further down the years, in 1997 a new model: Build-Operate-Own model was introduced under Law No 4283 which allowed for the Establishment and Operation of Electricity Generation Facilities and Sale of Electricity ("BOO Law"). Under the BOO law, investors could build generation facilities and own them without any time limit. This law was specifically enacted for the establishment of thermal power plants.

Despite all these efforts to create a liberal market, most of the market was still overseen by state-owned companies. Furthermore, the BOT, TOOR and BOO contracts included "take or pay" obligations where fixed quantities and prices were agreed on over the contract period, this did not create a competitive environment in the market. Evidently there was need of a more competitive market which led to the enactment of the Electricity Market Law (EML) under Law No 4268.

The much awaited EML was introduced to the public in early 2001, it paved the way for a free competitive market in electricity generation and distribution for Turkey. Under this law, TEAŞ was to be broken down into three state-owned public companies responsible for the generation, distribution and trade of electricity, while on the other hand, TEDAŞ was to establish 20 companies each of which was granted license to perform distribution activities in relevant distribution areas, this meant all distribution activities were still under the state. Most importantly, under the EML law, a new regulatory body was to be established and it would oversee the Turkish power market, set tariffs, issue licenses and prevent any uncompetitive activities.

Later in 2001, TEAŞ was restructured to form Turkish Electricity Transmission Corporation (TEİAŞ), Turkish Electricity Generation Corporation (EÜAŞ) and Turkish Electricity Trading Corporation (TETAŞ). Distribution activities would be handled by the Turkish Electricity Distribution Company (TEDAS), its affiliates and licensed private sector distribution companies in their respective regions as illustrated in Figure 2.1. In February 2002, the Electricity Market Regulatory Authority (EMRA) was established and started issuing new regulations on licensing and the electricity market, which took full effect in later the same year (TEIAS, 2018)

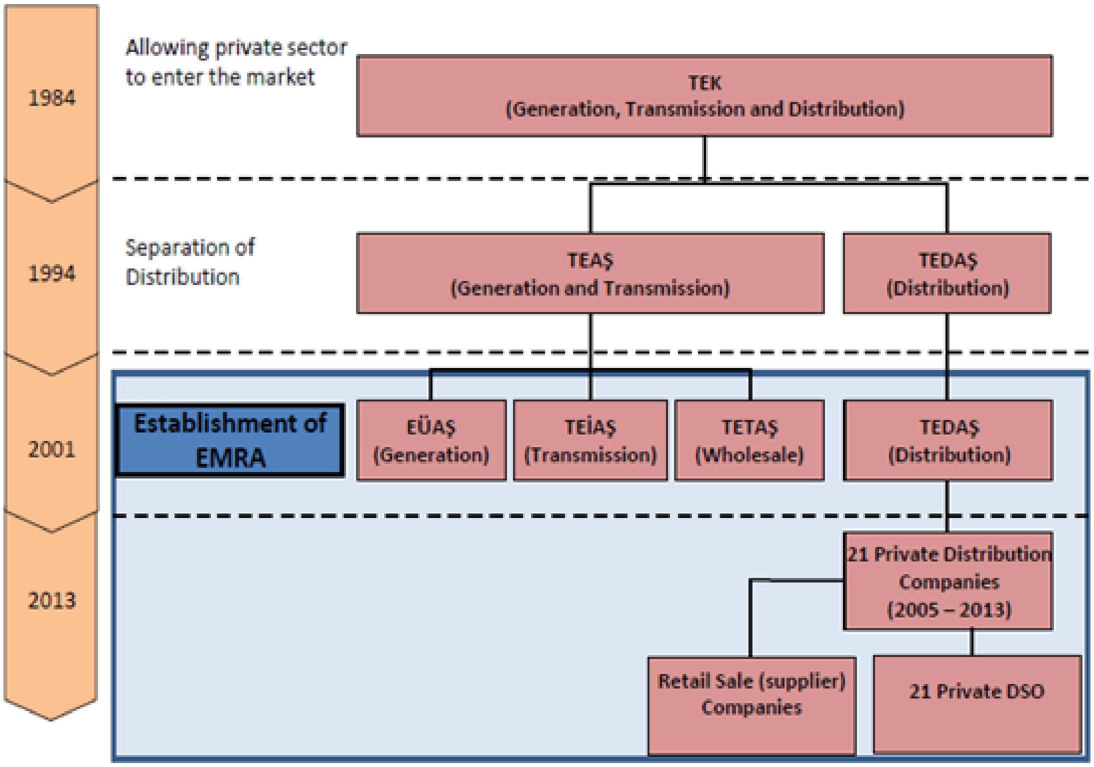


Figure 2.1 The Structure of the Current Electricity Sector in Turkey [IAEA,2014]

2.2. Current Electricity Market in Turkey

The EML ensured a competitive market where private investors be it local or foreign would be attracted to make investments. There are currently two regulatory bodies under the new EML, Ministry of Energy and Natural Resources (MENR) and EMRA. MENR is responsible in determining the country’s short-term and long-term energy and resources requirements, setting objectives and making appropriate policies to meet determined objectives, supervising the power of public facilities and to co-ordinate building of new facilities, production and distribution activities.

On the hand, EMRA was responsible for preparing and implementing electricity market legislation, establish and oversee the tariff pricing mechanism and most importantly to regulate and supervise the electricity market, revoking and issuing licenses to compatible investors participating in the market. EMRA licenses granted under the EML are as follows:

a. Production licenses,

b. Auto-producer licenses,
c. Auto-producer group licenses,
d. Distribution licenses,
e. Transmission licenses,
f. Wholesale licenses, and
g. Retail licenses

The state's responsibility was to conduct transmission activities under TEIAS and on top of that, the state acted as a supervisory and regulatory body for players under the EML law.
Since the enactment of the first EML law in 2001, it has been subjected to several amendments over the years, some major amendments include the introduction of Day-Ahead planning in 2009. Day-Ahead planning created a system where the system operator works easier and makes contribution to real-time market balancing. Day-Ahead Market (DAM) came into force in 2011. In DAM, there's opportunities to buy and sell energy for the day ahead in hand with the existing bilateral contracts of the market participants [Kiral, Kocatepe, & Uzunoglu, 2016].

In March 2013, one more amendment marked the introduction of the New EML (Law No 6446) and a new License Regulation on Generating Electricity Without a License (the "Unlicensed Generation Regulation") which entered into force in November 2013. Under the Unlicensed Generation Regulation, power generating facilities with a capacity of up to 1MW based on RES did not require a license to operate. In March 2015, the Energy Markets Operations Corporation (EPIAS) was established in line with the new EML (6446). EPIAS was established to act as a market operator, other than the already acting system operator TEIAS to manage energy stock exchange and become an attractive investment opportunity [IEA, 2016].

Intraday market started operating in 2015, it created a market place that provided extra means for balancing especially for renewable energy resources. In addition to that, in 2016, a new investment model for renewables, Renewable Energy Resources Area Support Mechanism was introduced to support renewable energy investments and motivate local manufacturing of renewable energy resources electricity generation facilities [EPIAS, 2016].

Further efforts are being made to integrate the Turkish power system. Recently there have been efforts to connect the Turkish power transmission system to the European Union (EU) power network. After a successful series of technical studies and trials carried out by Turkey's electricity transmission company, TEIAS, for the parallel operation between the Turkish power system and the European Network of Transmission System Operators for Electricity (ENTSO-E) Continental Europe Synchronous Area, the Turkish electricity system started to operate permanently with ENTSO-E, after the approval of the ENTSO-E Continental Europe Regional Group (ENTSO-E RG CE) in 2014. TEIAS complied with the regulations and obligations existing in the ENTSO-E RGCE Operational Handbook, thereafter, the "Long Term Agreement" was signed between TEIAS and ENTSO-E in April 15th, 2015 [TEIAS, 2019].

This marked the alliance of the Turkish electricity market with the European Internal Electricity Market. Currently, Turkey transfers electricity to and from Europe. Turkey uses interconnections with Bulgaria and Greece to export a maximum of 400 MW and import capacity of up to 500 MW. In 2015, Turkey imported a total of 10.3 TWh from Bulgaria (7.1 TWh) and Greece (3.2 TWh) which accounted for 2% of total electricity consumption in that year. In addition, an agreement signed on January 14th, 2016, Turkey's TEIAS became the first and only observer member in the newly initiated process of Observer Membership Status in the ENTSO-E. [Tagliapietra & Zachmann, 2015].

2.3. Electricity Consumption in Turkey

In recent years, electricity has emerged as an important energy form. Governments all over the world are on a mission to ensure they provide electricity in their respective countries. This is no different in Turkey, the Turkish citizens all over country have been supplied with this service since 1990 [World Bank, 2018]. Power outages in Turkey are a rare feature, the most recent power outage in Turkey was in March 2015 and it latest for ten (10) hours

[IEA,2016]. The blackout was a result of hydro oversupply from the eastern part of Turkey in transmission capacity storage. A heavy loaded transmission line tripped and led to disconnection of the Turkish electricity system from the ENTSO-E Continental Europe grid and eventually led to the blackout [ENTESO-E, 2015]

Over the years Turkey has experienced an increase in electricity demand due to growth of economic, demographic and social factors such as economic growth, urbanization, industrialization, population growth and so on. Electricity demand in Turkey reached 257.22 TWh in 2014 and the gross demand of electricity in 2017 reached 296.702 TWh, this shows an increase of 15.53% in electricity demand over a period of four years. Net consumption of electricity in 2014 was 207.375 TWh, respectively 2017 recorded 249.02 TWh, the latter is due to distribution and transmission losses [TEIAS, 2017]. Figure 2.2 shows the electricity consumption in Turkey in MWh from 1975 up to 2015.

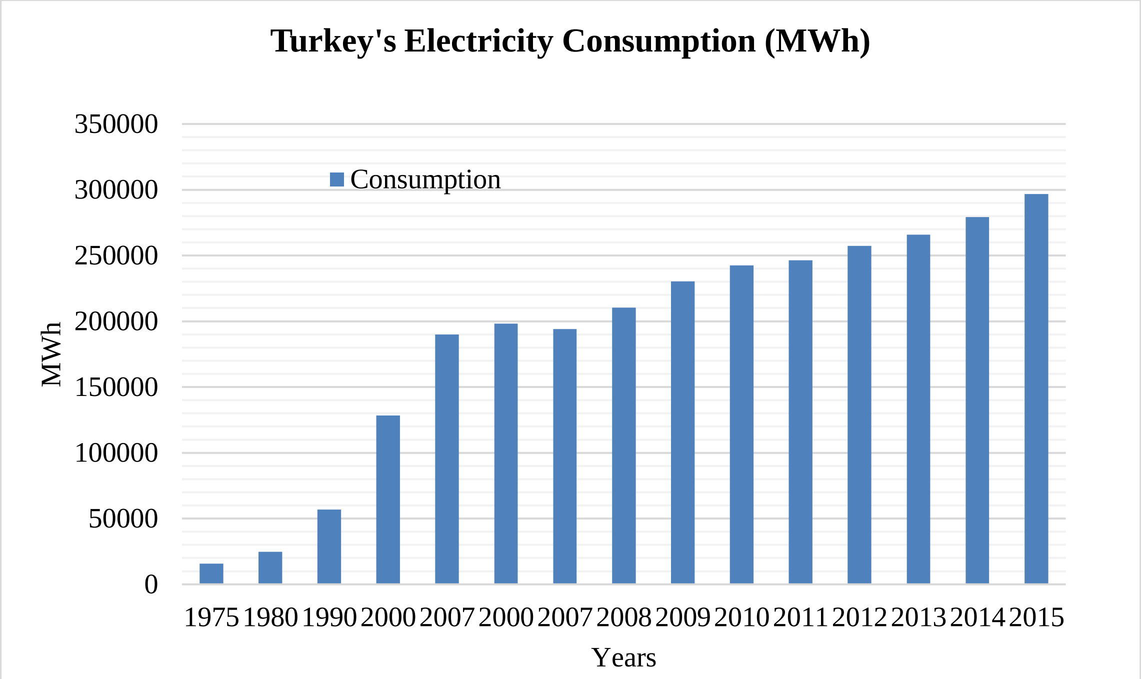


Figure 2.2 Electricity Consumption in Turkey [TEIAS,2017]

According to the data from the International Energy Agency, there are five sectors that consume significant amounts of electricity in Turkey namely;

- Industry Sector
- Residential Sector
- Commercial and public services Sector
- Agriculture Sector and,
- Transport Sector

In this study, electricity consumption by the transportation sector and agriculture sector are deemed insignificant hence the study only covers three main consumers: industrial, residential, and commercial and public services sectors. as illustrated in Figure 2.3, where the shares of electricity consumption by sector are given.

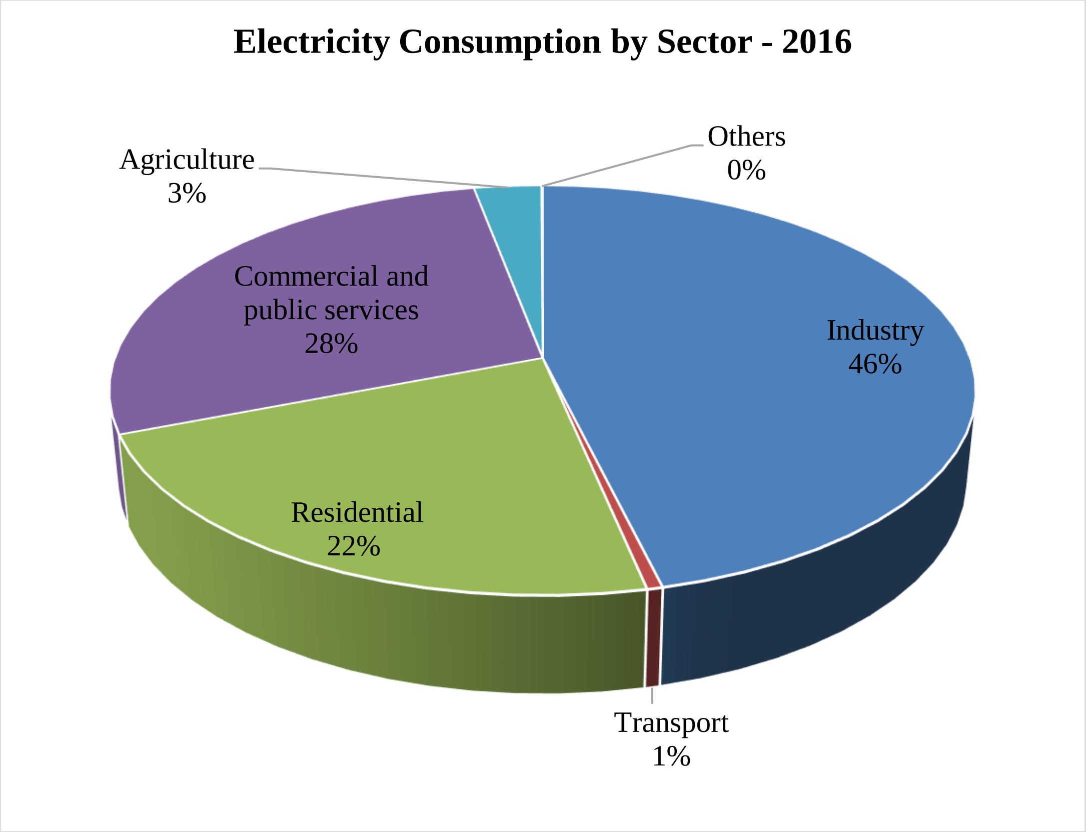


Figure 2.3 Electricity consumption by Sector [IEA, 2016]

2.3.1. Industry sector

The most electricity consuming sector in Turkey has always been the industrial sector. Major industries in Turkey are based on production of agriculture products such as tea, hazelnuts, tobacco, tomatoes, watermelons and so on. Other major industries include textile, food processing, automotive, electronics, mining, tourism, construction, lumber and paper.

Turkish products are very marketable in the world because of their high quality and durability and they are famous by their brand, "Made in Turkey". The products are mainly exported to countries in the European Union (EU), Middle East and the USA. Figure 2.4 shows the shares of Turkey's major exports partners in 2017. There is recent diversity in products exported out of Turkey, ranging from vehicles to jewelry, in Figure 2.5, the top ten products exported out of Turkey are given from 2012 to 2017 in Billions.

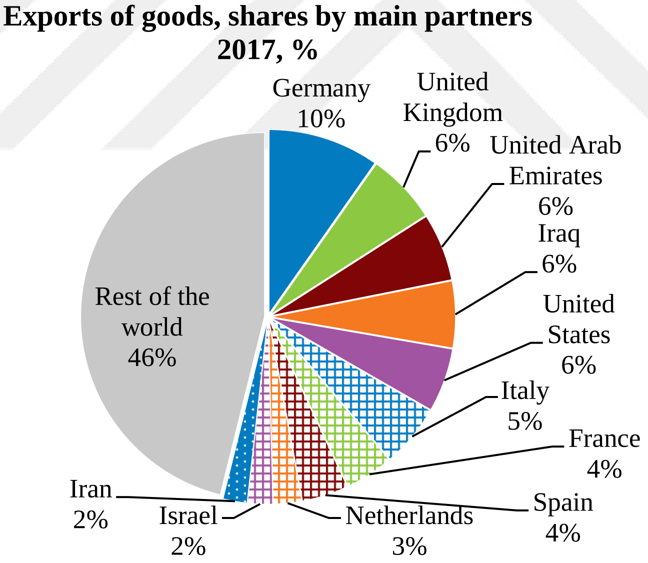


Figure 2.4 Turkey's major Export Partners [OECD, 2018]

Through these exports and import activities, the Turkish industrial sector established itself as one of the major contributors of value-added percentage in Turkey's GDP. In 2015, 27.9% of Turkey's GDP was from the value added by the industrial sector, in addition to this fact, the manufacturing sector alone, contributed 17.51% of the total 27.9%. In 2017, the value added as percentage of GDP from the industry sector rose to 29.19% [World Bank, 2017].

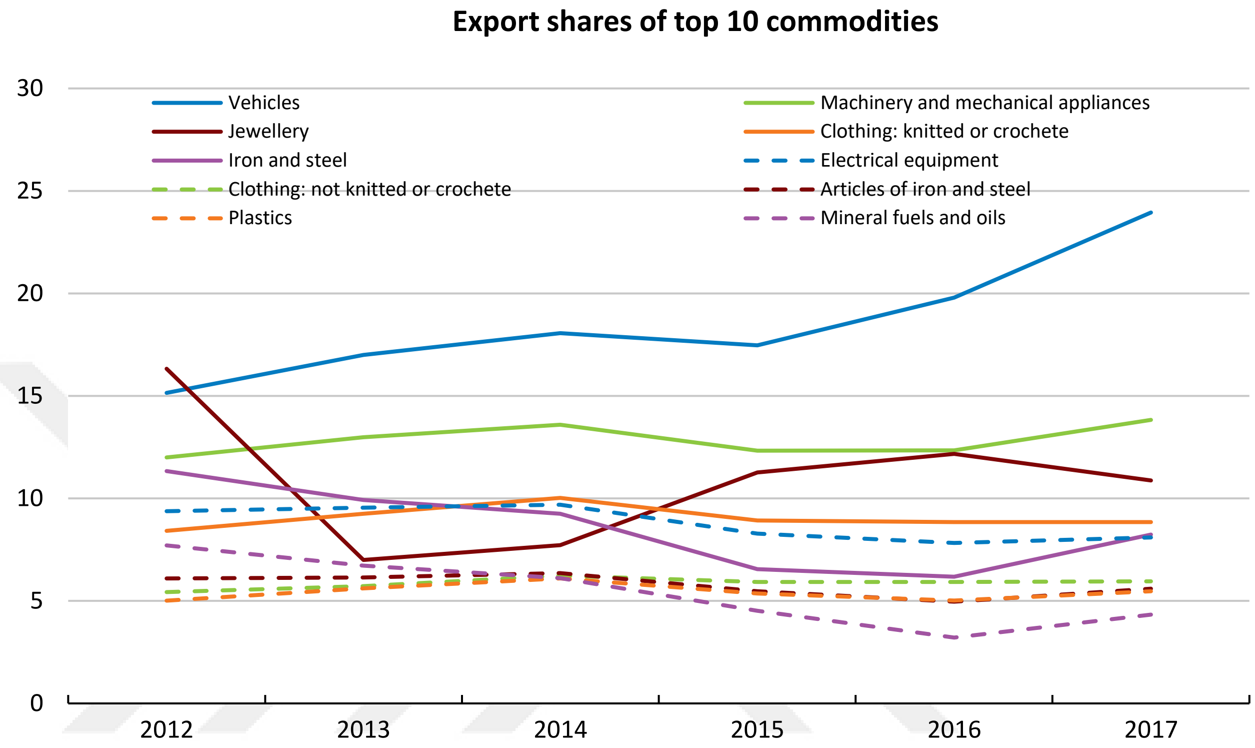


Figure 2.5 Top Ten Exported Products in Turkey [OECD, 2018]

According to the International Energy Agency report, Turkey was said to rank high among the OECD countries with energy intensive industries [IEA, 2009]. Figure 2.6 shows comparison in electricity consumption in Turkey's industries against other sectors from 1990 up to 2011 in TWh. From Figure 2.6, the industrial sector consumes almost half of the total annual electricity consumption. The industrial sector consumed 95.844 TWh which accounted for 46% of total electricity consumption in 2014. Consumption went up in 2017, as the value rose up to 105.491 TWh.

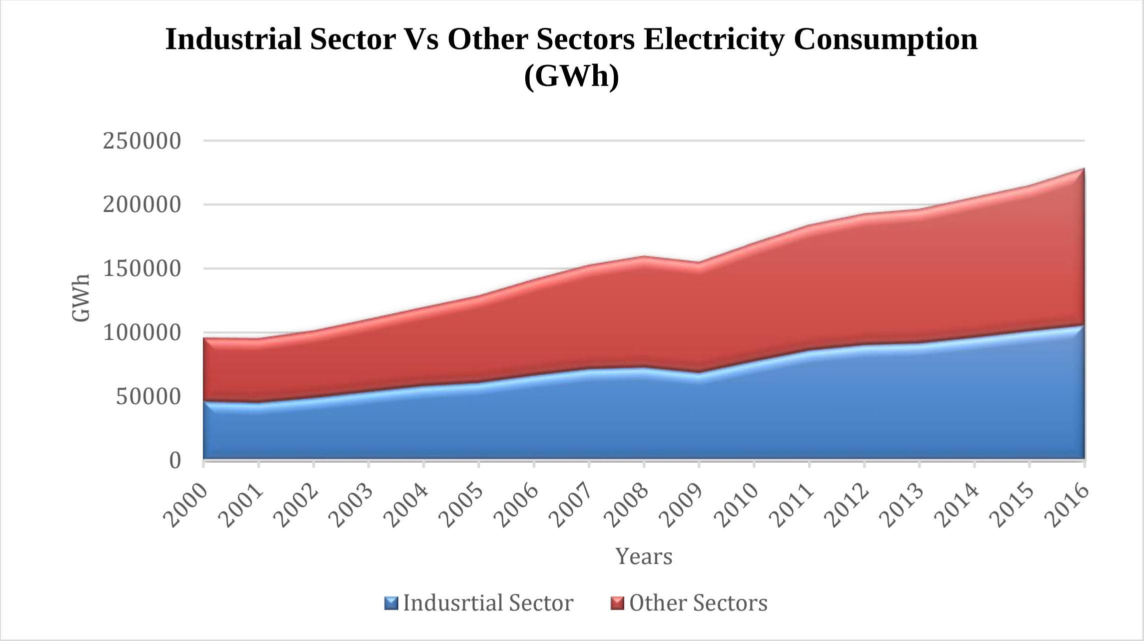


Figure 2.6 Electricity consumption in Turkish Industries [IEA,2016]

2.3.2. Residential sector

According to the results of the census carried out by the Address Based Population Registration System (ABPRS) in 2011; the number of households in Turkey was 19,481,678 and the average household size was 3.8 [TUIK,2013]. The average household size dropped to 3.5 in 2016 [TUIK,2017]. According to my calculations, Turkey's total households in 2016 was around 22.804 Million. The demand for houses in Turkey increases yearly so do the sales of houses in Turkey. This rise in demand is due to two main factors: rapid population growth and the growth rate of urbanization in Turkey. Population growth in Turkey's urban cities is greater than the overall growth of population, according to World Bank data, population growth in Turkey was 1.54% in 2017 while the urbanization rate was 2.22%. Figure 2.7 better illustrates this concept from 1960 to 2017.

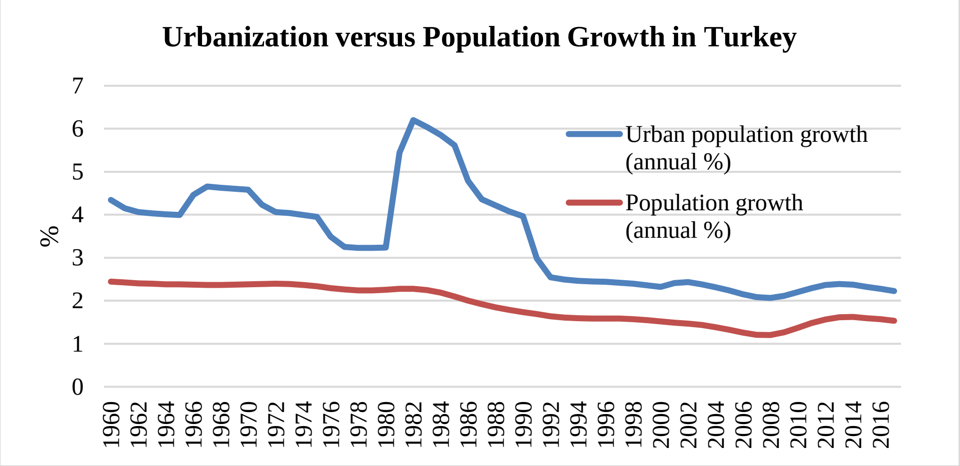


Figure 2.7 Population Growth and Urbanization in Turkey [TEIAS,2017]

This rural to urban migration and increase in household sizes in Turkey depicts high electricity demand and energy overall. Electricity consumption in residential sector was 41.464 TWh in 2010, moreover consumption reached 51.33 TWh in 2016 which marked a 23.79% increase in consumption. Figure 2.8 shows the increase in electricity consumption of Turkey's residential sector over the years.

