ENERGY POLICY ANALYSIS WITH THE BOĞAZİÇİ UNIVERSITY ENERGY MODELING SYSTEM BUEMS: PROSPECTS FOR THE DIFFUSION OF RENEWABLE ENERGY TECHNOLOGIES AND UTILIZATION OF DOMESTIC COAL RESERVES IN TURKEY

by

Fazlı İlke Yıldırım

B.S., Industrial Engineering, Boğaziçi University, 2014

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Industrial Engineering
Boğaziçi University
2019

ENERGY POLICY ANALYSIS WITH THE BOĞAZİÇİ UNIVERSITY ENERGY MODELING SYSTEM BUEMS: PROSPECTS FOR THE DIFFUSION OF RENEWABLE ENERGY TECHNOLOGIES AND UTILIZATION OF DOMESTIC COAL RESERVES IN TURKEY

APPROVED BY:

Prof. Dr. Gürkan Kumbaroğlu . . . .
(Thesis Supervisor)

Prof. Dr. İlhan Or . . . .

Assoc. Prof. Kemal Sarıca . . . .

DATE OF APPROVAL: 26.12.2018

ACKNOWLEDGEMENTS

First of all, I would like to give my thanks to my beloved grandmother Güler for her endless love and support during my whole life. I would also like to thank my lovely girlfriend Dilan for her huge love and support. I would also like to thank rest of my family (Şehabettin, Gamze, Giryan, Fevzi and Deniz) for all the good times of my life.

Special thanks to my thesis advisor Prof. Dr. Gürkan Kumbaroglu for his advice and support throughout the thesis work and precious knowledge during my undergraduate and graduate years. I would also like to express my deep gratitude to Professor İlhan Or, Assoc. Prof Yıldız Arıkan, Assoc. Prof Kemal Sarıca and Assoc. Prof Gönenç Yücel for their support to me and the project.

This thesis was supported by the Scientific and Technological Research Council of Turkey under Project No: 114M348 and by the Boğaziçi Univerisity Research Fund under Project No BAP12281.

ABSTRACT

ENERGY POLICY ANALYSIS WITH THE BOĞAZİÇİ UNIVERSITY ENERGY MODELING SYSTEM BUEMS: PROSPECTS FOR THE DIFFUSION OF RENEWABLE ENERGY TECHNOLOGIES AND UTILIZATION OF DOMESTIC COAL RESERVES IN TURKEY

In this thesis, the relationship among the use of renewable energy technologies, the use of coal resources and the implied changes in CO2 emission between 2017 and 2047 in Turkey are examined. This thesis aims to reveal cost and emission implications under various renewable energy and coal policy scenarios and guide government and private sector policy-makers to make more efficient and cost-effective investments.

In this study, puclicly available data of the Turkish Electricity Transmission Corporation (TEIAS), the Turkish Statistical Institute (TUIK), the Ministry of Energy and Natural Resources, the World Energy Council Turkish National Committee are used to estimate the useful energy demand as exogenous input into the Boğaziçi University Energy Modeling System (BUEMS).

The base scenario results indicate 82% growth in total energy-related CO2 emissions between 2017 - 2047. A 15% reduction in total CO2 emission is projected in 2047, if the electricity generation targets for wind and solar power technologies set in Renewable Energy Resource Zone (YEKA) tenders are reached. It is observed that, direct emission scenarios are more cost-effective in decreasing CO2 emission what compared to taxation and decreases total CO2 emission more than sectoral emission scenarios in the long term.

ÖZET

BOĞAZİÇİ ÜNİVERSİTESİ ENERJİ MODELLEMELERİ SİSTEMİ BUEMS İLE ENERJİ POLİTİKALARI ANALİZİ: TÜRKİYE'DE YENİLENEBİLİR ENERJİ TEKNOLOJİLERİ VE YERLİ KÖMÜR KAYNAKLARININ KULLANIMININ İNCELENMESİ

Bu tezin amacı Türkiye'de 2017-2047 yılları arasında yenilenebilir enerji teknolojilerinin kullanımının artırılmasıyla birlikte kömür kaynaklarının kullanımı ve bununla beraber karbondioksit emisyonunda meydana gelen değişimleri incelemekti. Farklı senaryoların simüle edildiği bu çalışma, yenilenebilir enerji kaynaklarının en etkili nasıl kullanılabileceği ve buna bağlı olarak gerek özel gerekse devlet kaynaklı yatırımların en doğru nasıl yapılabileceği konusunda yol gösterici bir çalışma olmayı hedeflemektedir.

Bu tezde, halka açık Türkiye Elektrik İletim A.Ş. (TEIAS), Türkiye İstatistik Kurumu (TUIK), Türkiye Cumhuriyeti Enerji ve Tabii Kaynaklar Bakanlığı, Dünya Enerji Konseyi Türk Milli Komitesi'nin enerji kaynakları kullanımı, sektörel enerji talepleri ve tüketim miktarları ve enerji fiyatları verileri kullanılmıştır