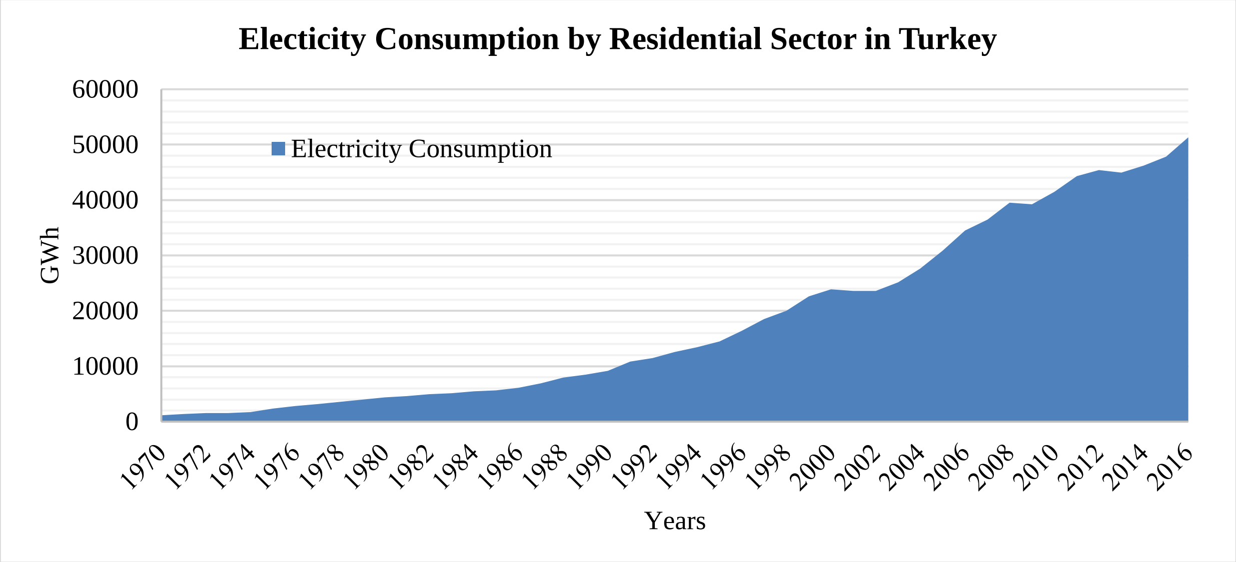


Figure 2.8 Electricity consumption in Turkey's Residential Sector [TEIAS,2017]

2.3.3. Commercial and services sector

Turkey's economy is booming especially with increase in number of foreign investments. According to Turkey's Ministry of Economy (MOE) the number of firms with foreign capital was 7% of total companies but the share rocketed up to 58.4% in 2017. [Turkey's Ministry of Foreign Affairs (MFA), 2018]. These foreign companies are spread out in almost all sectors, such automotive industries, machinery and equipment, energy, real estate, construction, aerospace and defense, retail, financial services and so on.

In return Turkey 's economy keeps rising and because of these activities conducted by foreign companies in Turkey together with local services contribute the largest share of value added to GDP. Value added to commercial and public services in Turkey contributed $453.76 Billion (51.13%) to overall GDP in 2017 [World Bank, 2017]. Turkey also benefits from job opportunities created by these companies hence it's expected that Turkey's income per capita will increase and decrease of unemployment rate in the coming years.

Electricity consumption by the commercial and public services had small share in 1970s but in the past two decades the consumption has been going up as it can be seen in Figure 2.9, whereby according to TEIAS the consumption sectors are categorized as household, governmental buildings, commercial, illumination, industrial, and others. Others sector is comprised of the total share of electricity consumption in the agriculture, livestock and fishery sector and municipal water abstraction pumping facilities and other public services. Commercial facilities consumed 27.70 TWh of electricity in 2010, in hand with growth and development of the commercial sector through local and foreign investments and policies by the government, in 2016, the consumption reached 43.47 TWh which was almost 19% of total electricity consumption [TEIAS,2017].

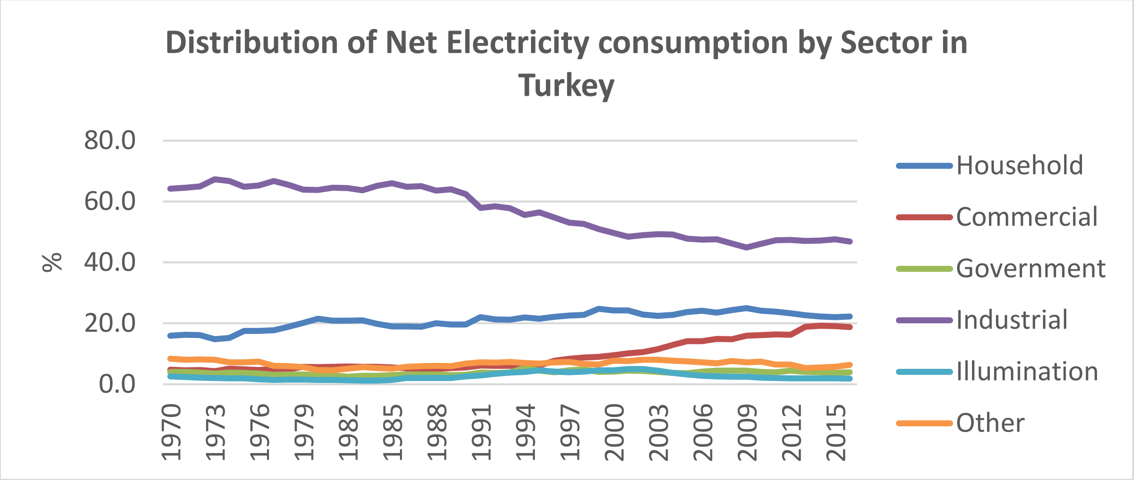


Figure 2.9 Shares of Net Electricity Consumption by Sector in Turkey (TEIAS, 2017**)**

2.4. Electricity Generation in Turkey

This significance increase of electricity demand requires enough and available electricity generation resources. Turkey is known for its rich fossil and renewable energy resources. Fossil fuels have been the dominant source of electricity generation in Turkey for many years. Among IEA member countries, Turkey ranked ninth-highest in shares of fossil fuel used for electricity generation in 2015, with a fifth-highest share in natural gas consumption [IEA, 2016]. Evidently, in 2017 natural gas contributed 37.2% of total electricity generated. Imported Coal and lignite were close second with a total of 32.8% of the total electricity generated. RES combined to generate 29.7% of total electricity generated in 2017. Hydro powered power plants (HPPs) contributed majority of the share among other RES (Table 2.1).

According to reports from the Ministry of Energy and Natural Resources, in 2017 Turkey invested a staggering 6.2 Billion USD in electricity generation plants. With this huge investment Turkey saw 5840 MW of capacity being taken into operation in 2017 and the total installed capacity in Turkey increased by 8.5% compared to 2016 values (see Table 2.2) [TEIAS, 2018]. The total installed capacity in Turkey was recorded at 85,200 MW by the end of 2017.

Table 2.1 Electricity generation by Resource in 2017 [TEIAS, 2018]

SOURCE	**GENERATION (GWh)**	**CONTRIBUTION (%)**
Imported Coal	51118.1	17.2
Hard Coal+Asphaltite	5663.8	1.9
Lignite	40694.4	13.7
Natural Gas	110490.0	37.2
Liquid Fuels	1199.9	0.4
Dam	41312.6	13.9
N.Lake And Run Of River	16905.9	5.7
Waste Heat	848.3	0.3
Wind	17903.8	6.0
Renewable Waste+ Waste	2124.0	0.7
Geothermal	6127.5	2.1
Solar	2889.3	1.0
TOTAL	**297,277.5**	**100,0**

Majority shares of investments made in Turkey’s power system in 2017 were based on natural gas and coal fired power plants. Natural gas power plants with a capacity of 2,621 MW were installed in 2017 and the investment cost for these power plants was around 2.23 Billion USD. Imported coal power plants with a capacity of 320 MW incurred an investment cost of 1.56 Billion USD. A total of 1821 MW of renewable energy capacity came into operation in 2017. Hydroelectric power plants (HPPs) and wind power plants (WPPs) with capacities of 736.9 MW and 746.3MW respectively started operating in 2017. An investment worth 1.1 Billion USD was made for the HPPs and 900 Million USD for WPP.

Table 2.2 Installed Capacity in Turkey in MW [TEIAS, 2018]

Year	Thermal	Hydro	Geothermal + Wind + Solar	Total Installed Capacity	% Increase
2010	32278.5	15831.2	1414.4	49524.1	10.6
2011	33931.1	17137.1	1842.9	52911.1	6.8
2012	35027.2	19609.4	2422.8	57059.4	7.8
2013	38648.0	22289.0	3070.5	64007.5	12.2
2014	41801.8	23643.2	4074.8	69519.8	8.6
2015	41903.0	25867.8	5375.9	73146.7	5.2
2016	44411.6	26681.1	7404.7	78497.4	7.3
2017	46926.3	27273.1	11000.6	85200.0	8.5

Despite Turkey’s efforts to increase the level of installed capacity in the country, Turkey still must import electricity from nations such as Greece and Bulgaria through the ENTSO-E network in order to meet its demand (see Table 2.3). The Turkish Statistical Institute reported that in 2016, Turkey’s electricity import bill was 213.6 Million USD. Furthermore, in 2017, due to large investments made to support and increase domestic installed capacity as explained before, the electricity import bill dropped to 85.5 Million USD which marked a 60% decrease between the two years. Further developments in investments of installed capacity in Turkey saw the electricity import bill drop by 33% in 2018. The electricity import bill in 2018 was 57.03 Million USD [TUIK, 2018].

Table 2.3 Electricity Generation, Imports and, Exports in Turkey in GWh

Years	Generation	Imports	Exports	Gross Demand
2007	191.558,1	864,3	2.422,2	190.000,2
2008	198.418,0	789,4	1.122,2	198.085,2
2009	194.812,9	812,0	1.545,8	194.079,1
2010	211.207,7	1.143,8	1.917,6	210.434,0
2011	229.395,1	4.555,8	3.644,6	230.306,3
2012	239.496,8	5.826,7	2.953,6	242.369,9
2013	240.154,0	7.429,4	1.226,7	246.356,6

Years	Generation	Imports	Exports	Gross Demand
2014	251.962,8	7.953,3	2.696,0	257.220,1
2015	261.783,3	7.135,5	3.194,5	265.724,4
2016	274.407,7	6.330,3	1.451,7	279.286,4
2017	297.277,5	2.728,3	3.303,7	296.702,1

2.5. Electricity Generating Resources in Turkey

2.5.1. Natural gas

Turkey has little primary natural gas reserves. Licenses to operate in natural gas exploration and production are issued by the Turkish General Directorate of Petroleum Affairs. Production and exploration activities are performed and monitored under the Turkish Petroleum Law, Law No 6491. Natural gas production in Turkey has been decreasing, reaching 12501 Million cubic feet (mcf) in 2017 compared to production levels in 2008, 34220 mcf (see Table 2.4). Domestic natural gas production accounts for 1% of total natural gas demand in Turkey, the rest is imported.

Table 2.4 Natural Gas Production in Turkey 2008 -2017 (million cubic feet) (EPDK, 2018)

Years	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Amounts	34220	24155	24085	26803	22319	18964	16916	13455	12960	12501

Due to insufficient natural gas reserves and low production levels, Turkey is dependent on importing natural gas. Most of the electricity demand in Turkey is genuinely met by natural gas. Experts believe that the current trend is unlikely to change, therefore, a major share of electricity demand will continue to be met by natural gas imports [Melikoglu, 2013]. Turkey started liberalization of its natural gas market in 2001. This process saw the monopoly player in the market, Turkey's Petroleum Pipeline Corporation (BOTAS) lose its power in the natural gas market with the enactment of Natural Gas Market Law (NGML) under Law No 4646 in 2001. BOTAS lost its monopoly power on natural gas imports, distribution and sales. Despite losing its monopoly power BOTAS is still the major player in the natural gas market as there haven't been enough efforts to disintegrate BOTAS into separate companies.

Liberalization of the natural gas market perpetuated the involvement of licensed companies other than BOTAS to operate in import activities in Turkey such as Enerco, Bosphorus Gaz, Shell Gaz and so on. Turkey currently imports natural gas from Russia, Turkmenistan Azerbaijan and Iran. There have also been developments in liquefied natural gas (LNG) consumption in Turkey, hence Turkey imports LNG from Nigeria and Algeria (see Table 2.5). Moreover, according to the energy balance data released annually by the MENR, almost half of the imported natural gas per year is used in electricity generation activities [MENR]. Natural gas has been the dominant electricity generation resource in Turkey and despite efforts to include RES in the generation mix, the importance of natural gas in Turkey’s electricity generation mix is almost unchanged, in fact electricity generated by natural gas in 2016 (89,227 GWh), is almost nine times compared to generated amount in 1990, 10192 GWh [IEA ,2018]. For the foreseen future, natural gas will still be included in Turkey’s generation mix, as a matter of fact, one of the objectives in the NREAP, is maintaining a maximum of 30% share of natural gas in the electricity generation mix [NREAP, 2018].

Table 2.5 Natural gas Import activities in Turkey [EPDK, 2018]

Countries	**Russia**		**Iran**		**Azerbaijan**		**Algeria**		**Nigeria**		**Others***		**Total**	**Change (%)**
Years	**Amount**	**Share (%)**	**Amount**	**Share (%)**	**Amount**	**Share (%)**	**Amount**	**Share (%)**	**Amount**	**Share (%)**	**Amount**	**Share (%)**	**Amount**	
2008	23.159	62,01	4.113	11,01	4.580	12,26	4.148	11,11	1.017	2,72	333	0,89	**37.350**	**4,21**
2009	19.473	54,31	5.252	14,65	4.960	13,83	4.487	12,51	903	2,52	781	2,18	**35.856**	**-4**
2010	17.576	46,21	7.765	20,41	4.521	11,89	3.906	10,27	1.189	3,13	3.079	8,09	**38.036**	**6,08**
2011	25.406	57,91	8.190	18,67	3.806	8,67	4.156	9,47	1.248	2,84	1.069	2,44	**43.874**	**15,35**
2012	26.491	57,69	8.215	17,89	3.354	7,3	4.076	8,88	1.322	2,88	2.464	5,37	**45.922**	**4,67**
2013	26.212	57,9	8.730	19,28	4.245	9,38	3.917	8,65	1.274	2,81	892	1,97	**45.269**	**-1,42**
2014	26.975	54,76	8.932	18,13	6.074	12,33	4.179	8,48	1.414	2,87	1.689	3,43	**49.262**	**8,82**
2015	26.783	55,31	7.826	16,16	6.169	12,74	3.916	8,09	1.240	2,56	2.493	5,15	**48.427**	**-1,7**
2016	24.540	52,94	7.705	16,62	6.480	13,98	4.284	9,24	1.220	2,63	2.124	4,58	**46.352**	**-4,28**
2017	28.690	51,93	9.251	16,74	6.544	11,85	4.617	8,36	1.344	2,43	4.804	8,7	**55.250**	**19,2**

2.5.2. Coal

Turkey is well known for its domestic coal reserves in contrast to its limited oil and gas resources. In line with efforts to decrease energy dependency on foreign nations, Turkey aims to increase utilization of its vast domestic lignite reserves. According to MENR, Turkey has acquired medium levels in terms of reserves and production levels of lignite and low levels in hard coal (anthracite). Turkey has approximately 3.2% of the world's total lignite reserves [MENR]. Lignite is Turkey's most important indigenous resource and, lignite reserves are located all over Turkey (see Figure 2.10). Turkey has a total of 17.3 gigaton of reported lignite reserves. The most important lignite reserves in Turkey are in the south-eastern Anatolia nearby the city of Maraş in the Afşin-Elbistan lignite basin. It is estimated that 46% of total coal reserves are in the area. The only problem is that, the grade of the lignite found in Turkey is low and according to a report by EURACOAL only 5.1% of total lignite reserves in Turkey have a heat content value of over 3000 kcal/kg (12500 kJ/kg), while another small share of the reserves (3.4%) have a heat content value above 4000 kcal/kg [EURACOAL, 2018].

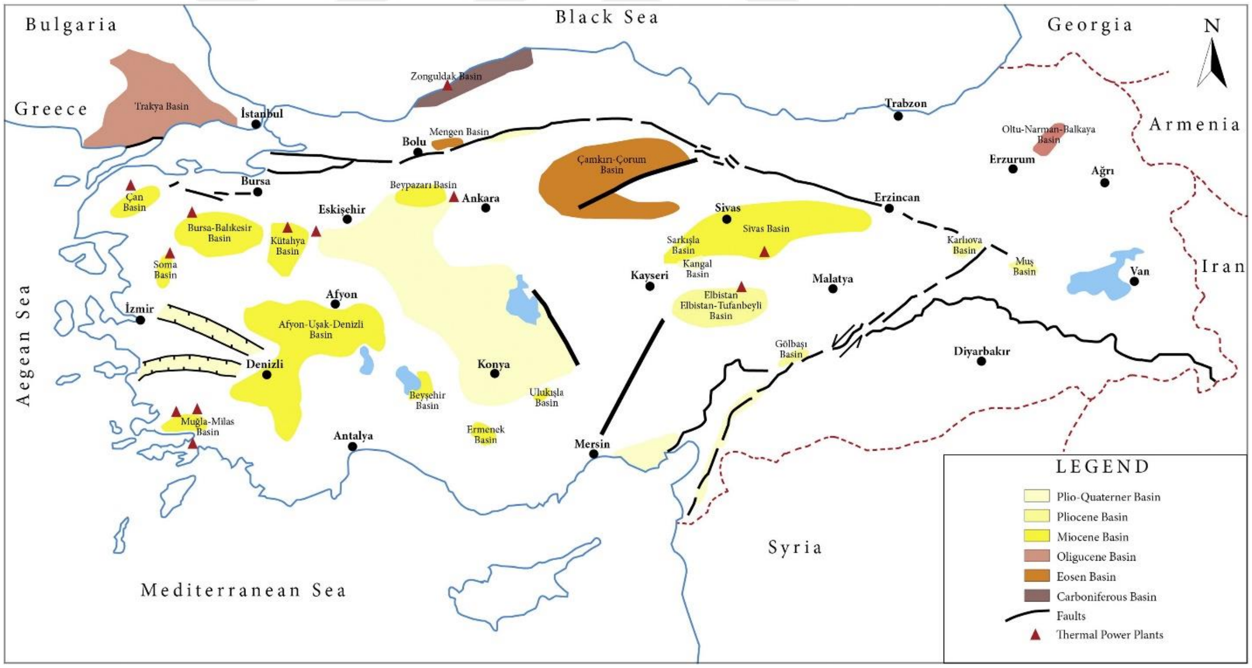


Figure 2.10 Lignite Reserves in Turkey [Ediger et al, 2014]

Another issue affecting coal production in Turkey is that there's only one main hard coal reserve in Turkey located in Zonguldak basin a province by the Black Sea coast in north-western region of Turkey. The total hard coal reserves in the Zonguldak basin are 1.3 gigaton but MENR reported only 506 Million tons are visible reserves [MENR, 2019]. In addition to that, the geological location of these reserves makes it difficult for mechanized coal extraction therefore coal production activities require intensive-labor methods.

On top of that, Turkey is also dependent on coal imports. In 2016, Turkey imported 36.2 Million tonnes (Mt) of coal which was an increase of 21.5% compared to 2014 Values (29.8 Mt). Almost 49% (17780 Mt) of the imported coal was used for electricity generation purposes [IEA, 2018]. According to TEIAS data, in 2017, Turkey recorded a total of 18666 MW of installed capacity from coal resources. The installed capacity of domestic coal was 9873 MW, whilst imported coal installed capacity was 8794 MW. Increased utilization of coal resources saw an increase in domestic coal installed capacity in Turkey, and by the end of September 2018, the total installed capacity from coal reached 18998 MW, installed capacity of domestic coal increased up to 10204 MW. There was no increase in imported coal capacity [TEIAS, 2018].

In the [Strategic Plan 2015 – 2019] which was prepared and released by the MENR, states the importance of diversifying electricity generation resources in Turkey. The plan states that electricity production from domestic coal will be increased to 60 Billion kWh annually by the end of the plan's period. The plan considers 2013 as the base year for these projections (see Table 2.6).

Table 2.6 Electricity Generation Projections by Domestic Coal in Turkey

Years	**2013**	**2015**	**2017**	**2019**
Generation (Billion kWh)	32.9	40	50	60

2.5.3. Oil

Oil is mostly used in the transportation sector and as industrial material. Turkey does not produce significant amounts of oil. In the early 2000s, oil was one of the major electricity generating resources in Turkey. In 2002, electricity generation from oil was 10192 GWh, but the generated amount has since then been dropping over the years and in 2017 it dropped to almost 1200 GWh, marking an 88.2% decrease in generation from oil. Moreover, in 2017, oil contributed only 0.4% of electricity generated (see Table 2.1). With current trends in the world and in Turkey particularly turning their attention away from electricity generated from fossil fuels especially from coal and oil, it is hard to see oil partake in any future electricity generation activities in Turkey. Seeing that oil is not a major contributor in the electricity generation mix in Turkey, in addition to that the government has not released plans involving oil in the electricity generation mix, so further details on oil will not be given in this study.

2.5.4. Renewable energy resources

In recent years, Turkey has seen an increase in investment towards electricity generation from renewable energy sources. With the new regulation on generating electricity without a license has seen major growth in number of RES power plants in Turkey. In fact, the Ministry of Energy and Natural Resources data shows that, by the end of the first half of 2018, Turkey had a total of 6,330 RES power plants. Solar power plants are the majority with a total of 5,422 power plants, followed by hydraulic power plants with a total of 636 power plants. Wind and geothermal resources account for 232 and 40 power plants respectively [MENR, 2019].

Efforts to further exploit RES in electricity generation in Turkey started in 2005, with the enactment of the Law on Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy, Law No 5346 (the RER Law, “YEKA” Law in Turkish)). Under the RER law, RES such as wind, hydro, solar, geothermal, biomass, biogas and wave were supported. In January 2011, a modified support mechanism for RES started operating under Law No 6094: Law Amending the Utilization of RES in Electricity Generation (RERSM, “YEKDEM” in Turkish). Under RERSM, the renewable energy sector was guaranteed long term and accelerated loans from Turkish banks, foreign banks and international institutions. In addition to that, under RERSM, technology-specific feed-in tariffs (FIT) were introduced. The United States’ Energy Information Agency defines feed-in tariff as a performance-based incentive rather than an investment-based incentive, and in that respect it’s a policy mechanism used to encourage deployment of RES electricity technologies. In a typical FIT mechanism, customers who possess eligible FIT renewable electricity generating technologies, receive a set price for all the electricity produced and provided to the grid by their technologies [EIA]. FITs in Turkey are granted to RES electricity generating facilities that were commissioned before 31st December 2020 for a period of ten (10) years, on the other hand, local content support is limited to five (5) years. FIT prices in Turkey are quoted in US dollars (Table 2.7). In addition to that, in 2013, EMRA decided that the remuneration process for facilities that started operating after 1 December 2015 be pushed forward to 2020.

Table 2.7 FITs for electricity generated from RES in Turkey [IEA,2016]

Type of facility	FITs (US$ cent/kWh)
Hydroelectric	7.3
Wind	7.3
Geothermal	10.5
Biomass (including landfill gas)	13.3
Solar power	13.3

Along with FITs, under RERSM, investors in Turkey enjoyed loans and grants benefits from the Clean Technology Fund (CFT) and the Global Environment Facility (GEF) to facilitate energy efficiency projects and call attention for further investments into renewable energy electricity generating facilities. On that note, in 2014, the MENR, in collaboration with the European Bank of Reconstruction and Development (EBRD) and Deloitte released the "National Renewable Energy Action Plan, 2013-2023" [NREAP, 2014], whose main aim was to promote and support further involvement of RES in the electricity generation mix. The NREAP also states that, one of Turkey's main target by the year 2023, which marks the 100th Independence of the Republic of Turkey, is to increase the share of RES in the electricity generation mix by 30%. The NREAP is also in line with the requirements of the EU Renewable Energy Directive, the NREAP outlines that for Turkey to meet the requirement of the EU Directive, the share of renewable energy in gross final consumption should reach 20.5% compared to 13.5% in 2013.

2.5.4.1. Solar energy

As seen from Table 2.7 above, the highest incentive is awarded to solar energy and biomass. There's promising solar energy potential in Turkey, in fact according to MENR, the solar energy produced per year in Turkey is close to 1527 kWh/m2/year. The Ministry of Energy and Natural Resources also prepared a Solar Energy Map (SEM) which shows Turkey's solar power potential (see Figure 2.11). On that note, solar energy entered Turkey's electricity generation mix for the first time in 2014, with an installed capacity of 40.2 MW which produced 17 GWh of electricity in the same year. Under the new EML law, the regulation on electricity generating from RES without a license has prompted further investments in RES sources electricity production especially solar energy. According to MENR data, solar energy has the highest number of power plants in Turkey, at 5224 power plants as of June 2018, and this shows how well motivated Turkey is to harness and utilize its solar energy potential. On the other hand, TEIAS reported that by September 2018, there were 5600 solar power plants in Turkey, of which 5591 were unlicensed generating facilities with a total installed capacity of 4768 MW, while only 9 solar power plants were licensed with a capacity of 81.7 MW. Either way, there's clearly a fast growth of interest in electricity generation from solar energy in Turkey and this acts in favor of Turkey's NREAP targets. In the NREAP, Turkey aims to increase the installed capacity of solar up to 1000MW [NREAP, 2014].

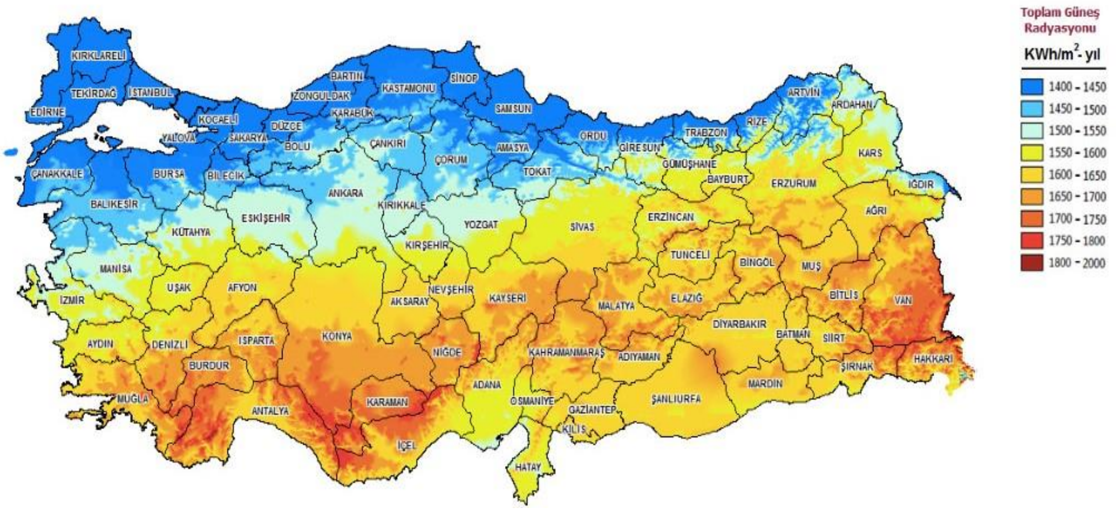


Figure 2.11 Turkey's Solar Energy Map (Energy Atlas, 2019)

2.5.4.2. Hydropower

Hydropower is the second most important domestic electricity generating resource in Turkey. In the past decade, hydropower has the highest installed capacity in Turkey (see Table 2.2). In terms of RES, hydropower is Turkey's most important resource, particularly in 2016, HPPs had the highest installed capacity at 26678 MW which accounted for 34.3% of total installed capacity in Turkey and generated 67303.1 GWh worth of electricity. However, studies suggest that installed capacity does not account for electricity generated, for instance in Turkey's case, natural gas had the second highest installed capacity at 25462 MW in 2016 but generated 20,344 GWh more electricity compared to HPPs [Yucekaya, 2017]. This calls for better efficiency in electricity generation activities.

Considering this information, in 2018, Turkey released a new energy efficiency strategic plan for the county for the years 2017-2023: "National Energy Efficiency Action Plan 2017-2023" [NEEAP, 2018]. The EU's Energy Efficiency Directive of 2012/27/EU calls for member countries to review and renew their energy efficiency action plan once every three years periodically. Therefore, in Turkey there are three strategic plans: 2012 Strategic Plan, Strategic Plan 2015-2019; which was briefly introduced above, and the latest version is the NEEAP 2017-2023. The NEEAP was prepared by the MENR for the sole purpose of increasing the level of energy efficiency and effectiveness in several other sectors in Turkey but most importantly for this study, the energy sector's resource efficiency. The NEEAP's Objective 3.2.4 aims to improve efficiency in existing power plants, where by the goal is to partake in service and maintenance of electricity generating technologies in order to improve energy efficiency of thermal power plants and HPPs [NEEAP,2018].

Nonetheless, seeing that the hydropower potential in Turkey is around 433 Billion kWh while the technically and economically exploitable annual potentials sit at 216 Billion kWh and almost 128 Billion kWh respectively [Melikoglu, 2013], hence Turkey aims to either completely utilize its hydropower potential or for installed capacity of HPPs to reach 36,000 MW by 2023 [NREAP, 2014].

2.5.4.3. Wind energy

Another RES that has been gaining much attention in Turkey is wind power. Wind power capacity installation has experienced an increasing trend in Turkey. Installed capacity of wind power plants (WPPs) was 18.9 MW in 2000 and it reached 3630 MW in 2014, is proof of the rapid growth in WPP capacity installation in Turkey, in addition to that, in 2017, the total WPPs installed capacity increased to 6857 MW [TEIAS, 2018]. Additionally, in 2017, the Global Wind Energy Council (GWEC) ranked Turkey the sixth (6th) nation among EU countries with the most installed wind power capacities, and Turkey was also ranked among top ten countries with highest newly installed wind power capacities in the world [Global Wind Statistics, 2017]. In the NREAP, Turkey aims to utilize its wind potential by reaching 20,000 MW installed capacity and since WPP installed capacity in Turkey is on the rise and given this trend continues, Turkey could meet this target [Oner et al, 2016].

According to MENR's data, WPPs of up to 5 MW of capacity can be established in Turkey at heights of 50 meters above ground level in areas where wind speed is above 7 m/s. In order to determine the attributes and allocation of wind energy resources in Turkey, in 2006, the General Directorate of Electrical Power Resources (EIE) developed the Wind Energy Potential Atlas of Turkey (REPA), as illustrated in Figure 2.12 [Ünlü, 2012]. The highest wind potential resources in Turkey are located along sea shores [Turkmenler et al, 2015]. The Turkish Wind Energy Association (TWEA) report of 2019, shows that most of the installed wind facilities in Turkey are located along the Aegean Sea with a total of 2832.1 MW installed capacity, followed by the Marmara Sea shore with 2448.7 MW installed capacity, the Mediterranean Sea and the Black sea shore recorded capacities of 996 MW and 272.5 MW respectively in 2018. Other notable regions with high WPP installed capacities are Central Anatolia and Southeastern Anatolia with installed capacities of 726.7 MW and 93.1 MW respectively [Turkish Wind Energy Association, 2019]

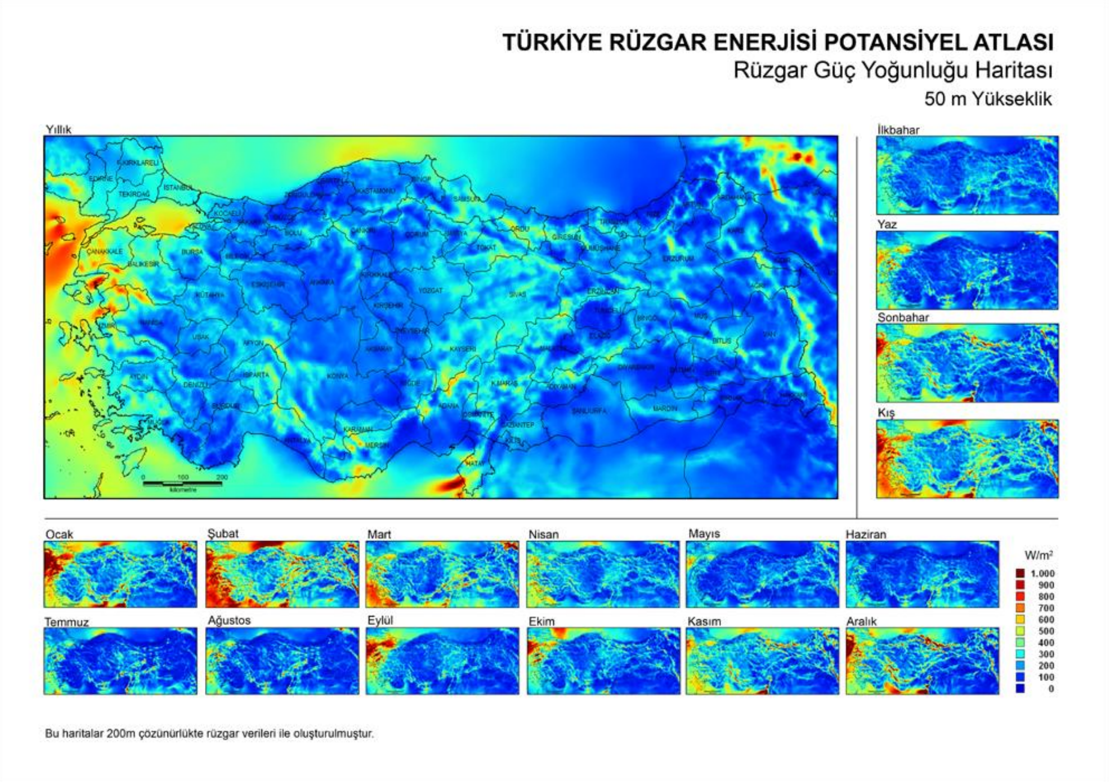


Figure 2.12 Allocation of Wind Energy Potential in Turkey [MENR]

Turkey’s total wind power potential at 50m altitude is estimated to be around 48 GW. In Table 2.8, the allocation of wind power potential for different wind classes in Turkey is given, moreover, according to Turkey’s Potential Wind Energy Map (PWEM), apart from onshore wind potential, Turkey has promising offshore wind potential. The offshore wind potential in Turkey is estimated at 10,013 MW, this accounts for 21% of total wind potential in Turkey [Ilhan & Bilgili, 2016]. In 2010, [İlkiliç & Nursoy] suggested that, given Turkey’s wind energy potential, the whole electricity demand could be met by electricity generated from WPPs. Efforts to exploit offshore wind power generation started in Last year (2018), WPPs generated 19,882 Billion kWh where by TWEA reported that the average share of electricity generated from WPPs in 2018 was 6.78%.

Table 2.8 Total Wind Energy Potential in Turkey at 50m altitude [Çalişkan, 2010]

Yearly Average Wind Speed (m/s)	**Power Density (W/m2)**	**Power Potential (MW)**
7.00 - 7.50	400 - 500	29,259.36
7.5 - 8.0	400 - 600	12,994.32
8.0 - 9.0	600 - 800	5,399.92
>9.0	>800	195.84
	Onshore	**37,836**
	Offshore	**10,013**
	Total	**47,849**

2.5.4.4. Geothermal

Turkey is located on top of an active tectonic zone and as a result the country has a lot of rich geothermal energy resources. Geothermal energy is defined as hot water and steam which is formed by heat accumulation in different depths of the earth’s crust and at different temperatures. Turkey is said to have approximately over 1000 geothermal springs dispersed all over the country. Some studies suggest that, with such geothermal resources approximately 5% of Turkey’s total electricity demand could be met by geothermal energy and Turkey would be able to meet 30% of its total energy demand from geothermal resources [Ertugrul et al, 2017]. One of the functions of Turkey’s General Directorate of Mineral Research and Exploration (MTA) is to conduct studies and further explore geothermal resources in Turkey. The MTA prepared a map showing the geothermal resources in Turkey and the map showed that, most of the geothermal resources in Turkey are located in Western Anatolia, and they account for about 78% of total resources, while areas such as Central Anatolia, Marmara region, Eastern Anatolia and the other regions account for 9%, 7%, 5% and 1% respectively (see Figure 2.13)

Figure 2. 13 Geothermal Resources Map for Turkey [Argun & Argun, 2011]

The geothermal heat potential in Turkey is reported to be around 31,500 MW thermal (MWt), in addition to that, almost 90% of Turkey's geothermal resources are of low and medium heat content, hence they are used directly for heating purposes (in households, greenhouses), thermal tourism, and so on. The remaining 10% is used for electricity generation activities. Turkey was among the first countries in Europe to build a geothermal power plant in the 1980s. To be exact, in 1984, Turkey's Kizildere geothermal power plant which is in Western parts of Turkey, was the second power plant established in whole of Europe. It had a total capacity of 17.4 MWe [Kindap et al, 2010]. Geothermal power plants produced 6127.5 GWh of electricity which was 2.1% of the total electricity generated in 2017 (see Table 2.1), while on the other hand, the installed capacity of geothermal power plants (GPPs) in Turkey has been increasing in recent years, for instance, in 2008, the total installed capacity of GPPs was 30 MW, however in 2017 the installed capacity of GPPs was 1064 MW [IRENA, 2018]. In line with this information, it is noticeable that Turkey's NREAP target for geothermal installed capacity to reach 1GW by 2023 has been exceeded.

2.5.4.5. Biomass

Biomass is probably the most widely used resource in the world [Toklu, 2017]. Biomass can be easily found in the world. More than 14% of the world’s total energy demand is met by biomass resources especially in developing countries [Parikka, 2004]. In developed countries biomass is used to push fossil fuels out of the electricity generation mix while in developing countries, the case is different as in these countries, biomass is a very important energy source for survival [Lu et al., 2009]. EIA defines biomass as organic materials that come from animals and plants and biomass is considered a renewable energy source. Biomass contains energy absorbed from the sun. Naturally when biomass is burned, the chemical energy in the biomass produces heat. Biomass include wood, agricultural crops, waste materials, animal manure and so on. Biomass can be directly burned or converted to liquid biofuels or biogas that can be burned as fuels using conversion technologies to produce bioenergy (see Figure 2.14 for conversion technologies)

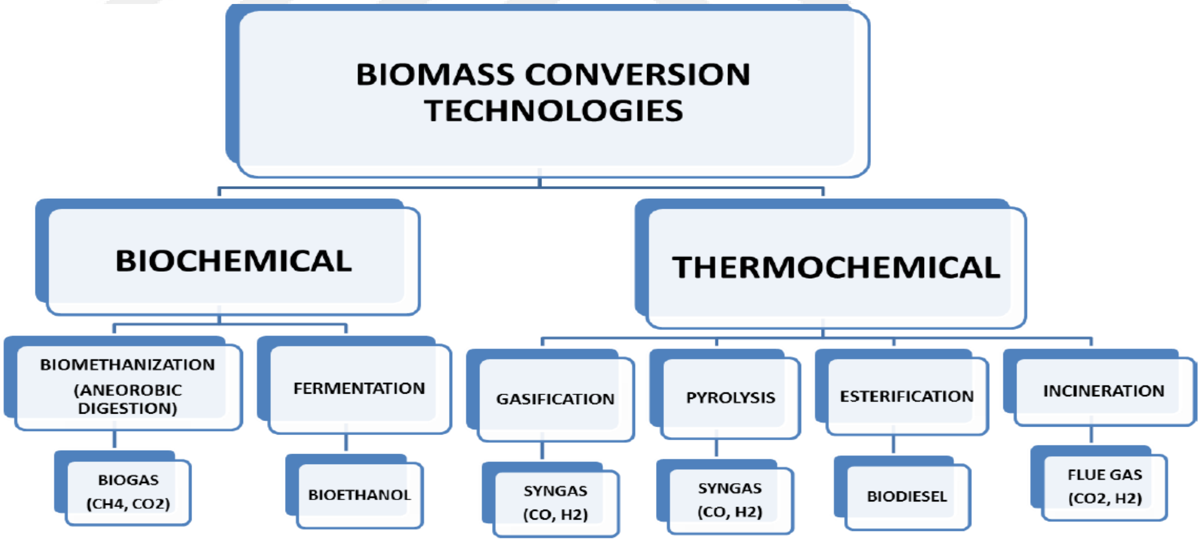


Figure 2.14 Biomass Conversion Technologies in Turkey

In Turkey, biomass is used for heating and other purposes, but it has also been used in electricity generation activities. The biomass potential in Turkey is very promising, in fact the MENR suggests that Turkey has almost 8.6 Million Tonnes of Equivalent Petroleum (MTEP) or 372,000 GWh annual biomass potential. In 2008, a study suggested that given the biomass potential in Turkey, the government should consider and support further biomass exploration activities [Kayguz & Keles, 2008]. The same author in 2002, determined that the exploitable bioenergy potential of Turkey of Turkey was almost 196.8 TWh [Kaygusuz & Türker, 2002]. With this huge biomass potential, the number and installed capacity of biomass power plants has been increasing over the years. Turkey expects to raise the installed capacity of biomass power plants to 1000 MW by 2023, which seems as an attainable target considering current developments in biomass exploration in the country. According to data from International Renewable Energy Agency (IRENA), the installed capacity of biomass was 88 MW in 2007 and the value has since then been increasing reaching 467 MW in 2017 (see Figure 2.15). On the power plants side, there are currently 100 biomass power plants with an annual average of 2277 GWh electricity production. On top of that, TEIAS reported that biomass resources produced 2972.3 GWh of electricity contributing 1% of total electricity production (see Table 2.1).

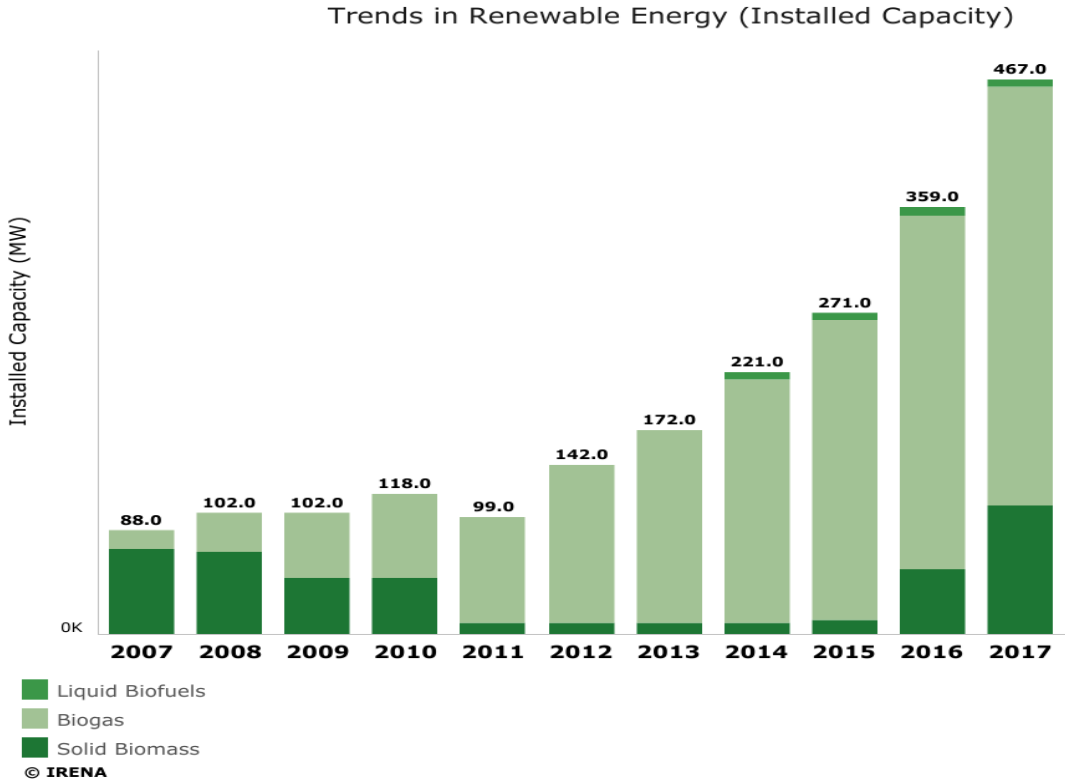


Figure 2.15 Biomass Installed Capacity in Turkey [IRENA, 2018]

2.5.4.6. Nuclear

Turkey has always had plans to develop and utilize nuclear energy. These plans date back as far as the 1950s, where nuclear energy was considered a promising source of cheap electricity production by most countries in the world [Surrey, 1988]. Furthermore, Turkey’s nuclear energy exploitation activities were fueled following the speech by the then US President Eisenhower at the UN General Assembly in 1953 and the Geneva Conference in 1955 on “Atoms for Peace”, which was a US policy that supported global development of nuclear energy activities in the beginning of the atomic energy era. In 1955, Turkey was one of the first nations to sign an “Atoms for Peace Agreement” [Kibaroglu, 1997]. The following year, 1956, Turkey established the Turkish Atomic Energy Commission (TAEC), whose duties were to oversee all nuclear energy activities such as issuing licenses to nuclear power plants (NPPs) facilities, opening nuclear training and research centers to perpetuate nuclear energy studies in Turkey.

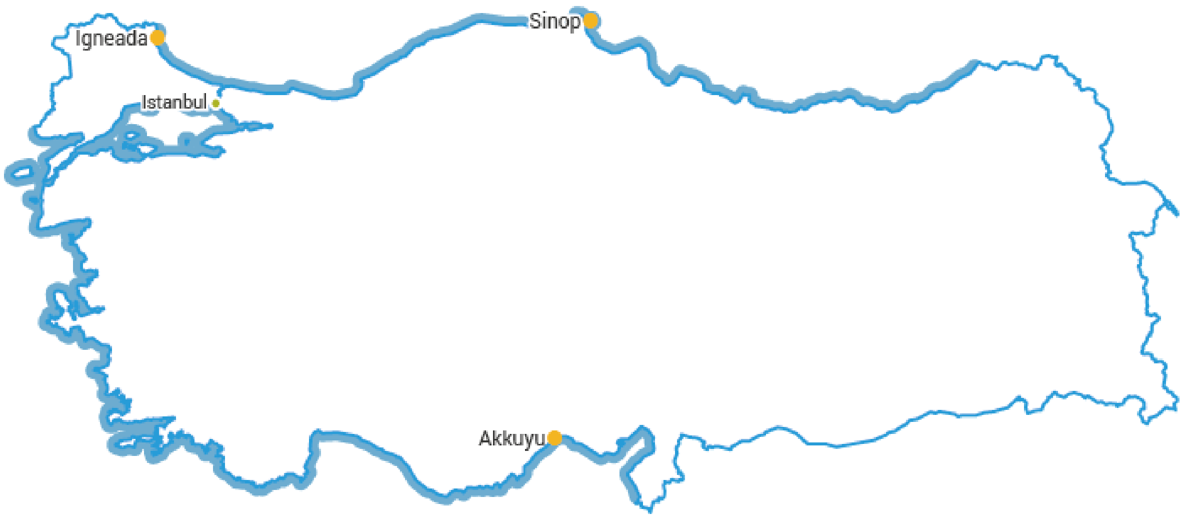
In 1967, one of the research centers launched a feasibility study for establishment of the first NPP in Turkey. The study presented a 300 to 400 MWe licensed nuclear reactor would start generating power by 1977, but with political and economic struggles in Turkey in the 1970s, this target was not achieved [Kibaroglu, 1997]. Since then there have been several attempts to include nuclear in Turkey’s power generation sector, for instance in 1972, another feasibility study presented two designated NPPs establishment sites at Akkuyu and Sinop. Kibaroglu, 1997, reports that, negotiations were held between one political party in Turkey, Republican Peoples Party (CHP) and two interested Swedish firms on financing and construction of the NPPs, but due to the 1980 military coup in Turkey there was no further developments of these negotiations. Even after the military administration tried to continue pursuing the negotiations there was still no successful negotiations.

Further attempts were made by Turkey, but they have all come to no success until the latest attempt in 2010. Under the Law of Construction and Operation of Nuclear Power Plants in Turkey, Law No. 5710, which came into power in 2007, opens up the way for foreign investors and their respective governments to be actively involved in the construction of a particular power plants and the law also enables the foreign investors to own the power plant after construction process is completed.

In 2010, this time Turkey tried the intergovernmental agreement (IGA) approach within Law No 5710, whereby Turkey signed an IGA with the Russian government for the establishment of the first NPP at the Akkuyu site. The “Intergovernmental Agreement on Cooperation on the Establishment and Operation of a Nuclear Power Plant on Akkuyu Site” between the Turkish government and the Russian Federation was signed on May 12, 2010 [MENR]. The Akkuyu NPP will be the first project to be built under the BOO model. The plant is owned and operated by Akkuyu NPP’s Joint Stock Company (JSC) which was established in 2013. Majority of the shares are to be sold to Rosatom, Russia’s state-owned nuclear company. Rosatom will be responsible for funding, providing fuel, designing, construction, engineering, operating and maintaining, waste management and decommissioning services of the NPP for a guaranteed electricity price of $12.35 ¢/kWh for 15 years [IEA, 2016]. The Akkuyu NPP will have a total of four power units of NPP-2006 project with VVER-1200 reactors of a total 4.8 GWe in Mersin a province Southern of Turkey (see Figure 2.16). Construction started in 2018 and operation of the first unit at Akkuyu NPP is anticipated to begin in 2023 [World Nuclear Association, 2018]

Three years later in 2013, after successful negotiations between the Japanese and Turkish governments, an IGA was signed for establishment of a second NPP in Sinop area, Northern of Turkey (see Figure 2.16). The “Cooperation for the Nuclear Power Plants and Nuclear Power Industry in the Republic of Turkey” was signed officially on the 3rd of May 2013. The Turkish state-owned company, EUAŞ is the majority shareholder with 49% of total shares and acts as the Turkish government representative in the Sinop NPP project, together with a consortium including Mitsubishi Heavy Industries (MHI), Areva, Itochu and Engie [IEA, 2016]. According to the World Nuclear Association (WNA), four Atmea1 reactors with a total capacity of 4.6 GWe will be established at Sinop. The Turkish electricity trading company, TETAŞ would purchase all the generated electricity from Sinop NPP at a guaranteed cost of 11.80¢/kWh for the next 20 years [HT, 2013]. The project’s estimated cost was about $22 Billion in 2013 [IEA, 2016], but since then, WNA reports that the cost has now almost doubled [WNA, 2018].

There has been a negative cloud of uncertainty surrounding establishment of the Sinop NPP. Recent developments and sources from the government describe the project as a build-own-transfer while Engie, which is a famous nuclear energy organization in Belgium describes the project as a build-own-operate, furthermore, initially EUAS was supposed to own 35% of shares while the other players would have equal shares but EUAS's shares have increased to 49% which has led to withdrawal of Itochu from the project. In May 2018, it was reported that the operational start date of 2023 for Sinop NPP had been dropped due to an incomplete feasibility study, and later that year, WNA reports that, MHI and other partners were thinking of withdrawing from the project [WNA, 2018].


Planned Nuclear Power Plants in Turkey

Source: World Nuclear Association

Figure 2.16 Planned Nuclear Power Plants in Turkey [WNA, 2018]

Despite the setbacks surrounding Sinop NPP, this hasn't affected Turkey's efforts to establish NPPs in Turkey. Igneada a city in Kirklareli province, Northwestern of Turkey near the Black sea was been identified by TAEK as site for a third NPP establishment in 2015 (see Figure 2.16). According to IEA report, EÜAŞ has attracted offers from a U.S based company

Westinghouse Electric Company and another state-owned firm from the People's Republic of China; State Nuclear Power Technology (SNPTC), and in November 2014, EÜAŞ signed a memorandum of understanding with the above mentioned partners on "Co-operation for the Development of a Nuclear Power Plant Project and the Nuclear Power Industry in the Republic of Turkey" [IEA, 2016]. Currently, there is no further information on the third power plant in Turkey. Further information on the start dates of construction and operation of the other units of the Akkuyu and Sinop NPPs are given in Table 2.9.

Table 2.9 Under construction, Planned and Proposed NPPs in Turkey [WNA, 2018]

	Type	**MWe Gross**	**Start Construction**	**Start Operation**
Akkuyu1	VVER-1200	1200	Apr-18	2023
Akkuyu2	VVER-1200	1200	2019	2023
Akkuyu3	VVER-1200	1200	2020	2024
Akkuyu4	VVER-1200	1200	2021	2025
Sinop 1	Atmea1	1150	Uncertain	
Sinop 2	Atmea1	1150	Uncertain	
Sinop 3	Atmea1	1150	Uncertain	
Sinop 4	Atmea1	1150	Uncertain	
Igneada 1-4	CAP1000 X 2	2 x 1250		
	CAP1400 X 2	2 x 1400		

3. METHODOLOGY

In this chapter, the first section will briefly introduce the LEAP algorithm and the peculiar features of LEAP will be explained, and in the second section, Turkey’s LEAP Electricity Model will be explored, and each module will be explained further.

3.1. Introduction to LEAP

Energy models are a crucial part of energy system planning [Sargunam & Iniyan, 2006], moreover, energy models can be used to analyze how a proposed energy policy would affect the future of energy demand and supply relations and how the policy could improve the overall socio-economic aspects of a certain region. The Long-range Energy Alternatives Planning (LEAP) was developed by the Stockholm Environment Institute (SEI) [Heaps C. , 2012]. In 2002, Pandey (2002) classified LEAP as a bottom-up optimization/accounting model which can be used to provide long-term information on issues concerning the energy sector of a nation or region [Pandey, 2002].

The LEAP model follows the accounting approach to create a logical view of energy demand and supply based on substantial description of the energy system. LEAP operates on two conceptual levels. At the first level, LEAP uses inbuilt calculations to handle accounting calculations on non-controversial energy, emissions and cost benefits. On the second level, LEAP uses speed-sheet like expression entered by the user not find the least cost solution as in the optimization model but rather it uses the accounting and simulation approaches to provide answers to “what-if” type of inquiries under alternative scenarios [Bhattacharyya & Timilsina, 2010].

LEAP offers users the ability to create and build definitive plans that would suite the problems of a geographical area, be it at city, country, regional or world level. LEAP also allows users to perform several analyses of their energy systems such as analyses of demand, transformation, resources, and environmental. This concept is made easier with the “scenario analysis" concept in LEAP. Scenarios act as pathways of how the future of an energy system is expected to emerge over a period under socio-economic or demographic drivers of a given policy. Scenario analysis covers energy consumption, transformation (energy supply), GHG gas emission and local air pollutants, and cost analyzes of each scenario and users can compare results of one scenario against the other [LEAP, 2011].

Another important feature of LEAP is the Technology and Environmental Database (TED). The TED is an inbuilt feature in LEAP and in contains an extensive database providing information about the environmental impacts, costs, and technical characteristics of approximately thousands of energy producing technologies. TED is comprised of summaries from reports of renowned organizations such as Intergovernmental Panel on Climate Change (IPCC) With the help of TED, LEAP can be used to account for both energy and non-energy sector GHGs emission sources. The GHGs emissions calculations in LEAP are set to Intergovernmental Panel on Climate Change (IPCC) Tier 1 module [LEAP, 2011].

3.2. Turkey's LEAP Electricity Model

In LEAP analysis, a tree always appears in the analysis view, the notes view and the results view. This hierarchical outlined tree is used to enter and edit data in LEAP. The tree usually has several main levels such as Key Assumptions, Demand, Transformation, Resources, Non-Energy Sector Effects, Stock changes and Statistical Differences and, Indicators. Users enter data into these modules depending on their energy models [LEAP, 2011]. Figure 3.1 shows this study's LEAP tree. All these initial data for the model is entered in the current accounts on the analysis view. In most studies, LEAP has been used to forecast results ranging between 20 to 50 years. In this study, LEAP was used to simulate Turkey's electricity demand and supply for the next 22 years. The base year of Turkey's model in this study is 2018, meaning 2018 is current accounts of the model and the end year for projections is 2040.

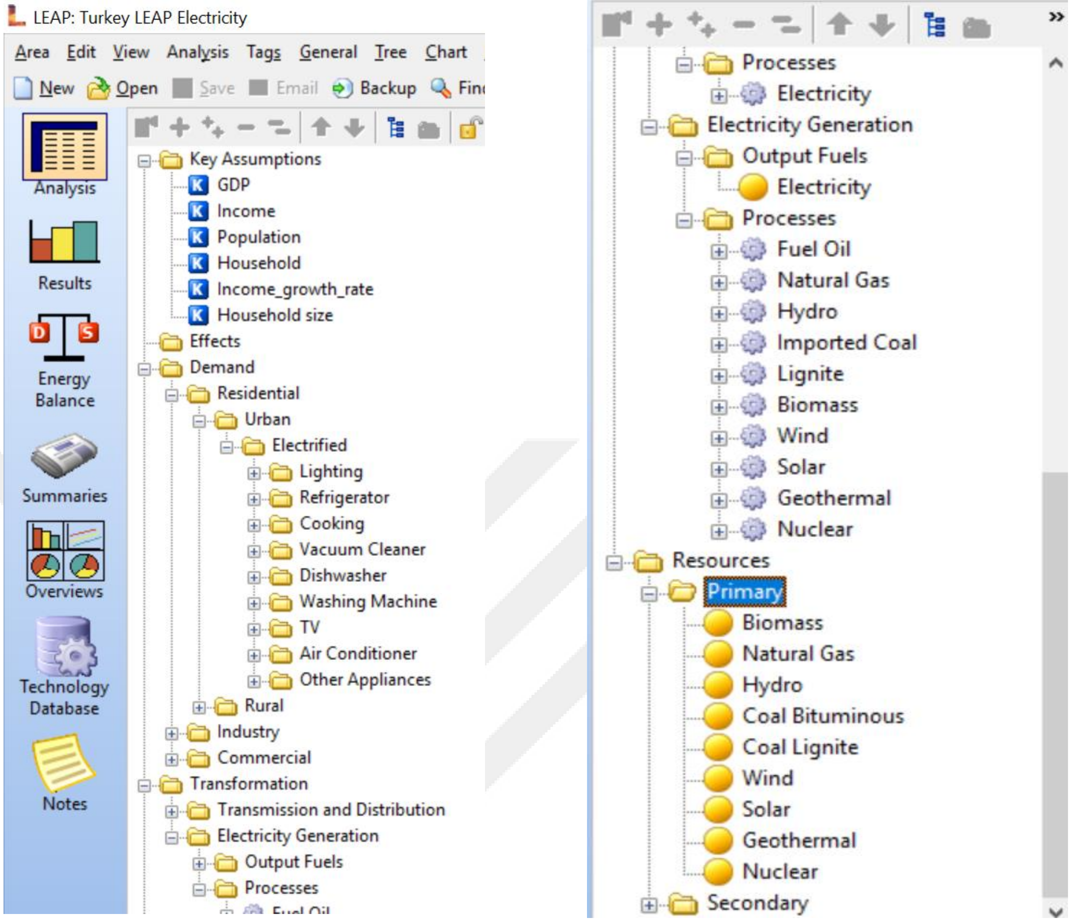


Figure 3.1 Turkey's LEAP Model

3.2.1. Current accounts

In the key assumptions branch, starter data sets of demographics, economic and development drivers used by leap in calculating Demand, Transformation and Resource analyses were entered for the base year in the current accounts view. The data for these drivers were attained from different resources such as the World Bank Data, TUIK, and the OECD Database. The average total number of households in Turkey was calculated in LEAP using Equation 3.1 shown below. The expression uses the total population of Turkey in 2018 and divides it by the household size in Turkey for the year 2018. Key assumption data for Turkey in 2018 are given in Table 3.1.

$$\text{Households} = \text{Population [Million People]} / \text{Household size[people]} \qquad (3.1)$$

Table 3.1 Key Assumption Data

Data Type	Value of Data in 2018	Source of Data
GDP	766.509 Billion USD	World Bank Data
Population	82.32 Million	TUIK
Households	22.9 Million	LEAP (Calculated)
Household size	3.6 people	TUIK

3.2.2. Design of electricity demand

In demand analysis, Turkey's final electricity consumption for each sector were entered. All Transformation and Resource calculations are driven by the levels of demand calculated in the demand analysis, hence demand analysis marks the start of energy analysis of the models [LEAP, 2011]. In LEAP, energy demand is calculated as the product of the total activity level and energy intensity at every technology branch. Energy demand is calculated for the Current Accounts year (base year) and for each future year in each scenario in Equation 3.2. [Heaps, 2016]

$$D_{b,s,t} = TA_{b,s,t} \text{ x } EI_{b,s,t} \qquad (3.2)$$

where D is energy demand, TA is total activity, EI is energy intensity, b is the branch, s is scenario and t is year (ranging from the base year (0) to the end year (n)). Note that all scenarios evolve from the same Current Accounts data, so that when t=0, the above equation can be written as in Equation 3.3 [Heaps, 2016]:

$$D_{b,0} = TA_{b,0} \text{ x } EI_{b,0} \qquad (3.3)$$

Electricity demand in this study is divided into three main sectors: Residential sector, Industrial sector and Commercial and Services sector. The electricity demand for sectors with low electricity consumption such as Transportation, Agriculture, and Fishing sectors is included in Commercial and Services sector's demand. Electricity demand is expressed of the sectors are expressed in TWh of consumption by each sector.

The electricity demand in Turkey for the year 2018 was 251.74 TWh. The Industrial sector consumed 108.4 TWh, while the residential and, commercial and services sectors consumed 51.84 TWh and 91.47 TWh respectively [TEIAS, 2018] as illustrated in Figure 3.2. Residential electricity demand and consumption is subjected to efficient and standard household electrical appliances such as refrigerators, washing machines, personal computers, and so on. Data on the saturation levels of the electrical appliances were retrieved from [Utlu, 2017] while the data used for final energy intensities of household electrical appliances was retrieved from [Yumurtacı & Dönmez, 2013]. Note that the study assumes there are no efficient electrical appliances, building or production machinery in any of the sectors of demand.

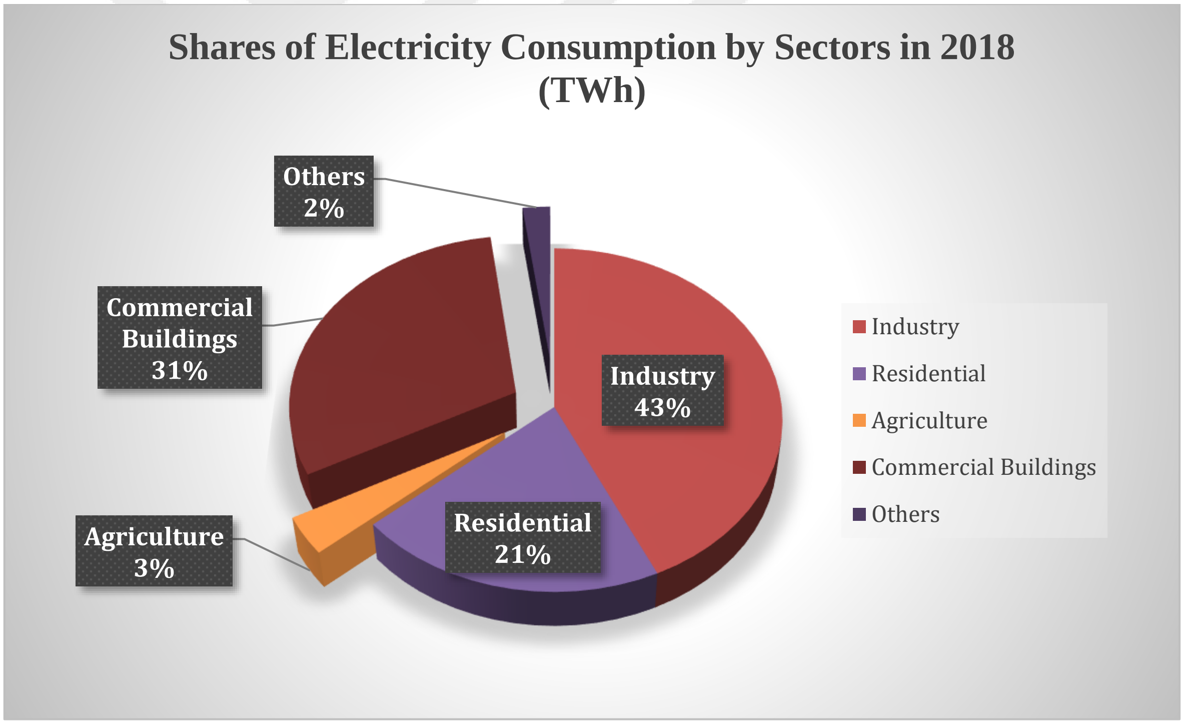


Figure 3.2 Shares of Electricity consumption by sector in Turkey in 2018

In the Yumurtaci & Donmez [2013] study, there was no difference in consumption between standard appliances and efficient appliances for some electrical appliances such as iron, television and so on, hence this study opts those appliances out. (Table 3.2).

Table 3.2 Data used in Turkey's Residential Demand

Type of Appliance	**Annual Consumption by Standard Appliances (kWh)**	**Annual Consumption by Efficient Appliances (kWh)**	**Saturation in Turkish Households (%)**
Lighting	403.2	115.2	100
Refrigerators	409.32	214.2	99
Cooking Stoves	696	576	100
Vacuum Cleaners	432	216	93
Washing Machines	171	135	95
Dish Washers	261.6	163.2	76
Televisions	111.96	57	99

This study also assumes that there's no difference in energy intensities of appliances in rural and urban households. Table 3.2 shows the saturation values, standard and efficient data used in the residential sector of Turkey's LEAP model.

3.2.3. Transformation design

In the Transformation analysis, data concerning the resources and conversion of resources to produce electricity was entered. Transformation Analysis accounts for costs data, capacities, system load curve, efficiencies and so on. Data for these parameters will be given below as well as the explanation of each parameter. In this model, electricity is generated from the following resources: lignite, hard coal, fuel oil, natural gas, hydro-power, nuclear, solar, wind, biomass and geothermal.

In the Electricity generation module, LEAP requires users to enter capacity data for each power plants. LEAP has two types of capacity variables: exogeneous and endogenous capacities. Capacity data can be described in four different ways in LEAP. The first method, user can ignore capacity limits in the Transformation module. This method is commonly used when users have no capacity data of the processes to be involved in electricity generation activities. Therefore, users need to specify the shares of each process to be involved in electricity generation activities. In the second method, using the exogenous capacity variable users can specifically select timeframe and amounts of future capacity should be added.

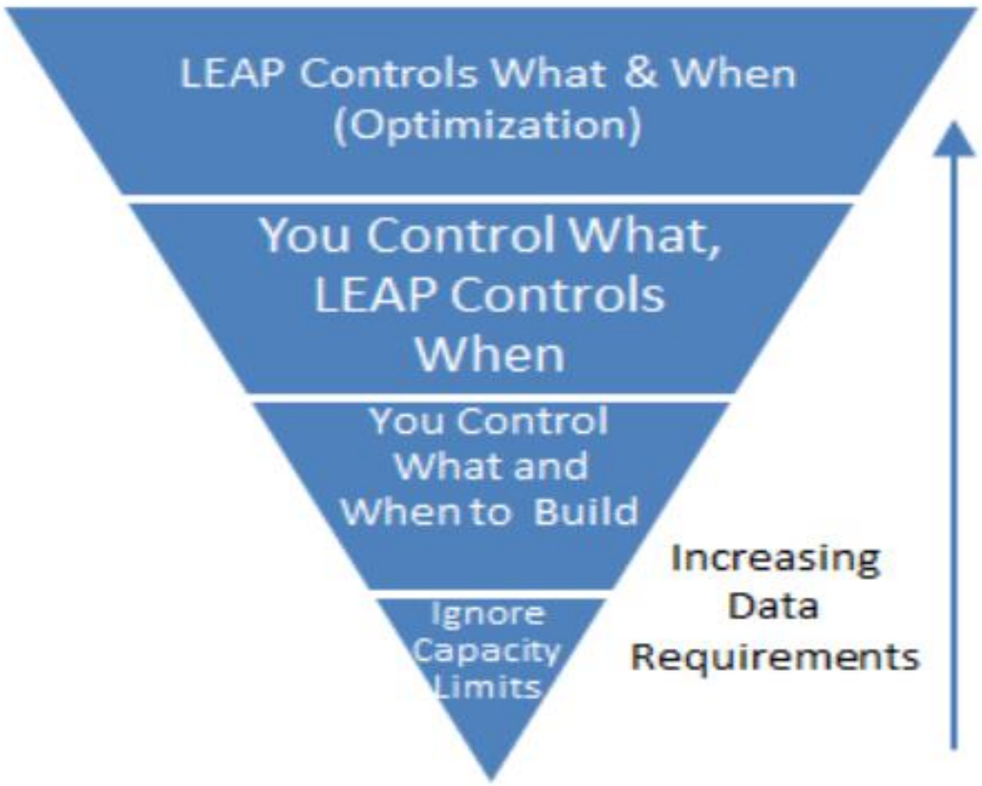


Figure 3.3 Capacity Specifications in LEAP [LEAP,2011]

The third method, the user also uses the exogenous capacity variable to specify historical existing capacities as well as planned capacity additions and retirements but moreover, the endogenous capacity variable can be used to add capacity automatically. In this method, the user has control on which resource’s capacity should be added but LEAP decides when those plants will be added by monitoring the system’s reserve margin and consequently adding needed power plants to keep the reserve margin above the planned reserve margin the user specified. In the fourth method, LEAP uses a least-cost optimization technique to select what types of capacity should be added and when they should be added. Furthermore, Optimization in LEAP also controls the dispatch procedures, Figure 3.3 graphically present the four methods on the concept of capacity specification in LEAP [LEAP, 2011].

This study uses the third and fourth approaches. The exogenous capacity data for Turkey in 2018 was retrieved from TEIAS as illustrated in Table 3.3. LEAP also requires the user to enter historical production data for each power plant. The data for historical production of power plants in Turkey were also retrieved from TEIAS (see Table 3.3).

Table 3.3 Installed Capacities and Electricity Generation Data for Turkey in 2018

Process Type	Exogeneous Capacity (MW)	Electricity Production (GWh)
Fuel Oil	715	958
Natural Gas	25896.7	91227.1
Hydro	28292.6	59946.3
Hard Coal	8938.9	62949.6
Lignite	10618.3	50389.3
Biomass	666.03	2615.9
Wind	6991.7	20003.4
Solar	5099.2	7859.8

Electricity generating power plants incur various types of costs in LEAP. Capital costs, fixed operating and maintenance costs (FOM) and variable operating and maintenance costs (VAROM) are among the costs incurred by power plants in LEAP. Capital costs are a combination of all construction and any capitalized costs. In the case of the operating and maintenance costs, fixed O&M are costs incurred by the system whether electricity is produced or not, while variable O&M are costs incurred per unit of electricity produced [LEAP, 2011]. The total cost of generating electricity is calculated as the total net present value of the system costs over the entire period of calculation, expressed as in Equation 3.4 [Filatova et al, 2019]:

$$\mathrm{TC} = \sum_{t}^{N_t} \sum_{p} \frac{1}{(1+d)^t} (\mathrm{CAP} * \mathrm{Ca}_t + \mathrm{FIXOM}_t * \mathrm{Ca}_t + \mathrm{VAROM}_t * \mathrm{P}_t + \mathrm{FCO}_t) \quad (3.4)$$

where TC is total cost, $\mathrm{N_t}$ denotes the total years from 2018 through to 2040, p is the technology, d is the discount rate, CAP is the initial capital cost, $\mathrm{Ca_t}$ is the capacity in year t, $\mathrm{FIXOM_t}$ is the fixed operation and maintenance costs in year t, $\mathrm{VAROM_t}$ is the variable operation and maintenance costs in year t, $\mathrm{P_t}$ is the output power in year t , and $\mathrm{FCO_t}$ is the fuel cost in year t.

The cost data for all power plants used in this study were obtained from three main resources: Projected Costs of Generating Electricity 2010 and 2015 editions and from [Arslan, 2017] as illustrated in Table 3.4. The study also takes into consideration the fuel prices of generating resources. Fuel prices are basically import prices assumptions for hard coal and natural gas [OECD, NEA, 2015].

Table 3.4 Cost of Electricity Generating Power plants in Turkey

Process Type	**Capital Costs (Thousand USD/MW)**	**FOM Cost (Thousand USD/MW-year)**	**VAROM Costs (USD/MWh)**	**Fuel Costs (USD/MWh)**
Geothermal	1583	34.3	34.3	-
Wind onshore	1940	37.282	9.1	-
Hydro	3492	25	6.6	-
Oil	1589	33.11	23	-
Natural Gas	1021	30.568	4.10	59.77
Hard Coal	1900	49.1	11.7	18.84
Lignite	2080	37.8	5.4	18.34
Biomass	4447	105	16.6	-
Solar	4898	30.081	4.7	-
Nuclear	4480	100.169	7.8	9.1

The Reserve Margin is a parameter in LEAP and is defined as the ratio of available capacity to actual needed capacity. The reserve margin helps in dealing with unexpected peak demand and therefore, LEAP calculates and decides when to add additional capacity (endogenous capacity) to maintain the reserve margin. Turkey's reserve margin is reported to be around 34% [IEA, 2016]. For this study, the planning reserve margin was 0%. LEAP defines planning reserve margin as in Equations 3.5 and 3.6 [Heaps, 2016]:

$$\text{Planning Reserve Margin (\%)} = 100 * (\text{Module Capacity} - \text{Peak Load}) / \text{Peak Load} \qquad (3.5)$$

$$\text{Module Capacity} = \text{Sum}(\text{Capacity} * \text{Capacity Value}) \text{ for all processes in the module.} \qquad (3.6)$$

LEAP uses the following formula to decide the amount of endogenous capacity additions required (Equation 3.7):

$$\text{Endogenous Capacity Additions Required} = (\text{Planning Reserve Margin} - \text{Reserve Margin Before Additions}) * \text{Peak Requirement} \qquad (3.7)$$

LEAP then calculates the endogenous capacity additions for each process by cycling through the processes listed on the Endogenous Capacity screen in the order listed on the screen by the user. In each year, capacity continues to be added in the amounts specified on the screen in the Addition Size column, until the amount added is greater than or equal to the Endogenous Capacity Additions Required [Heaps, 2016].

LEAP also considers the amount of electricity lost during transmission and distribution activities. Total electricity demand in the electricity system for a specific year (TEDt) is calculated as the sum of electricity demand ($ED_{t)}$ and electricity losses (ELt) during transmission and distribution (T&D) process in that year. TEIAS reported 12.1% of the total electricity available for consumption in 2017 was lost during transmission and distribution activities. The distribution and losses are expected to change within each scenarios. Electricity losses during transmission and distribution (T&D) processes in LEAP are calculated as in Equations 3.8 and 3.9 [Filatova et al, 2019]:

$$TED_t = ED_t + EL_t \qquad (3.8)$$

$$EL_t = ED_t * TL_t \tag{3.9}$$

where TEDt is the total electricity demand of year t, ED_t is the electricity demand and EL_t is the electricity lost during transmission and distribution (T&D) process in that year, TL_t is the percentage of T&D losses in year t.

In LEAP, processes (power plants) can dispatched using different dispatch rules. This study uses the Merit Order Dispatch Rule. In the merit order dispatch rule, processes are dispatched in ascending order of their assigned dispatch value. For instance, a process given a dispatch value of 1, will be dispatched first also known as baseload, while those with higher dispatch values are to be dispatched last to meet peak-demand also known as peak load [LEAP, 2011]. Merit orders for processes used in this study are all set to 1.

Maximum availability in LEAP is the ratio of the maximum energy produced to what would have been produced if the process ran at full capacity [Heaps, 2016]. The Maximum availability of each process must be entered, the value acts as the upper bound of availability of a process. Maximum availability of processes is an important variable in cases where two or more processes have the same merit-order value assigned to them, in such cases the process whose availability is greater will be dispatched first. In this study, the yearly availability shapes of each resource during each time slice were used. The availability of all resources are 100% except for solar and nuclear, whose availabilities are 35% and 95% respectively.

Efficiencies of power generating processes are also required to determine how well each process functions yearly. Efficiencies of renewable electricity generating processes are usually considered to be 100% while those of fuel oil power plants vary depending on the fuel [LEAP, 2011]. For this study, efficiencies of all processes were set to 100%. Lastly, the lifetime of each power producing process should be entered in years. The lifetime of all power generating processes was set to 50 years.

One of the aims of this study is to reduce the levels of CO2 emissions in electricity generation activities in Turkey. According to [Feng & Zhang, 2012] CO2 emission calculations are as in Equation 3.10:

$$\mathrm{CE} = \sum_{\mathrm{p}} \sum_{\mathrm{f,p}} \mathrm{EF}_{\mathrm{f,p}} * \mathrm{P}_{\mathrm{p}} * \frac{1}{\mathrm{E}_{\mathrm{p}}} \tag{3.10}$$

where CE is the CO_2 emissions, $\mathrm{EF}_{\mathrm{f,p}}$ is the CO_2 emission factor from one unit of primary fuel type f consumed for electricity production through technology p, E_{p} is efficiency of technology p , and P_{p} is the output power from technology p.

3.3. Scenario Description and Design

As it was mentioned before, two models were developed using LEAP, an accounting model and an optimization model, to run three scenarios, namely BAU, EE and REN. These two models share similarities in all aspects except for minor details in the transformation analysis module on the supply side. Both models share the same data in Current accounts, i.e. base year data for 2018. In addition, the datasets used to create the scenarios (BAU, EE, and REN) are identical in both accounting and optimization models.

Table 3.5 Parameters Comparison in Accounting versus Optimization Model

	Type of Model	
Type of Parameter	**Accounting**	**Optimization**
Planning Reserve Margin	YES	YES
Historical Production	YES	NO
Exogenous Capacity	YES	YES
Endogenous Capacity	YES	NO
Maximum Availability	YES	YES
Merit Order	YES	NO

In Table 3.5, a comparison of some important LEAP parameters in the accounting and optimization models used in this study are given. Parameters such as costs, process lifetime, system energy load shape, process efficiencies etc. do not change across scenarios unless stated. In Table 3.5, Yes indicate that the model type takes into consideration the given parameter, while no means the latter. Scenarios in the accounting model will be referred to as Business as Usual (BAU_ACC), Energy Efficiency (EE_ACC) and Renewable Energy Resources (REN_ACC) while those in the optimization model will be referred to as Business as Usual_Optimization (BAU_OPT), Energy Efficiency_Optimization (EE_OPT) and Renewable Energy Resources_Optimization (REN_OPT)

3.3.1. Design of BAU scenarios

The main goal of the BAU scenario is to determine how the future electricity demand and supply will be assuming demand will follow the current and past trends. That means the scenario does not take into consideration any new policies implemented by the state. In BAU scenario, the population forecast data was retrieved from TUIK for the years 2018 to 2040 [TUIK, 2018].

On the Demand side, residential demand is expected to grow directly proportional to increase in number of households. For the Industry, and Commercial & Services part of demand, the projected demand values for these two sector were used and the data for the projections were retrieved from MENR projections data [MENR, 2018]. Figure 3.4 illustrates Turkey's total forecasted demand data used in this study.

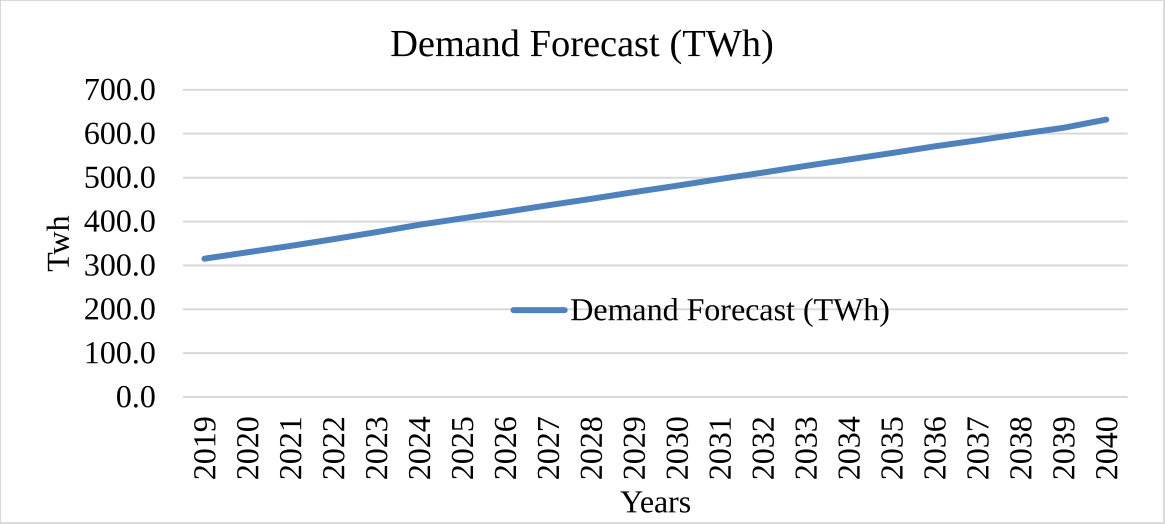


Figure 3.4 Data used to Forecast Demand

In the exogenous capacity variable, some future committed capacity additions were used in this study to project the capacity values from 2019 up to 2027. The exogenous capacity data were retrieved from TEIAS report [TEIAS, 2018] see Table 3.6 below. Exogenous Capacity in Table 3.6 were inherited by the Energy Efficiency scenarios (EE_ACC and EE_OPT)

Table 3.6 Exogenous Capacity Addition in BAU_ACC and BAU_OPT

	Capacity Additions (MW)					
Resources	**2019**	**2020**	**2021**	**2022**	**2023**	**2027**
Natural Gas	-	392.8	-	-	-	-
Hydro	1435.5	1470.3	531.1	5.3	-	863
Imported Coal	-	-	2045.5	-	-	-
Lignite	790	-	-	500	-	3800
Biomass	36.1	20	20	20	-	270
Wind	879.6	2259.2	535	30	-	4100
Solar	1000	1000	500	500	-	4700
Geothermal	20.3	3	-	-	-	-
Nuclear	-	-	-	-	1200	3600

In the BAU_ACC scenario, apart from exogeneous capacity, some endogenous capacities were added to maintain the planning reserve margin at 0% and are presented in Table 3.7. Data on endogenous capacity and addition order were retrieved from MENR's LEAP Energy Model for Turkey. Moreover, notice the expression used for Nuclear power plants in Table 3.7: *"If (year<2023, 0, 110)"*, this expression exempts LEAP from adding nuclear capacity before the year 2023. It is important to point out that in the optimization model, LEAP does not take into consideration the endogenous capacity instead it calculates values that will maintain some reserve margin.

Table 3.7 Endogenous Capacity in BAU_ACC and EE_ACC Scenarios

Process	**Additional Size (MW)**	**Addition Order**
Lignite	104	1
Hard Coal	112	2

Process	Additional Size (MW)	Addition Order
Natural Gas	15	3
Nuclear	If (year<2023, 0, 110)	4

3.3.2. Energy efficiency scenarios

The EC scenario was modeled using the targets set out by the state in National Energy Efficiency Action Plan 2017-2023 and Energy Efficiency Strategy Paper 2012-2023. The NEEAP 2017-2023 aims to reduce primary energy consumption in Turkey by 14% across all sectors by the end of the plan period. One of the main targets of the NEEAP is to reduce industrial energy intensity by at least 10% by 2023. This study assumes that there was no installment of energy efficient appliances in all sector of demand in 2018, hence energy efficient appliances will be introduced first in 2019. The study also assumes that there is no cost associated with installing efficient appliances.

For commercial and services sector, the Energy Efficiency Strategy paper 2012-2023 aims to decrease the energy consumption in public enterprises and facilities by 20% by the year 2023, therefore in this study, the commercial and services sector would reach 20% electrical efficiency by 2023. Furthermore, both Efficiency strategy papers emphasize on the importance of market transformation of electrical appliances such as refrigerators, electrical motors and so on to more energy efficient products but they do not specify energy saving targets, although in Energy efficiency paper 2013-2013, there’s a target to decrease the demand side electrical intensity of at least 20% by 2023. With this notion, this study assumes all electrical efficient appliances will reach 20% electrical efficiency by 2023.

On the supply side, one of targets of the Energy Efficiency paper 2012-2023 is to increase efficiency in production, transmission and distribution of electricity while decreasing the energy losses and harmful emission for the environment. Moreover, in Strategic Plan 2015-2019, the electricity losses during distribution were predicted to drop to 11% and 10% in 2018 and 2019 respectively. All other transformation variables data in the EE scenarios will be inherited from the respective parent scenarios (BAU_ACC and BAU_OPT) in respective accounting and optimization models.

3.3.3. Renewable energy scenarios

The National Renewable Energy Action Plan (NREAP) was used to model the REN scenarios. In this scenario, only the supply side will be altered to see how RES affect the future of electricity generation mix in Turkey. The NREAP details Turkey's plans to increase capacity installed of RES, these targets are shown in Table 3.8.

Table 3.8 Exogenous Capacity Data used in REN_ACC and REN_OPT

Resource	Capacity by 2023 (MW)
Hydropower	34000
Geothermal	1000
Solar	5000
Biomass	1000
Wind	20000
Nuclear	4800

The NREAP also emphasizes that there should be an increase in energy efficiency in electricity transmission grids and that the percentage of electricity lost or stolen should drop to 5%. Furthermore, the REN_ACC scenario in the accounting model takes into consideration the endogenous capacity to maintain the planned reserve margin. In REN_ACC scenario, RES were particularly used as the source of endogenous capacity additions. Data on the endogenous capacity were retrieved from the MENR LEAP Energy Model for Turkey.

Table 3.9 Endogenous Capacity in REN_ACC Scenario

Process	Additional Size (MW)	Addition Order
Wind	185	1
Solar	22	2
Nuclear	If (year<2023, 0, 110)	3
Geothermal	11	4

4. RESULTS AND DISCUSSION

In this section, the results of the three scenarios: BAU, EE, REN will be presented for both accounting and optimization models. Results section is categorized into four main sections, electricity demand projections, electricity supply analysis, costs analysis and finally, emissions analysis. All the results concerning nuclear energy will be presented separately to compare nuclear energy powered plants (NPPs) effect on the generation mix. The results analyses are carried out focusing on results of the base year, 2023 and 2040. In the results section, the following abbreviations will be used to reference the scenarios:

Table 4.1 Scenario Referencing

Scenarios	Reference Name
Business as Usual Scenario	BAU_ACC
Energy Efficiency Scenario	EE_ACC
Renewable Energy Resources Scenario	REN_ACC
Optimized Business as Usual Scenario	BAU_OPT
Optimized Energy Efficiency Scenario	EE_OPT
Optimized Renewable Energy Resources Scenario	REN_OPT

4.1. Electricity Demand Projections

The results of the electricity demand forecasts in both models are the same because the study used the same demand forecast data. In addition to that, results of BAU and REN scenarios are identical throughout the simulated period. Electricity demand rose to 331.47 TWh by 2023 in BAU and REN scenarios, while in EE scenarios electricity demand is expected to reach 274.45 TWh. In 2040, electricity demand reached 567.71 TWh for BAU and REN scenarios while EE scenario attained 471.61 TWh as illustrated in Figure 4.1.

In BAU and REN scenarios, residential demand rose to 54.7 TWh from 51.84 TWh in 2018, industrial and, commercial and services sector demand for electricity reached 150.15 TWh and 126.7 TWh respectively in 2023. In 2040, residential electricity demand rose to 63.19 TWh, while industrial demand rose to 282.96 TWh, and electricity demand in services and commercial sector was 238.76 TWh in 2040 (see Figure 4.2).

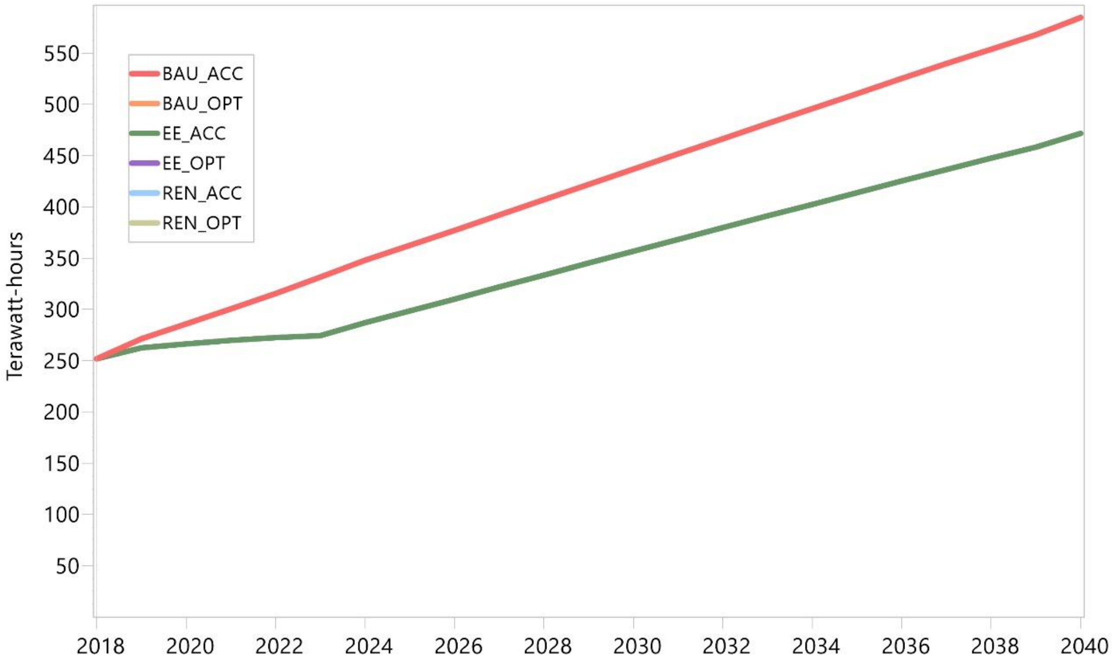


Figure 4. 1 Electricity Demand Projections

In EE scenarios, residential demand rose to 55.8 TWh in 2023 and dropped to 54.23 TWh in 2040. Electricity demand in industrial sector reached 120.12 TWh in 2023 and rose to 226.37 TWh in 2040, while commercial and services sector demand reached 101.36 TWh in 2023 and reached 191.01 TWh in 2040, see Figure 4.3. Electricity consumption of each household appliance and demand sectors in general throughout the simulated period in all scenarios are given in Appendix A.

Electricity demand projections in BAU and REN scenarios are the closest to the MENR data. In 2040 MENR projects that electricity demand will reach 630.7 TWh, the results from this study’s BAU and REN scenarios project 567.71 TWh in 2040, which is about 10% off the MENR projections.

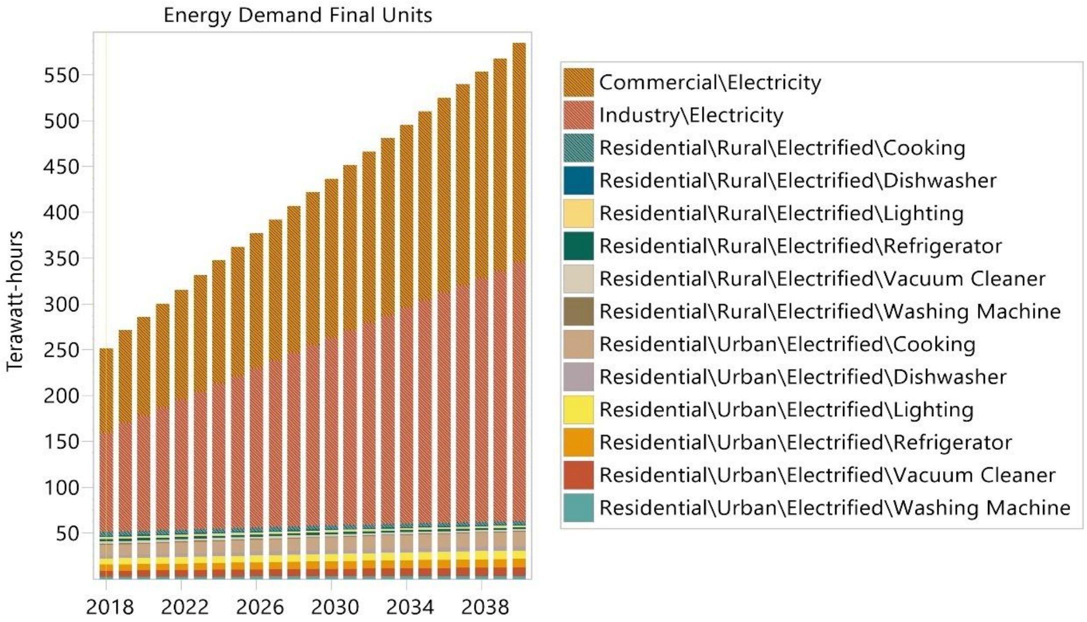


Figure 4. 2 Electricity Demand Projection in BAU and REN scenarios

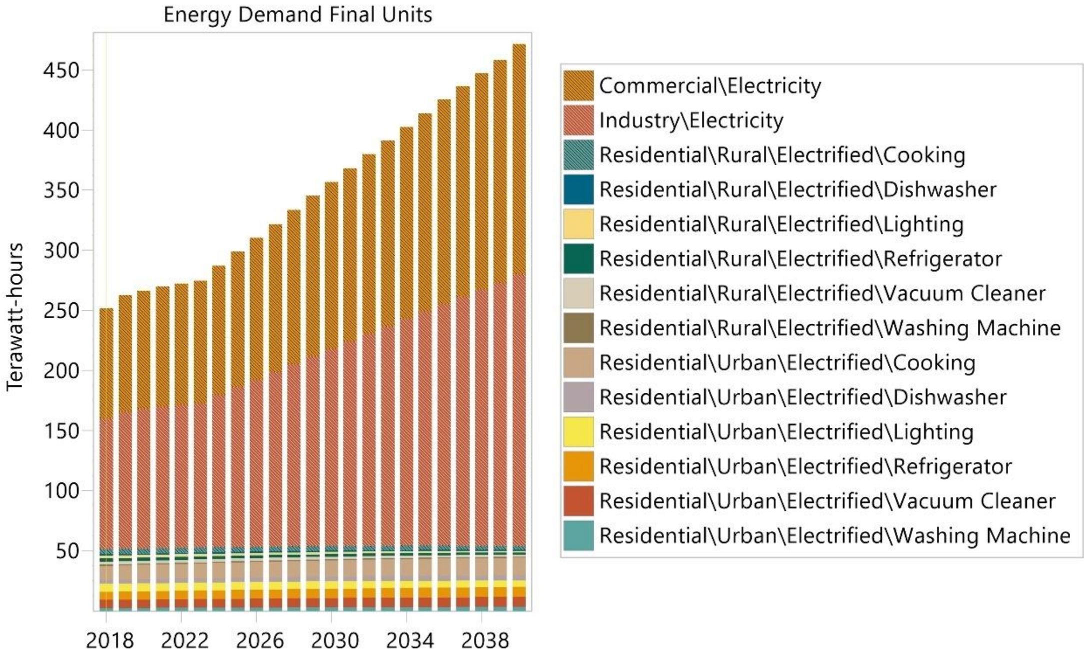


Figure 4. 3 Electricity Demand Projections in EE scenarios

4.2. Electricity Generation Projections

This study aims to find a solution that would increase Turkey's energy security by increasing generation of electricity form local and clean resources. In 2014, Turkey imported a total of 80,698.86 ktoe primary energy, which comprised of 40,641 ktoe of natural gas, 19,202 ktoe of coal, 20,172 ktoe of oil and 683.86 ktoe of electricity [MENR]. The rate of imports for electricity generation purposes in Turkey has been decreasing as years progress brought by continuous activities in developing and implementing energy policies in Turkey, the aim is to provide a pathway for a more independent energy system.

In terms of electricity generation, each optimized scenario matched the electricity generated from their respective accounting scenarios (Figure 4.4). Electricity generated in 2018 amounted to 303.56 TWh (Table 3.4). In 2023, electricity generation in BAU (BAU_ACC and BAU_OPT) and REN (REN_ACC and REN_OPT) scenarios were recorded at 377.23 and 349.03 TWh respectively. In 2023, BAU scenarios showed an increase of 73.66 TWh compared to electricity generated in 2018, while REN scenarios electricity generation increased by 45.47 TWh.

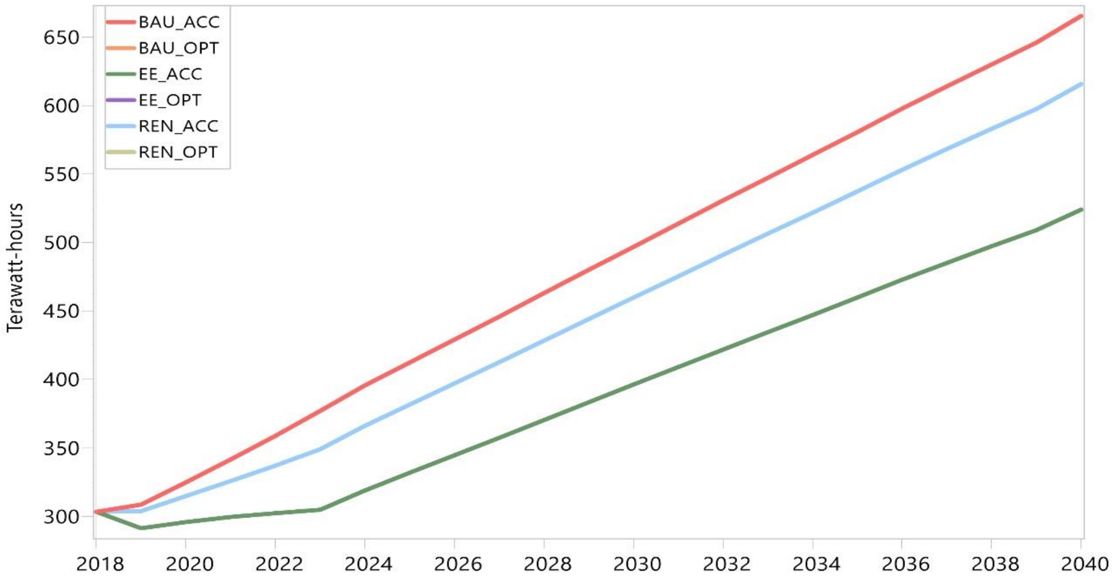


Figure 4. 4 Electricity Generation Projections 2019-2040

On the other hand, EE scenarios (EE_ACC and EE_OPT) generated the least amount of electricity throughout the modelled period (Figure 4.4). In 2023, electricity generation from the EE scenarios reached 304.94 TWh. Compared to electricity generated in 2018, EE scenarios showed a slight increase of 1.39 TWh. In 2040, electricity generation in BAU, EE and REN scenarios reached 655.43, 524.01 and 615.68 TWh respectively.

As stated earlier, the BAU scenarios generated more electricity than any of the other scenarios when compared to 2018 generation values, Figures 4.5 and 4.6 shows the generation mix in BAU_ACC, BAU_OPT scenarios respectively. In 2018, share of renewables in the electricity generation mix was 32.3%. The results showed that in 2023, 74.4% of the electricity generated in the REN_OPT scenario was generated using renewable energy resources (RES), (Figure 4.7). The shares of renewables in REN_OPT the generation mix is more than double the amounts in 2018.

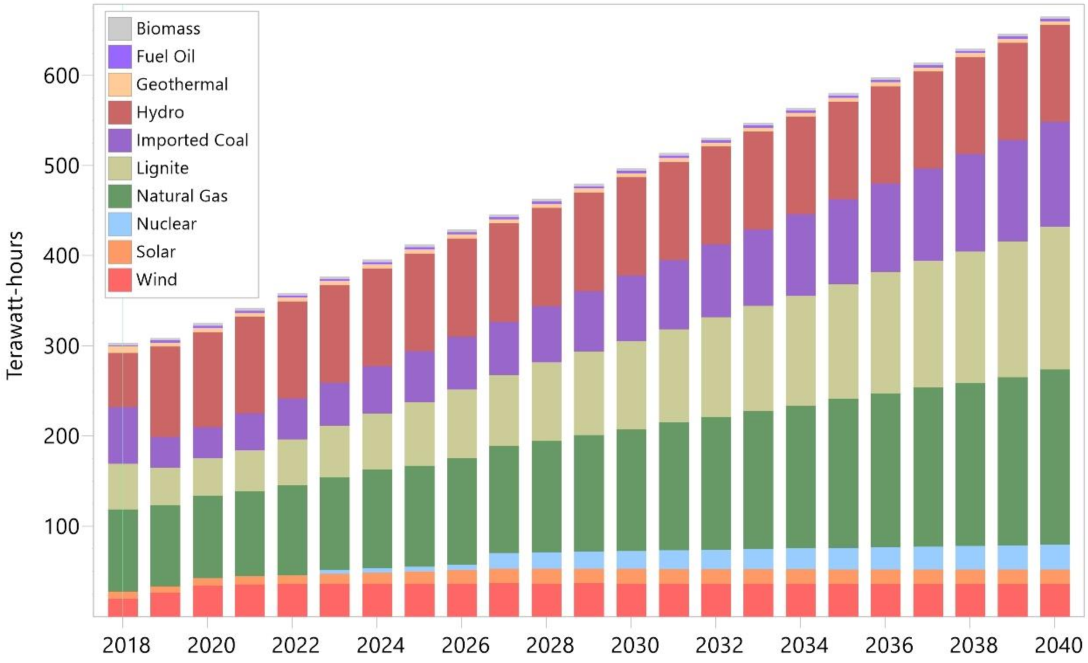


Figure 4. 5 Electricity Generation Mix in BAU_ACC Scenario

On the other hand, in the BAU_ACC scenario, 43.13% of generated electricity in 2023 was generated by RES, thus the optimized renewable energy scenario (REN_OPT) showed a 31% improvement in RES utilization. The dominant RES in 2018, were wind (6.59%) and hydro (19.75%), while in 2023, REN_OPT's generation mix was dominated by wind and hydro, which had 44.72% and 15.86% respective shares in 2023.

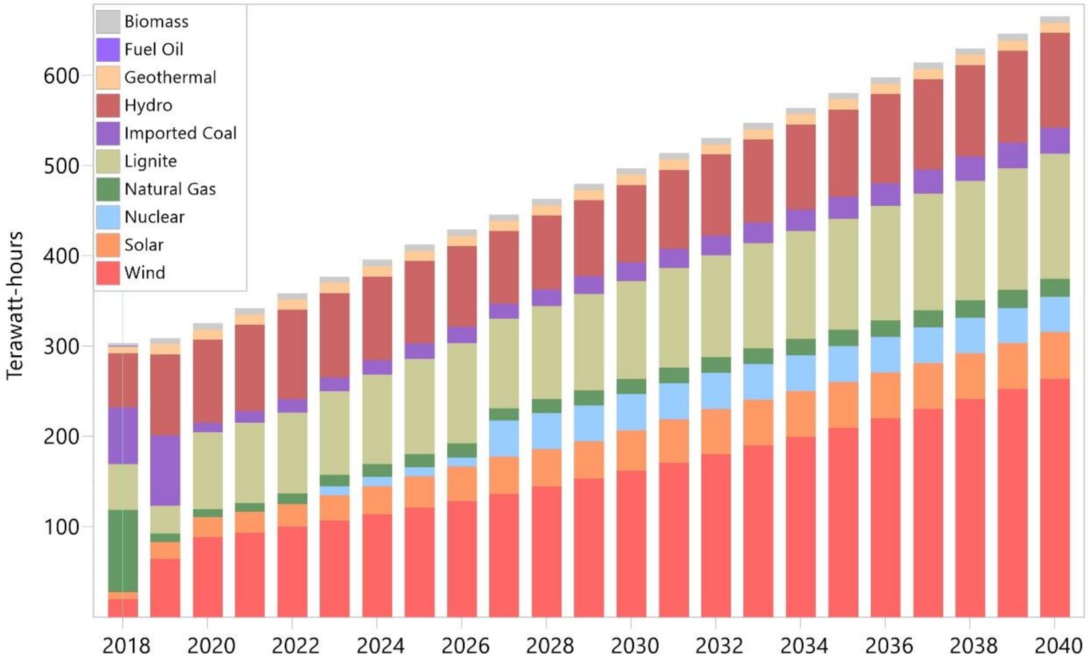


Figure 4. 6 Electricity Generation Mix in BAU_OPT Scenario

Fossil fuel power plants (FFPs) consist of lignite-fired power plants, hard coal (imported) power plants, and gas-fired power plants. The share of electricity generated from FFPs was 67.71%, which accounted for 204.57 TWh of electricity generated in 2018, Table 3.4. The BAU_ACC scenario recorded the highest share of electricity generated from FFPs in 2023 compared to other scenarios. FFPs electricity generation accounted for 55.1% (207.86 TWh) of total electricity generated in the BAU_ACC scenario in 2023, that is 389.6 TWh (Figure 4.5). This means a 12.61% decrease in the shares of FFPs generated electricity by the end of 2023 compared to FFPs shares in 2018.

Nuclear energy was introduced into the electricity generation mixes of all scenarios in 2023, there was no prior electricity generated from nuclear-powered power plants. The REN scenarios (REN_ACC and REN_OPT) recorded the highest shares of electricity generated from nuclear energy, see Figures 4.7 and 4.8 for electricity generation mixes in REN_OPT and REN_ACC respectively. In the REN_OPT scenario, nuclear power plants (NPPs) generated 39.95 TWh (11.44% of total generation) while in the REN_ACC scenario, NPPs generated 14 TWh of total electricity (4% of total generation) in 2023. In the REN scenarios 4.8 GW of nuclear energy capacity was added in 2023 as planned in the National Renewable Energy Action Plan 2014-2023 (NREAP), whereas in other scenarios 1.2 GW of nuclear energy capacity is added, therefore REN scenarios generated more from NPPs in 2023. The optimized renewable energy scenario (REN_OPT) scenario had the least share of electricity generated from FFPs (14.13%) compared to other scenarios in 2023 (Figure 4.7).

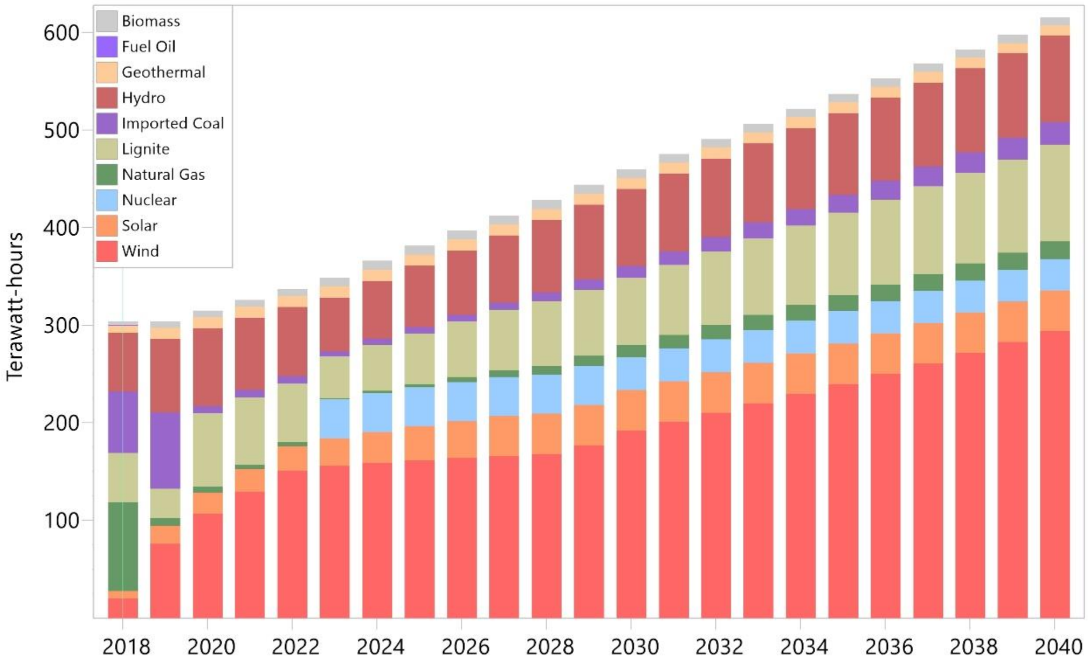


Figure 4. 7 Electricity Generation Mix in REN_OPT Scenario

There is always a decrease in electricity generated in EE scenarios compared to the REN and BAU scenarios, this is brought by the introduction of efficient appliances in all demand sectors in EE scenarios. This decreases the energy intensity and consumption hence it results in the drop of electricity produced to meet lowered demand (Figures 4.9 and 4.10). In 2023, the share of RES in EE_OPT scenario rose to 68.86% from 32.3% in 2018 (Figure 4.10). In 2023, EE_ACC generated 48.33% of its electricity from RES (Figure 4.9) while in EE_OPT electricity generated from RES accounted for 69% of total electricity generated (Figure 4.10). In 2040, RES electricity generation shares in EE_ACC and EE_OPT dropped to 32.1% and 64% in EE_ACC and EE_OPT scenarios, respectively.

In the year 2040, BAU_ACC generated 25% of its electricity from renewable energy resources which accounted for 166.3 TWh. Compared to RES share in BAU_ACC generation mixes in the years 2018 and 2023, the results showed a continuous drop in RES in BAU_ACC generation mix. The shares of RES dropped from 48.33% in 2018, to 43.13% in 2023 and dropped further in 2040 to 29%. In the REN_OPT and BAU_OPT scenarios, the share of electricity generated from RES accounted for 71.92%, 65.97% respectively. When compared to corresponding 2023 values, the RES shares in REN_OPT and BAU_OPT were less by 2.51% and 2.89% respectively.

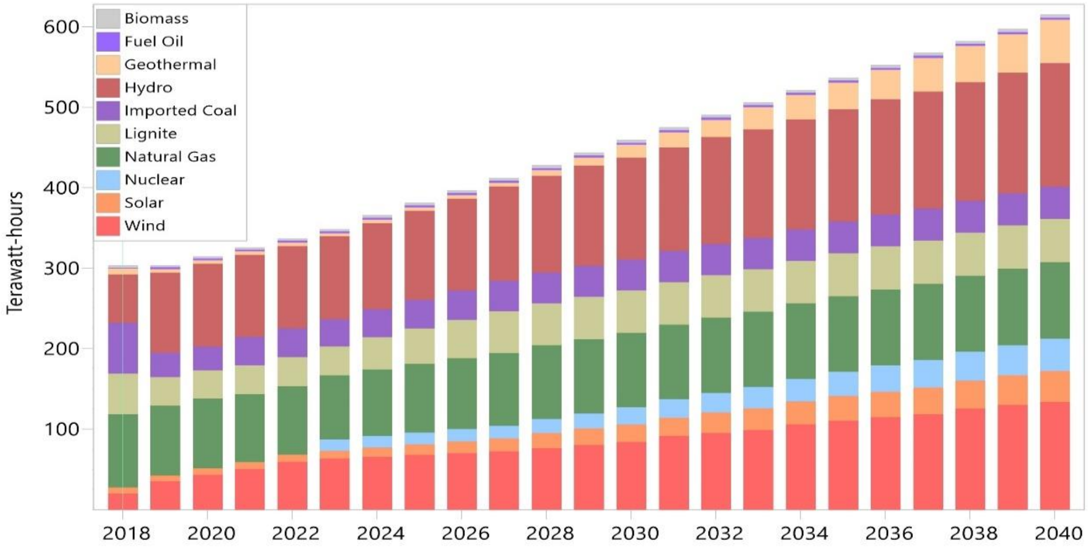


Figure 4. 8 Electricity Generation Mix in REN_ACC Scenario

In the BAU_ACC scenario, fossil fuel powered plants (FFPs) generated 70.47% of total electricity generated in 2040, which accounted for 468.94 TWh, (Figure 4.11). In the BAU_OPT, EE_OPT, and REN_OPT scenarios, the results showed a reduction of 42.3%, 42%, and 48% respectively in electricity generated from FFPs in 2040 when compared to BAU_ACC. Compared to 2023, FFPs share in electricity generation activities in 2040 increased across all scenarios except for the REN scenarios (REN_ACC and REN_OPT), in which both scenarios generated about 6% less FFPs based electricity in 2040 compared with 2023.

In 2040, EE_OPT scenario had the biggest share of electricity generated from nuclear energy across all scenarios, 7.47% generation mix (Figure 4.11). REN_ACC scenario had the second highest share of nuclear energy generated electricity in 2040, which accounted for 6.48% of the REN_ACC generation mix (Figure 4.8). Furthermore, the results showed that there was a decline of nuclear energy shares in the generation mix of REN_OPT scenario and an increase in the REN_ACC scenario compared to corresponding values in 2023. The share of electricity generated from nuclear energy powered plants (NPPs) in REN_OPT was 11.44% in 2023 which dropped to 5.27% in 2040, while in the REN_ACC scenario the share of NPPs was 4% in 2023 which slightly increased to 6.48% in 2040.

The electricity generation projections of each scenario throughout the simulated period are given in Appendix B.

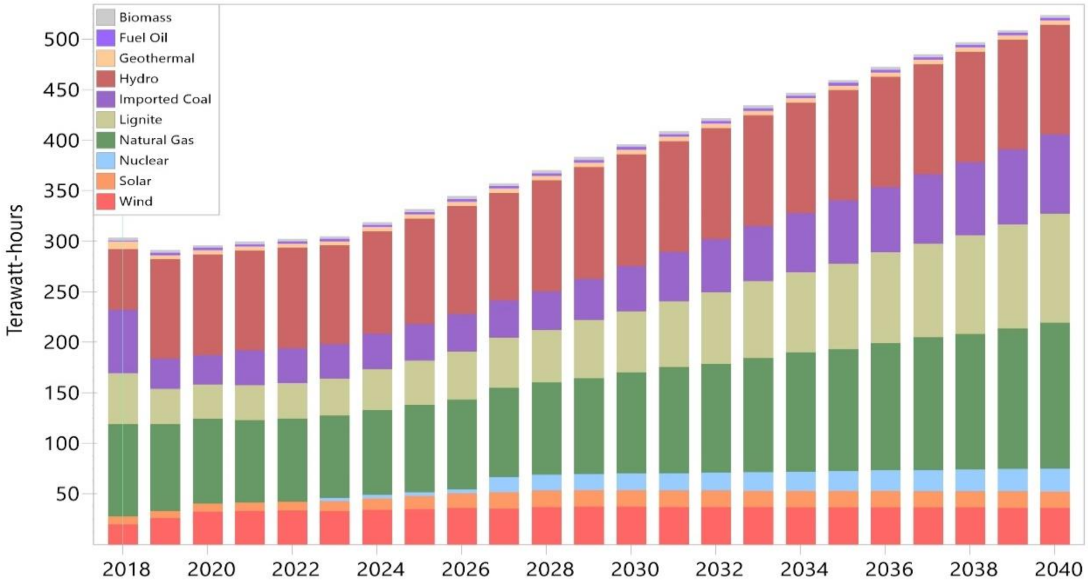


Figure 4. 9 Electricity Generation Mix in EE_ACC Scenario

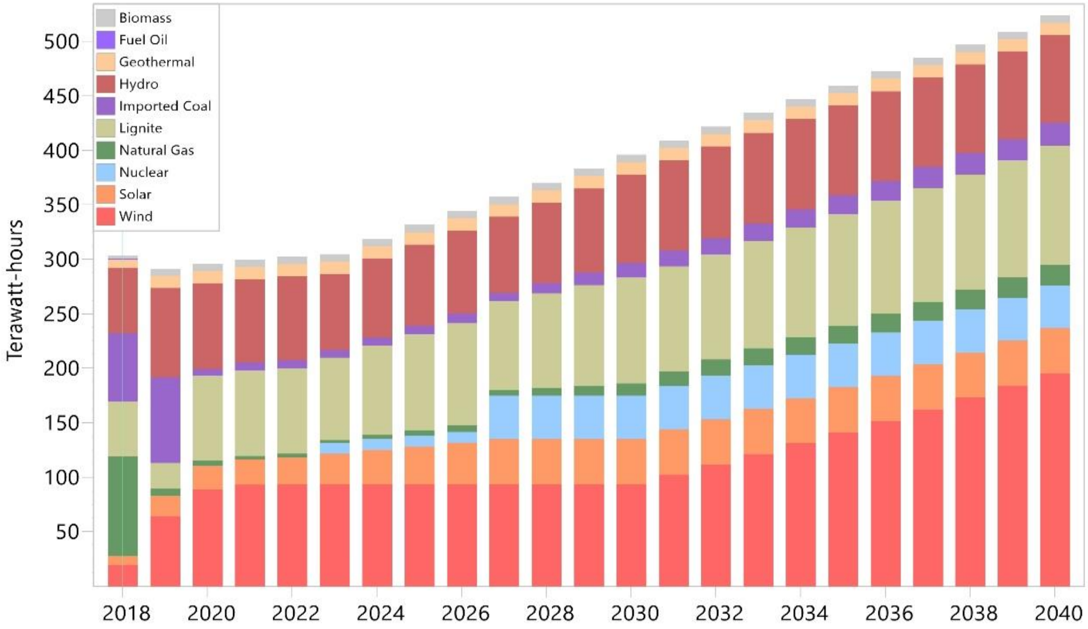


Figure 4. 10 Electricity Generation Mix in EE_OPT Scenario

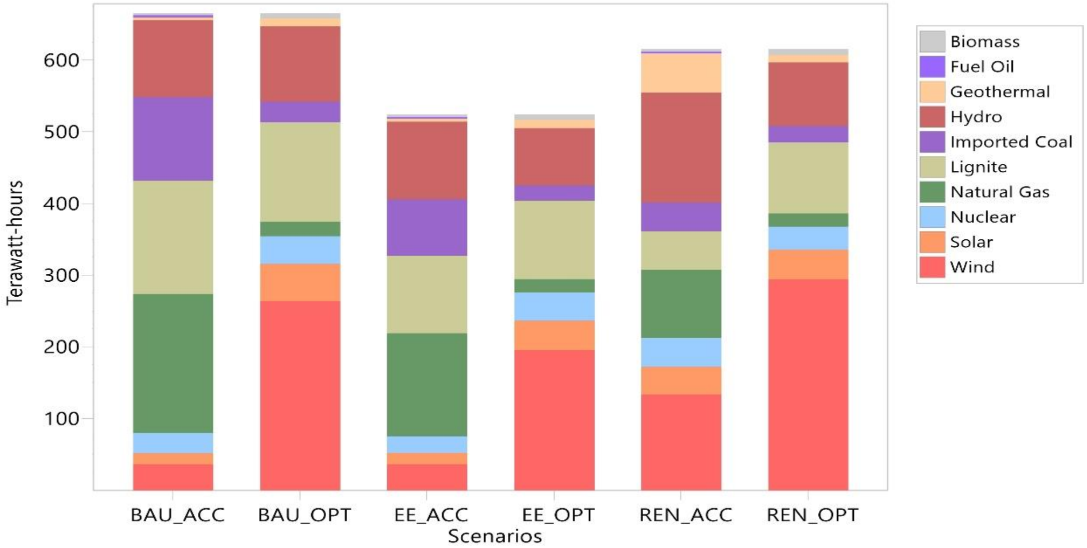


Figure 4. 11 Electricity Generation Mixes by Scenarios in 2040

In term of imports, the accounting scenarios had no imports as illustrated in Figure 4.12. More importantly, it is crucial to point out that no imports or export targets were set in 2018, the imports values to be reported in the results are basically electricity imports not resource imports. Electricity imports were used to fill gaps in supply when the module was unable to meet all the requirements on it, as a result of capacity limitations.

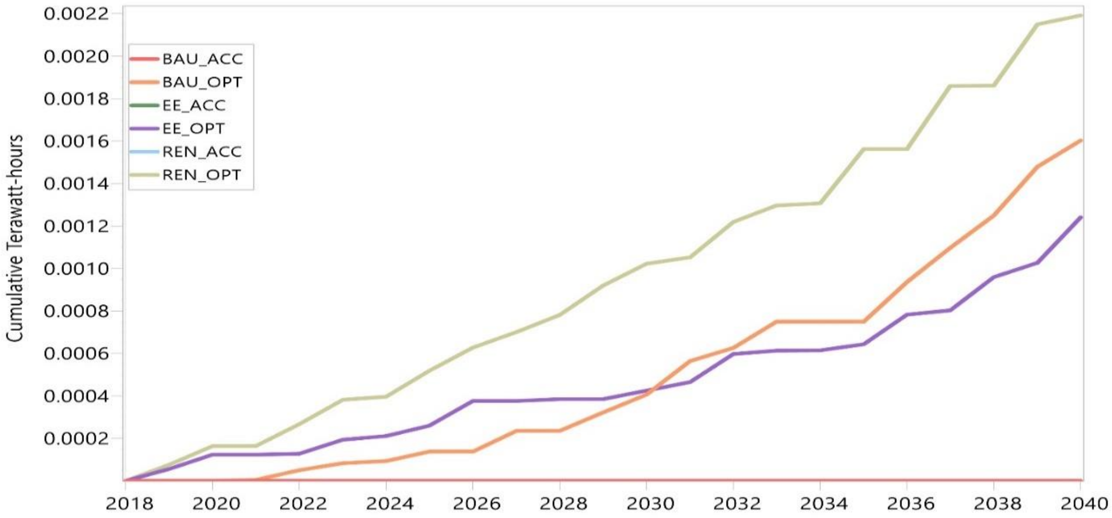


Figure 4. 12 Electricity Imports Projections

As it can be seen in Figure 4.12, the electricity imports that took place throughout the simulated period are very low. The imports are incurred only in the optimization scenarios. This indicates that most of the demand is met entirely by resources provided, only in minor cases is when the system imported some electricity.

The total capacity used in electricity generation in all scenarios in 2018 and 2040 are given in Figure 4.13. The total capacity required for electricity generation in 2018 was 88.49 GW, (Table 3.4). The results showed that, the BAU_ACC scenario required 206.2 GW of generation capacity which was the highest across all scenarios followed by the REN_ACC scenario which required 190.4 GW of capacity for electricity generation in 2040. Comparing the 2040 total capacity to total capacity values in 2018, there was an increase of 118 and 102 GW of capacity in BAU_ACC and REN_ACC respectively. The EE_OPT scenario required 146.2 GW, which meant EE_OPT required the least capacity for electricity generation in 2040 (Figure 4.13).

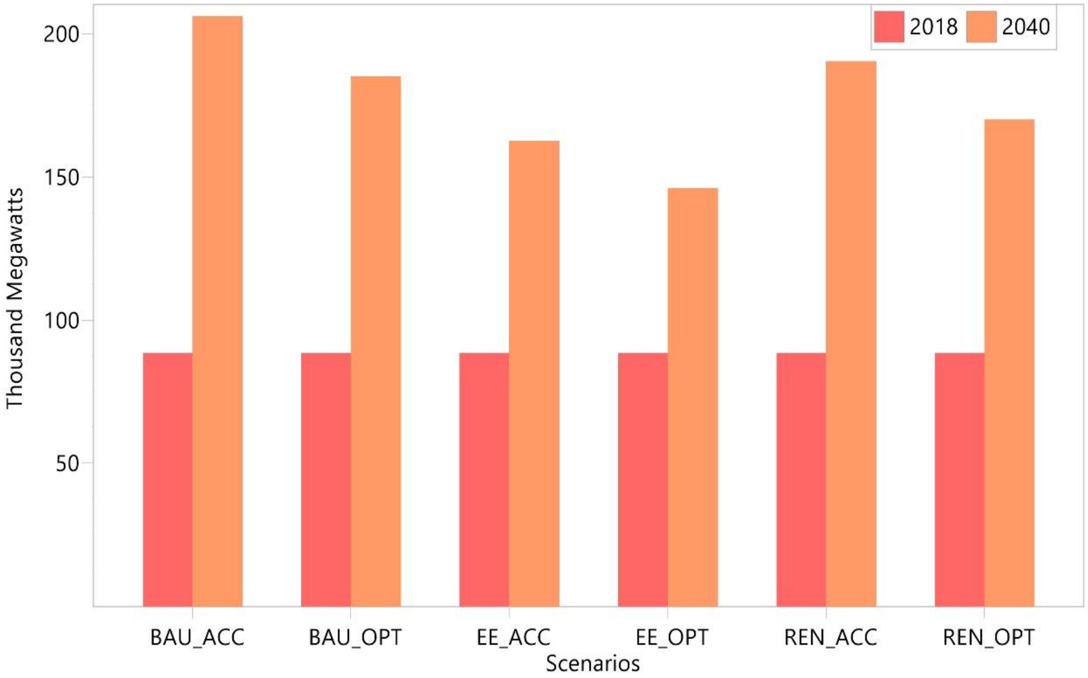


Figure 4. 13 Total Capacity across all scenarios in 2040.

In 2040, the exogenous capacity required for electricity generation in BAU_ACC, BAU_OPT, EE_ACC, EE_OPT was 115.71 GW while exogenous capacity in REN_ACC and REN_OPT required about 11.82 GW of more capacity (Figure 4.14). In terms endogenous capacity, BAU_ACC scenario was required 90.5 GW of additional capacity in 2040 which was recorded as the highest capacity added in 2040 compared to other scenarios. The REN_OPT and EE_OPT scenarios recorded the least endogenous capacity added.

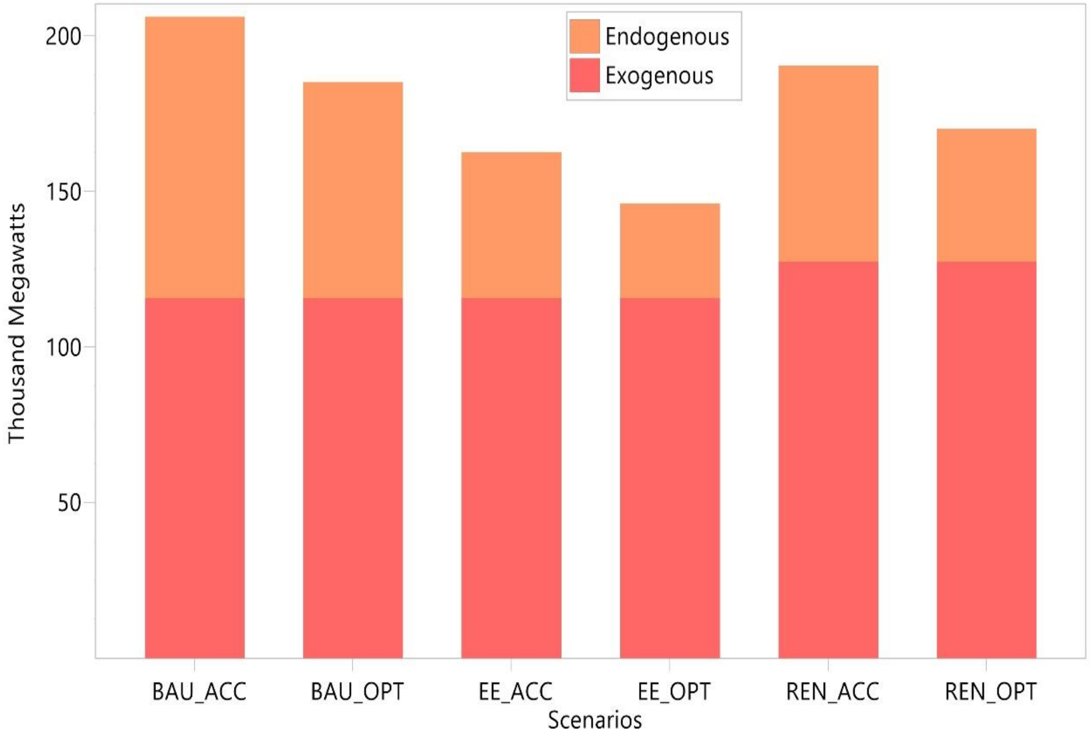


Figure 4. 14 Endogenous and Exogenous Capacities in 2040

4.3. Costs Analysis

In this subsection, the results of costs incurred by each scenario in their respective models will be presented graphically. In terms of the capital costs incurred by each scenario, the Renewable Energy scenario in the accounting model (REN_ACC) was the most expensive scenario which recorded a net present value (NPV) of 8.43 Billion USD in 2023. The NPV of capital costs in Billion USD from the base year 2018 to 2040 in all scenarios of both accounting and optimization models are presented in Figure 4.15.

The results further showed that there is little difference in NPV of capital costs incurred by the REN_OPT scenario (8.24 Billion USD in 2023) compared to REN_ACC scenario. In 2040, the most expensive scenario was still the REN_ACC with a NPV of 28.39 Billion USD in capital costs. In 2040, the cheapest scenario was the was the EE_OPT scenario which incurred a NPV of 12.04 Billion USD. As presented in Figure 4.15, the optimized scenarios are all cheaper than their respective accounting scenarios. Furthermore, the reason that the REN scenarios are the most expensive scenarios is because RES generating technologies incur more capital costs compared to other resources.

The NPV of fixed operating and maintenance costs (FIXOM) in 2018 were recorded at 2.89 Billion USD. In 2023, the REN_ACC scenario was slightly the most expensive scenario with a NPV of 4.36 Billion USD, Figure 4.16. The second most expensive scenario was the REN_OPT scenario which recorded a NPV of 4.32 Billion USD. In 2040, the BAU_ACC scenario was the most expensive scenario (7.83 Billion USD) followed by the REN_ACC scenario which incurred a NPV of 7.07 Billion USD (Figure 4.16). The EE_OPT scenario was the cheapest scenario again in terms of FIXOM in 2040, incurring a NPV of 5.26 Billion USD.

The NPV of variable O&M costs (VAROM) values in 2018 was recorded at 7.17 Billion USD (Figure 4.17). The NPV of VAROM were the most expensive in BAU_ACC which incurred 8.75 Billion USD in 2023. In the same year, REN_ACC, BAU_OPT, and REN_OPT incurred 7.96, 7.85, and 6.92 Billion USD respectively. In 2040, BAU_ACC incurred the most NPV VAROM costs at 16.31 Billion USD. EE_OPT and REN_OPT scenarios were two of the cheapest scenarios in terms of NPV VAROM in 2040, with 8.15 and 8.94 Billion USD respectively.

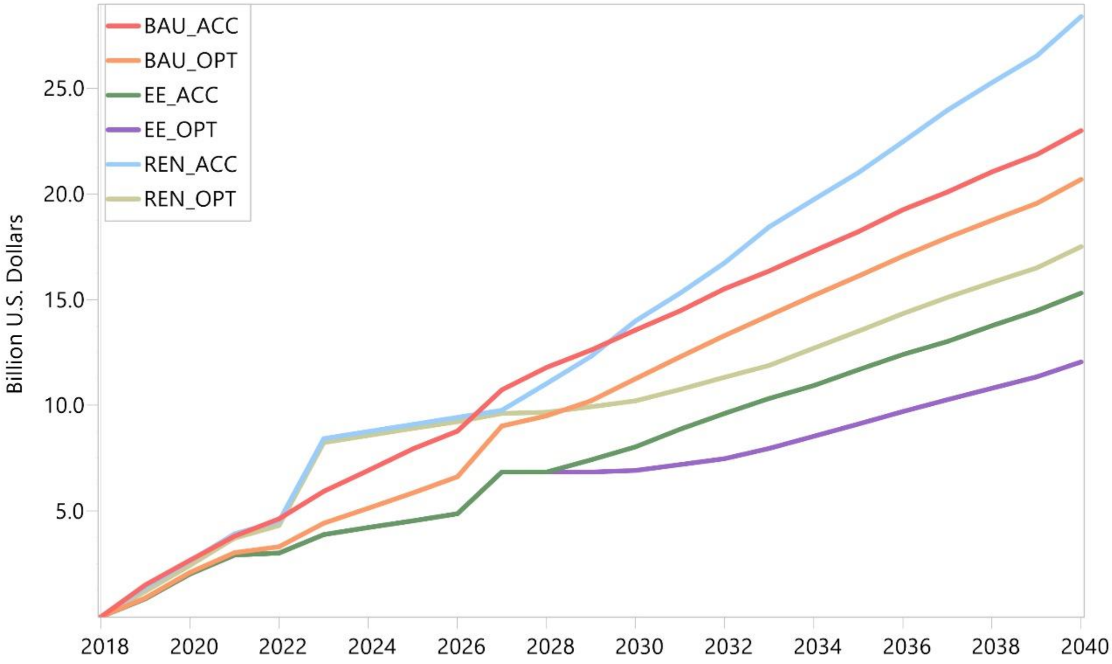


Figure 4. 15 Capital Costs

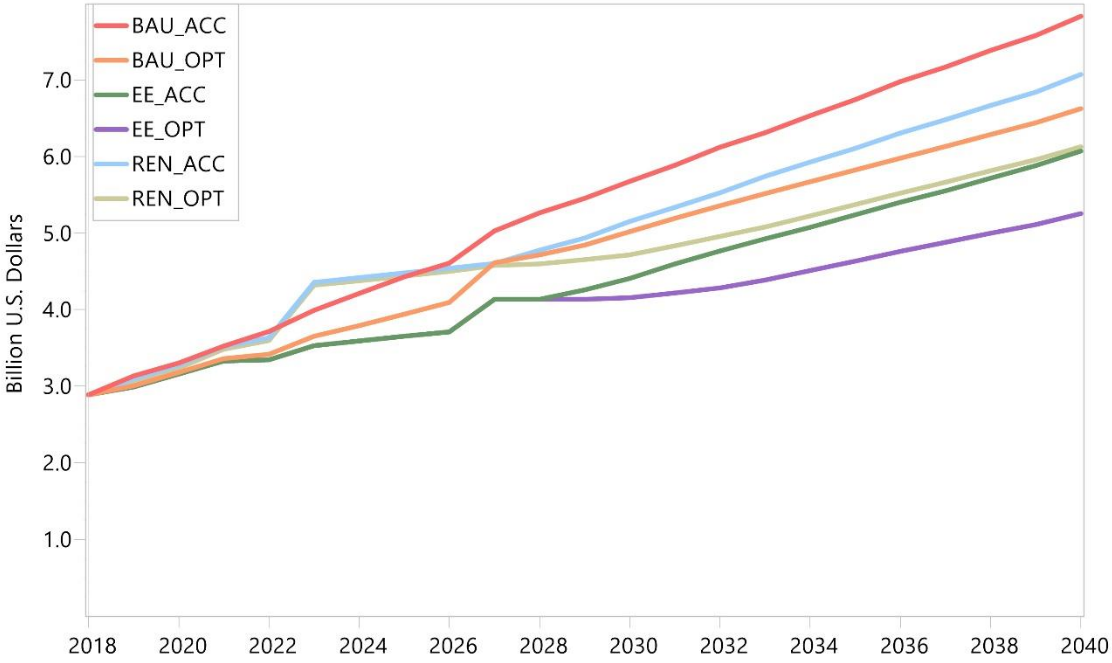


Figure 4. 16 Fixed Operating and Maintenance Costs

In 2040, the NPV of total costs were highest in REN_ACC at 47.32 Billion USD, while BAU_ACC scenario was close behind with 47.13 Billion USD (Figure 4.18). The optimized scenarios showed a decrease in cumulative NPV of total costs incurred compared to their corresponding accounting scenarios. In BAU_OPT, there was a decrease of 9.63 Billion USD compared to BAU_ACC, while REN_OPT and EE_OPT showed reductions of 14.76 and 8.47 Billion USD respectively when compared to total costs incurred in their corresponding accounting scenarios.

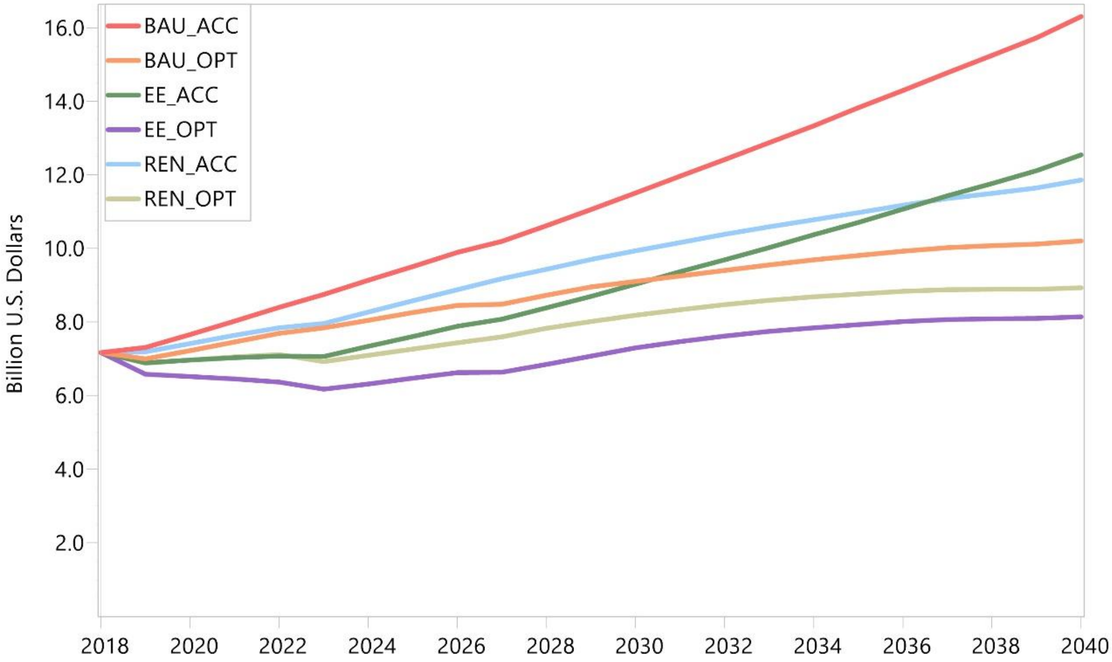


Figure 4. 17 Variable Maintenance and Operating Costs

Furthermore, the Cost-Benefit summary in LEAP shows is a special designed summary report available in the Summaries view. In the cost-benefit summary report, a provisional overview of the total cumulative costs and benefits from 2018 to 2040 of all six scenarios: EE_ACC, REN_ACC, BAU_OPT, EE_OPT, and REN_OPT scenarios compared to BAU_ACC discounted at 10% in 2018. The cost-benefit summary implied that a reduction of 30.7, 32.9, and 65.3 Billion USD in total cumulative discounted cost of electricity generation could be achieved by optimizing the generation mix, see Table 4.2.

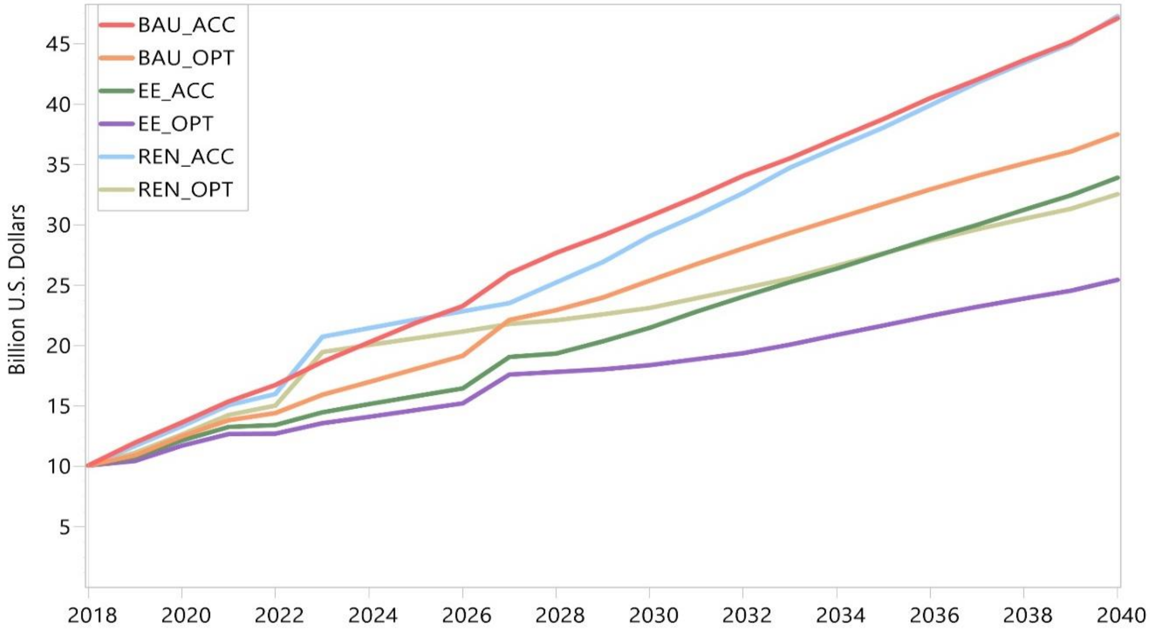


Figure 4. 18 Total Costs

The electricity system also incurs investment costs required in each transformation technology in a particular year. Investment costs. are defined as the product of the capacity added in that year and the unit capital cost [Heaps, 2016]. In this study the investment costs are divided into costs from exogenous, and endogenous capacity additions (Figures 4.19 and 4.20, respectively).

In terms of investment costs incurred as a result of exogenous capacity expansion, the results showed two outliers in years 2023 and 2027 (Figure 4.19) In 2023, the REN scenarios required 38.84 Billion USD worth of investment costs while BAU and EE scenarios required 8.67 Billion USD. The reason behind this large investment in REN scenarios is mainly due to RES capacity expansion plans derived from the NREAP but more importantly, 2023 was the first year for nuclear energy inclusion in Turkey’s electricity generation mix. In 2023, the amount of nuclear energy capacity added exogenously in REN scenarios was 4.8 GW whilst in BAU and EE scenarios 1.2 GW was installed, hence this resulted in higher exogenous investment costs in REN scenarios. In 2027, nuclear energy added exogenously in EE and BAU scenarios was 3.6 GW while no nuclear energy was added after 2023 in REN scenarios, hence this resulted in higher exogenous investment costs in BAU and EE scenarios compared to REN scenarios. Exogenous investment costs in BAU and EE scenarios was 19.42 Billion USD while REN scenarios required 3.29 Billion USD in 2027. There was no further exogenous capacity expansion across all scenarios after the year 2027, hence the exogenous investment costs dropped to zero in 2028 maintaining the same value up to 2040 (Figure 4.19).

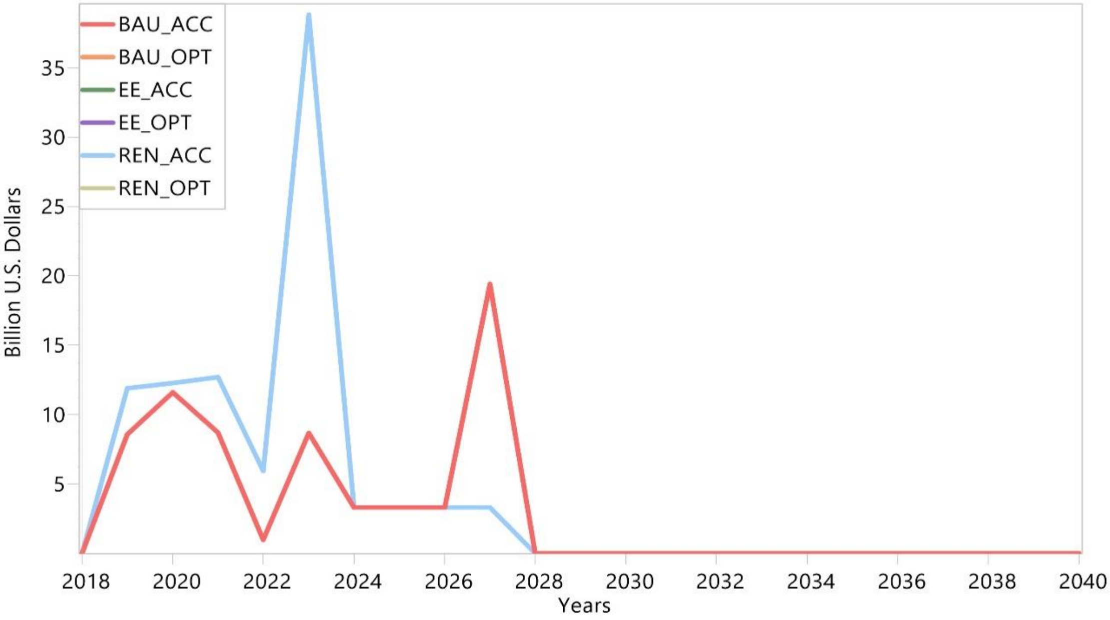


Figure 4. 19 Investment Costs due to Exogenous Capacity Additions

It's important to remember that in this study LEAP automatically decided on when and which resources' capacity to be added endogenously to maintain the planning reserve margin. Moreover, since there was no further exogenous capacity additions after 2027, there were rapid increases in endogenous capacity expansions across all scenarios after 2027 which led to increased endogenous investment costs. In 2040, the investment cost incurred as a result of endogenous expansion were highest in REN_ACC which incurred investment cost of 18.44 Billion USD. EE_OPT required the least amount of investment at 6.87 Billion USD in 2040 (Figure 4.20).

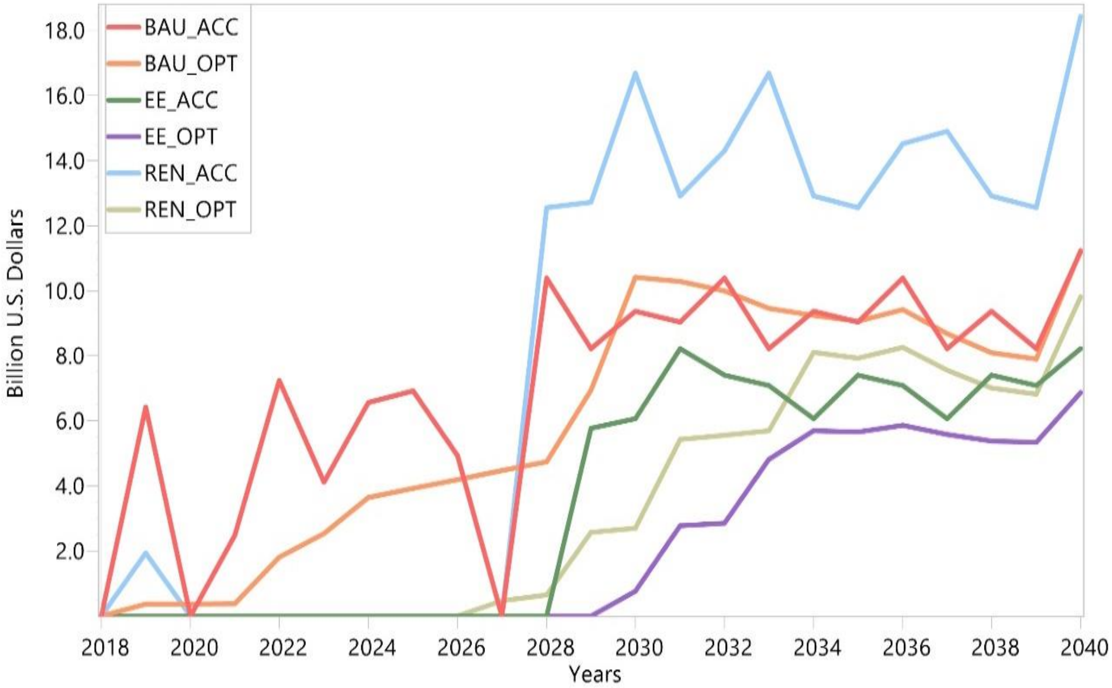


Figure 4. 20 Investment Costs due to Endogenous Capacity Additions

The total investment costs incurred are summation of the exogenous and endogenous investment costs (Figure 4.21). From 2018 (the base year) up to 2027 the investment costs incurred were mostly due to exogenous capacity expansion. In that 9-year period REN_ACC was the most expensive scenario to invest in (38.84 Billion USD in 2023). After 2027 leading up to 2040, the total investment costs incurred in REN_ACC were still the highest compared to rest of the scenarios. The next expensive couple of scenarios to invest are BAU_ACC and BAU_OPT. EE_OPT scenario recorded the least investment costs in the same period (Figure 4.21).

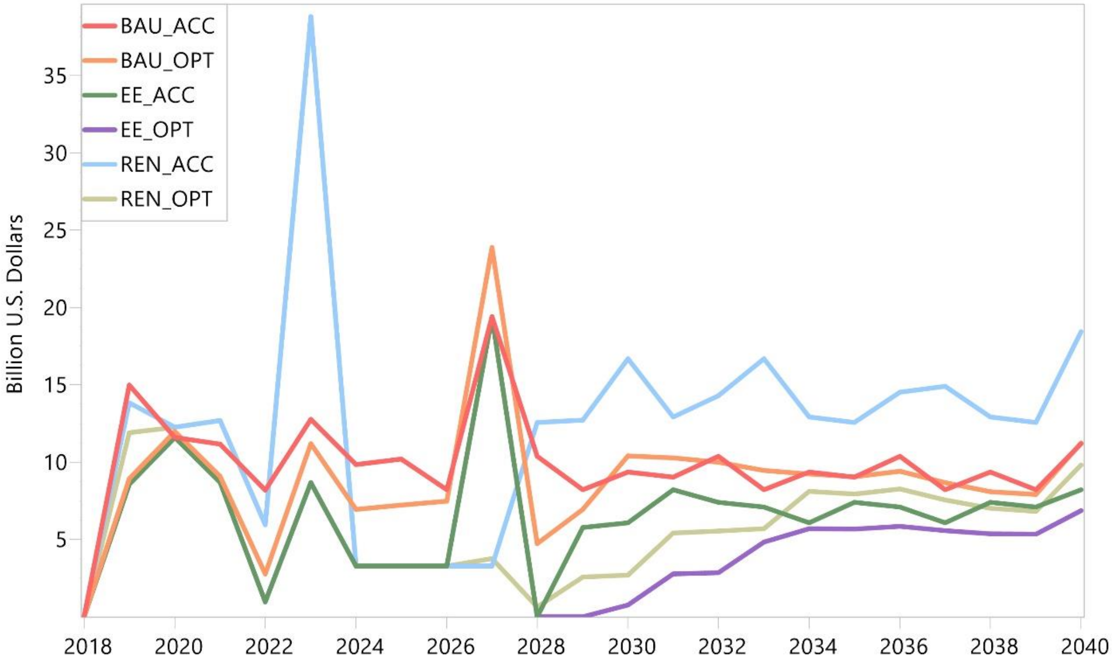


Figure 4. 21 Total Investment Costs due to Capacity Additions

4.4. Emission Analysis

There are three greenhouse gases (GHGs), namely, carbon dioxide, methane, and nitrous oxide that contribute most to the total GHG emissions. The results are measured in Million metric tons of carbon dioxide equivalent (CO2eq). GHGs emissions in 2018 were recorded at 56.57 Million tonnes of CO2eq. Moreover, the results show that greenhouse gas (GHG) emissions from BAU_ACC are way above all other scenarios throughout the modeled period. (Figure 4.22). In 2023, the GHGs emissions in BAU_ACC decreased by 0.12 Million tonnes of CO2eq compared to GHGs emissions in 2018. The REN_ACC scenario, which recorded 39.89 Million tonnes of CO2eq (Figure 4.22), which marked a decrease of 16.68 Million tonnes of CO2eq. The REN_OPT scenario emitted the least GHGs in 2023 at 16.41 Million metric tonnes of CO2eq, while the EE_OPT scenario emitted the second least GHGs at 28.17 Million metric tonnes of CO2eq. Emissions levels in 2023 across all scenarios are lowered compared to emission values in 2018 this due to intensive RES utilization across all scenarios within the first five years of simulation, 2019-2023.

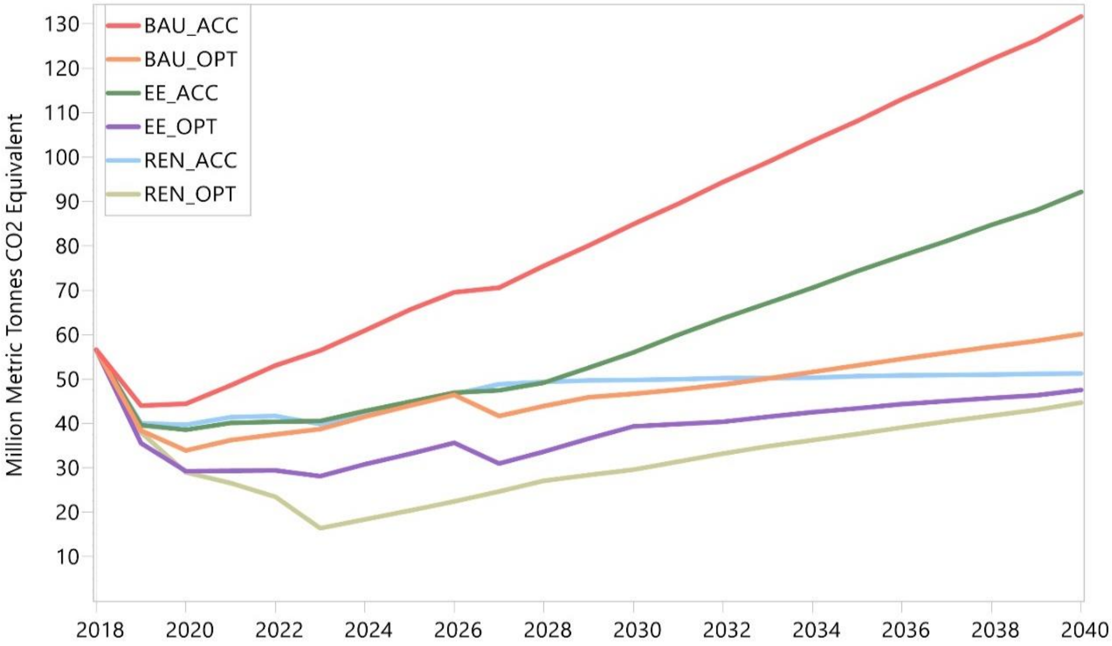


Figure 4. 22 Greenhouse gas emissions

GHGs emissions in BAU_ACC reached 131.71 Million metric tonnes of CO2eq in 2040, while GHG emissions in EE_ACC, REN_ACC scenarios were 92.18 and 51.26 Million metric tonnes of CO2eq, respectively. The REN_OPT scenario recorded the least emissions in 2040 followed by the EE_OPT as the second least GHGs emitting scenario. REN_OPT, EE_OPT and BAU_OPT scenarios emitted 44.66, 47.5 and 60.15 Million metric tonnes of CO2eq respectively in 2040.

Coal (Lignite and imported coal) and natural gas-fired power plants emitted the highest share of GHGs in 2040 (Figure 4.23). In the BAU_ACC scenario, coal-fired power plants emitted a total of 1279.52 Million metric tonnes of CO2eq while natural gas power plants emitted 620.93 Million metric tonnes of CO2eq (Figure 4.23). BAU_ACC has the highest share of GHG emissions, because Turkey utilizes its coal resources to ensure energy security, although doing so increases the pollution levels in Turkey.

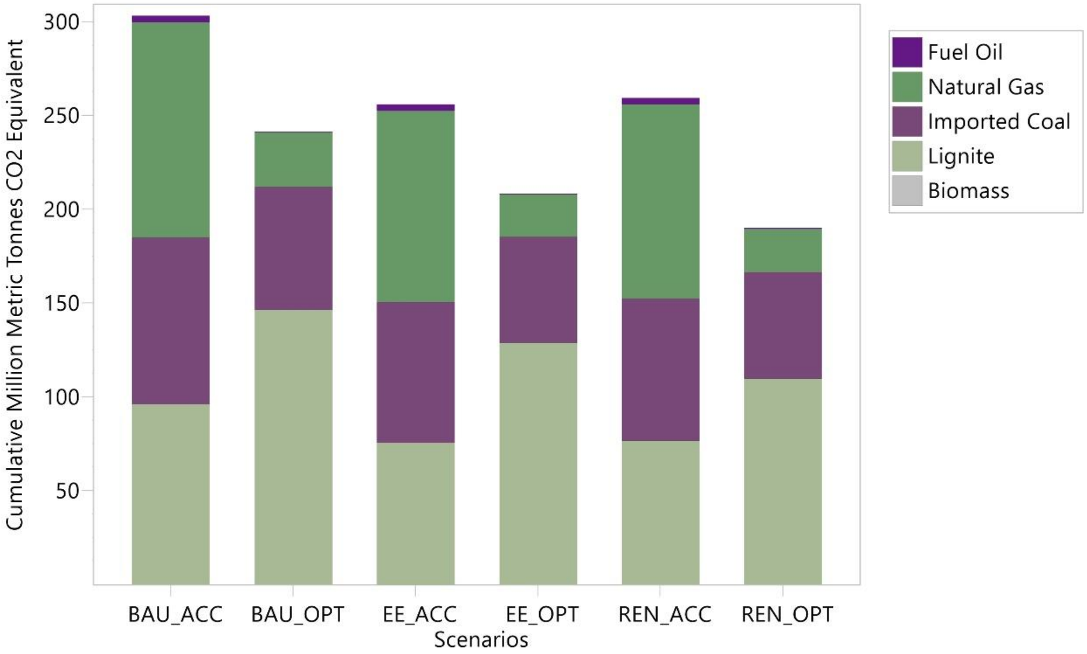


Figure 4. 23 Cumulative GHGs contribution by Resources in 2040

In addition, the cost-benefit summary report, an overview of cumulative costs and benefits summary (2018-2040) compared Business as Usual (BAU_ACC) scenario, is presented in Table 4.2. In this study, the cost summary also compared the environmental externality costs of each scenario. Environmental externality costs refer to social damage costs per unit of pollutant. The costs relative to the reference scenario (BAU_ACC) are shown as positive values, while benefits are shown as negative values [LEAP, 2011].

The cost-benefit summary displays the total cumulative emissions of all greenhouse gases avoided by each scenario (expressed in terms of the global warming potential of those pollutants in tonnes of CO2 equivalent). LEAP uses the 100-year integration global warming potential factors suggested by the IPCC (by default) in calculating the GHGs saving potential of a given scenario and simultaneously calculates the costs of avoiding GHGs for Turkey. The cost of avoided GHG emissions (USD/Tonnes CO2eq) is given by dividing the NPV savings (compared to reference scenario) by the Tonnes of CO2e avoided [LEAP, 2011].

Table 4. 2 Cumulative Costs and Benefits Summary: 2018-2040. Compared to Scenario: Business as Usual (BAU_ACC). (Billion 2018 US Dollar. Discounted at 10% at year 2018

	BAU_OPT	REN_ACC	EE_ACC	REN_OPT	EE_OPT
Demand	-	-	-	-	-
Residential	-	-	-	-	-
Industry	-	-	-	-	-
Commercial	-	-	-	-	-
Transformation	-30.7	-4.2	-48.0	-32.9	-65.3
Transmission and Distribution	-	-	-	-	-
Electricity Generation	-30.7	-4.2	-48.0	-32.9	-65.3
Resources	-	-	-	-	-
Production	-	-	-	-	-
Imports	-	-	-	-	-
Exports	-	-	-	-	-
Unmet Requirements	-	-	-	-	-
Environmental Externalities	-	-	-	-	-
Non-Energy Sector Costs	-	-	-	-	-
Net Present Value	-30.7	-4.2	-48.0	-32.9	-65.3
GHG Savings (Mill Tonnes CO2e)	826.2	818.3	560.3	1,171.6	1,030.1
Cost of Avoiding GHGs (U.S. Dollar/Ton CO2e)	-37.2	-5.2	-85.7	-28.1	-63.4

The cost-benefit summary shows that REN_OPT scenario had the highest GHGs saving potential, followed by EE_OPT scenario. The REN_OPT scenario had 1171.6 Million tonnes of CO2eq saving potential, while the EE_OPT scenario recorded a saving potential of 1030.1 Million tonnes of CO2eq (Table 4.2). In terms of costs of avoiding GHGs, EE_OPT and EE_ACC scenarios results in 63.4 and 85.7 USD/tonnes CO2eq respectively when compared to BAU_ACC. REN_ACC and REN_OPT scenarios results in 5.2 and 28.1 USD/tonnes CO2eq respectively in costs of avoiding GHGs, as presented in Table 4.2.

The results showed that REN scenarios have better potential of GHG savings due to high levels of RES utilization in electricity generation processes, the cost of electricity generation in REN scenarios is higher than in EE scenarios (Table 4.2). Lowered demand due to efficient appliances introduced in demand sectors in EE scenarios did not result in significant reduction in GHGs emissions from electricity generation activities. Therefore, the cost of avoiding GHGs (which is measured in US Dollar/Ton CO2eq) in EE scenarios are the higher than in REN scenarios.

Both [NEEAP] and [NREAP] emphasize on reducing the amount of electricity lost during transmission and distribution processes as applied in EE and REN scenarios. By reducing the demand (as presented in EE scenarios) and increasing domestic electricity generating resources in the generation mix (as presented in REN scenarios) would be able to reduce transmission costs. The less electricity demanded from large distant power plants and distribution centers will result in less electricity needs to be transmitted, hence this will reduce transmission costs. These cost savings could in turn be used to further improve energy efficiency and impel customers to generate their own RES generated electricity such as rooftop solar panels.

Furthermore, despite optimized scenarios matched the amount of electricity generated by their respective accounting scenarios, in terms of costs, the optimized scenarios incurred less costs compared to their corresponding accounting scenarios, hence the cost minimization concept of optimizing the scenarios has been realized.

5. CONCLUSION AND RECOMMENDATIONS

This study analyzed the Turkish government’s released energy documents on improving energy efficiency [National Energy Efficiency Action Plan (NEEAP) 2017-2023] and renewable energy utilization [National Renewable Energy Action Plan (NREAP) 2017- up to the year 2023, which marks Turkey’s 100 years of Independence] to create two scenarios, that are Renewable Energy (REN) and Energy Efficiency (EE) to project Turkey’s future energy generation mix up to year 2040. The study analyzed each scenario under accounting and optimization approaches in LEAP. The scenario results were benchmarked with Business-as-usual scenario (BAU_ACC) that assumes current trend will continue as in the past. Furthermore, this study aimed to perform an in-depth analysis on how the proposed energy plans by the government fair against the reference scenario (BAU_ACC) on aspects such as levels of GHGs emissions, costs of generating electricity and import levels using scenario analysis in LEAP.

The demand analysis showed that electricity demand projections in BAU and REN scenarios will reach 584.91 TWh in 2040. Our calculations show that, the government’s plan on implementation of effective and efficient energy-intensive appliances in the demand sectors as applied in the of the EE scenarios (EE_ACC and EE_OPT) could result in decrease in electricity demand by at least 113.3 TWh in 2040 compared to BAU_ACC scenario. The results suggest that electricity demand projections are minimized in EE scenarios and are more likely to match actual demand values in the future [NEEAP, 2014].

In terms of costs of generating electricity, EE_ACC and EE_OPT showed a reduction of 48 and 65.3 Billion USD respectively in total costs incurred for electricity generating purposes (Table 4.2). The result suggest that the most cost-effective scenario compared to BAU_ACC is the EE_OPT scenario.

Furthermore, in the cost benefit summary (Table 4.2), the EE scenarios recorded the highest potential of reducing the costs of avoiding greenhouse gases (GHGs). The costs of avoiding

GHGs in EE_ACC and EE_OPT scenarios (compared to BAU_ACC scenario) were 85.7 and 63.4 USD/Ton CO2eq respectively (Table 4.2). Meanwhile, the REN_OPT scenario was the best scenario in terms of costs of avoiding GHGs emission compared to BAU_ACC (Table 4.2). This was due to large share of RES in electricity generation mix of REN_OPT throughout the modelled period which resulted in big GHG savings (Table 4.2). Therefore, the optimized renewable energy scenario (REN_OPT), presents an environmentally friendly option with minimized GHG emissions as well as the cheapest option to reduce GHGs emissions.

In 2040, REN_OPT had a share of 72% of its electricity generated from renewable energy resources. Moreover, in terms of fossil fuel power plants (FFPs), REN_OPT had the least share of electricity generated from FFPs. For these reasons, the optimized renewable energy scenario (REN_OPT) proves to be the best pathway for Turkey in terms of RES utilization. Transition to a renewable energy-based electricity system in Turkey, would favor the country very much because as mentioned before, Turkey has an abundance of renewable resources in hydro, geothermal, wind and solar. Utilizing these domestic and renewable resources will help Turkey both economically and socially and further strengthen Turkey’s energy security.

Additionally, the results of the electricity generation mixes across all scenarios suggested that natural gas still plays a major role in electricity generation in Turkey. Experts believe that Turkey’s natural gas demand will continue to grow steadily and will reach 67-70 bcm/year in 2030 [Rzayeva, 2014]. Most of the contracts that BOTAŞ has will run out around mid-2020s (Iran in 2026, Azerbaijan in 2022 and Russia in 2025), besides that, Gazprom has ongoing contracts with private companies in Turkey that run out in 2021 and this would affect around 36bcm/year of gas. Moreover, Turkey and Azerbaijan have an agreement to establish a Trans Anatolian Natural Gas Pipeline system (TANAP) that started flowing gas into Turkey in 2018. Its capacity is expected to be 16 bcm/year in 2020 and would be increased to 23 and 31 bcm/year in 2023 and 2026 respectively.

The optimized renewable energy scenario (REN_OPT) promised to emit the least amounts of GHGs and to increase the RES utilization in Turkey. As Turkey is currently focusing all its attention on increasing the levels of renewable energy resource utilization, REN_OPT is the perfect fit for this target, only that renewable energy technologies (RETs) requires large investment and operating & maintenance costs. One advantage of dealing with RETs, is that RETs installment and maintenance activities can trigger industrialization in Turkey. Industrialization would bring many benefits to Turkey's economy, such as higher production of goods and services, therefore higher gross domestic products. In 2017, a study conducted by Stanford University [Jacobson et al., 2017] reports renewable energy roadmaps that 139 countries should follow in order to achieve 100% electricity from water, wind and solar energy. The study predicted that, by 2050, there will be as many as 52 Million jobs to be created worldwide from RETs installments and maintenance activities. Transition to RES in Turkey would likewise boost the economy, save a lot of money Turkey spends on energy imports from neighboring countries and at the same time, strengthen Turkey's energy security by utilizing its abundant domestic RES.

The optimized energy efficiency scenario (EE_OPT) offer an easy way out by issuing energy efficient technologies across all sectors. This would slow down the rapid increase in electricity demand in Turkey. Furthermore, EE_OPT scenario proved to be the most cost-efficient scenario and the least import dependent scenario. Evidently, in this study the best scenario pathway proposed for Turkey was the Optimized Energy efficiency scenario (EE_OPT). In early 2018, Turkey's Minister of Energy spoke at the Energy Efficiency Forum stating that Turkey's National Energy Efficiency Action Plan (NEEAP) [MENR, 2017] could save the country $30.2 Billion by 2033. Currently, there has been an increase in energy efficient house construction in Turkey. The Minister went on to say that by 2023, around 1.7 Million energy efficient households will be constructed, and this would save the government a total of $1 Billion due to energy savings. These efficient homes will save 40% on residential heating and will save $10 Billion in the industrial energy consumption. This implies that implementing energy efficiency policies can help with a smooth energy transition in Turkey.

This study used both accounting and optimization approaches because, the accounting model offers a chance to answer “what if” questions about the changes in the electricity system while the optimization model offers a more concrete analysis and a single optimal solution that minimizes the costs of generating electricity from various resources.

The author recommends future studies to use advanced and detailed modelling tools such as MARKAL/TIMES and OSeMOSYS to perform a similar study. Furthermore, the model could be expanded to model the whole energy system of Turkey (including electricity, heating, transportation, etc.).

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Senior Design Project:

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Teaching Experience:

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PUBLICATIONS, PRESENTATIONS AND ABSTRACTS:

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- Massaga D. J, Kirkil G, "Renewable Energy Transition Scenario for Turkey using LEAP", 12th International NCM Conference: New Challenges in Industrial

Engineering and Operations Management, Ankara Yildirim Beyazit University, Ankara, Turkey, September 11-12, 2018

- Received Certificate of attendance for participating in DiploHack Istanbul, Sustainable Development Goals (SDGs), Nov 2-3, 2018
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Internship Experience

- **July 2010** Intern at The College of Engineering and Technology (COET), University of Dar es Salaam, Tanzania.
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APPENDICES

Appendix A. Electricity Demand Projections

A.1 Electricity Demand in BAU_ACC, BAU_OPT, REN_OPT and REN_ACC scenarios

Energy Demand Final Units
Scenario: BAU_ACC, All Fuels
Branch: Demand
Units: Terawatt-hours

Branches	2020	2025	2030	2035	2040
Commercial\Electricity	106.56631	140.27960	172.98071	205.52168	238.76027
Industry\Electricity	126.29358	166.24779	205.00243	243.56730	282.95893
Residential\Rural\Electrified\Cooking	4.26294	4.15859	3.99492	3.77070	3.49153
Residential\Rural\Electrified\Dishwasher	1.21773	1.18792	1.14117	1.07712	0.99737
Residential\Rural\Electrified\Lighting	2.46956	2.40912	2.31430	2.18440	2.02268
Residential\Rural\Electrified\Refrigerator	2.48198	2.42123	2.32593	2.19538	2.03285
Residential\Rural\Electrified\Vacuum Cleaner	2.46074	2.40051	2.30603	2.17660	2.01545
Residential\Rural\Electrified\Washing Machine	0.99499	0.97064	0.93243	0.88010	0.81494
Residential\Urban\Electrified\Cooking	11.95773	13.01809	14.04860	15.01681	15.90584
Residential\Urban\Electrified\Dishwasher	3.41579	3.71869	4.01306	4.28963	4.54359
Residential\Urban\Electrified\Lighting	6.92723	7.54152	8.13850	8.69939	9.21442
Residential\Urban\Electrified\Refrigerator	6.96206	7.57943	8.17941	8.74312	9.26074
Residential\Urban\Electrified\Vacuum Cleaner	6.90249	7.51458	8.10944	8.66832	9.18151
Residential\Urban\Electrified\Washing Machine	2.79100	3.03849	3.27902	3.50500	3.71251
Total	285.70414	362.48619	436.76595	510.29557	584.91262

A.2 Electricity Demand Projections in EE_ACC and EE_OPT scenarios

Energy Demand Final Units Scenario: EE, All Fuels Branch: Demand Units: Terawatt-hours					
Branches	2020	2025	2030	2035	2040
Commercial\Electricity	98.04101	112.22368	138.38457	164.41735	191.00822
Industry\Electricity	116.19010	132.99823	164.00194	194.85384	226.36714
Residential\Rural\Electrified\Cooking	4.23621	4.06734	3.84464	3.56975	3.25073
Residential\Rural\Electrified\Dishwasher	1.20940	1.15949	1.09434	1.01450	0.92234
Residential\Rural\Electrified\Lighting	2.37335	2.08060	1.77329	1.46100	1.15582
Residential\Rural\Electrified\Refrigerator	2.46047	2.34778	2.20498	2.03365	1.83904
Residential\Rural\Electrified\Vacuum Cleaner	2.43837	2.32413	2.18025	2.00841	1.81391
Residential\Rural\Electrified\Washing Machine	0.99118	0.95763	0.91102	0.85146	0.78063
Residential\Urban\Electrified\Cooking	11.88276	12.73243	13.52013	14.21654	14.80889
Residential\Urban\Electrified\Dishwasher	3.39243	3.62967	3.84838	4.04027	4.20178
Residential\Urban\Electrified\Lighting	6.65734	6.51313	6.23600	5.81843	5.26538
Residential\Urban\Electrified\Refrigerator	6.90172	7.34950	7.75406	8.09901	8.37783
Residential\Urban\Electrified\Vacuum Cleaner	6.83974	7.27548	7.66710	7.99850	8.26336
Residential\Urban\Electrified\Washing Machine	2.78031	2.99778	3.20371	3.39096	3.55619
Total	266.39439	298.65688	356.62441	413.77367	471.61125

Appendix B. Electricity Supply Projections

B.1 Electricity Generation Projections in BAU_ACC

Outputs by Feedstock Fuel
Scenario: BAU_ACC, All Fuels, All Output types
Branch: Transformation\Electricity Generation\Processes
Units: Terawatt-hours

Branches	2018	2023	2030	2035	2040
Biomass	2.62	2.58	2.60	2.57	2.56
Fuel Oil	0.96	2.44	2.46	2.43	2.42
Geothermal	7.61	4.45	4.49	4.44	4.41
Hydro	59.95	108.22	109.09	107.93	107.22
Imported Coal	62.95	47.69	72.83	94.50	116.18
Lignite	50.39	56.88	98.04	126.92	158.53
Natural Gas	91.23	103.29	134.38	165.60	194.24
Nuclear	-	4.24	19.99	23.68	27.76
Solar	7.86	10.96	16.25	16.08	15.98
Wind	20.00	36.47	36.77	36.38	36.14
Total	303.56	377.23	496.89	580.54	665.43

B.2 Electricity Generation Projections in BAU_OPT

Outputs by Feedstock Fuel Scenario: BAU_OPT, All Fuels, All Output types Branch: Transformation\Electricity Generation\Processes Units: Terawatt-hours Branches	2018	2023	2030	2035	2040
Biomass	2.62	6.63	6.63	6.63	6.63
Fuel Oil	0.96	-	-	-	-
Geothermal	7.61	11.44	11.44	11.44	11.44
Hydro	59.95	93.62	85.76	96.48	104.94
Imported Coal	62.95	15.13	20.25	24.22	28.97
Lignite	50.39	92.51	108.90	123.05	138.44
Natural Gas	91.23	12.94	16.71	18.23	20.06
Nuclear	-	9.99	39.95	39.68	38.98
Solar	7.86	28.15	45.24	51.05	51.90
Wind	20.00	106.83	162.02	209.76	264.07
Total	303.56	377.23	496.89	580.54	665.43

B.3 Electricity Generation Projections in EE_ACC

Outputs by Feedstock Fuel

Scenario: EE_ACC, All Fuels, All Output types

Branch: Transformation\Electricity Generation\Processes

Units: Terawatt-hours

Branches	2018	2023	2030	2035	2040
Biomass	2.62	2.34	2.64	2.61	2.58
Fuel Oil	0.96	2.21	2.50	2.46	2.44
Geothermal	7.61	4.03	4.56	4.50	4.46
Hydro	59.95	98.04	110.80	109.34	108.28
Imported Coal	62.95	33.93	44.63	62.65	78.42
Lignite	50.39	36.69	60.46	84.48	108.22
Natural Gas	91.23	81.21	100.16	120.90	144.29
Nuclear	-	3.52	16.65	19.67	22.69
Solar	7.86	9.93	16.51	16.29	16.13
Wind	20.00	33.04	37.34	36.85	36.49
Total	303.56	304.95	396.25	459.75	524.01

B.4 Electricity Generation Projections in EE_OPT

Outputs by Feedstock Fuel
Scenario: EE_OPT, All Fuels, All Output types
Branch: Transformation\Electricity Generation\Processes
Units: Terawatt-hours

Branches	2018	2023	2030	2035	2040
Biomass	2.62	6.63	6.63	6.63	6.63
Fuel Oil	0.96	-	-	-	-
Geothermal	7.61	11.44	11.44	11.44	11.44
Hydro	59.95	70.08	81.26	82.72	80.42
Imported Coal	62.95	6.75	13.32	17.54	20.86
Lignite	50.39	75.67	97.09	102.06	109.48
Natural Gas	91.23	2.55	11.46	16.56	18.89
Nuclear	-	9.99	39.95	39.95	39.14
Solar	7.86	28.15	41.42	41.42	41.42
Wind	20.00	93.69	93.69	141.43	195.75
Total	303.56	304.95	396.25	459.75	524.01

B.5 Electricity Generation Projections in REN_ACC

Outputs by Feedstock Fuel
Scenario: REN_ACC, All Fuels, All Output types
Branch: Transformation\Electricity Generation\Processes
Units: Terawatt-hours

Branches	2018	2023	2030	2035	2040
Biomass	2.62	3.04	3.52	3.58	3.62
Fuel Oil	0.96	2.17	2.52	2.56	2.59
Geothermal	7.61	3.97	15.86	33.29	53.98
Hydro	59.95	103.24	126.71	139.52	153.91
Imported Coal	62.95	33.35	38.66	39.30	39.78
Lignite	50.39	36.07	52.51	53.37	54.03
Natural Gas	91.23	79.83	92.53	94.05	95.21
Nuclear	-	13.85	21.40	29.91	39.91
Solar	7.86	9.76	21.57	30.69	38.67
Wind	20.00	63.77	84.47	110.90	134.00
Total	303.56	349.04	459.75	537.15	615.70

B.6 Electricity Generation Projections in REN_OPT

Outputs by Feedstock Fuel
Scenario: REN_OPT, All Fuels, All Output types
Branch: Transformation\Electricity Generation\Processes
Units: Terawatt-hours

Branches	2018	2023	2030	2035	2040
Biomass	2.62	8.76	8.43	8.09	7.91
Fuel Oil	0.96	-	-	-	-
Geothermal	7.61	11.44	11.44	11.34	10.56
Hydro	59.95	55.34	78.97	83.91	88.54
Imported Coal	62.95	5.13	11.89	18.09	23.15
Lignite	50.39	42.93	68.86	84.39	99.06
Natural Gas	91.23	1.27	12.60	16.28	18.26
Nuclear	-	39.95	33.73	33.47	32.43
Solar	7.86	28.15	41.42	41.42	41.42
Wind	20.00	156.08	192.43	240.17	294.37
Total	303.56	349.04	459.75	537.15	615.70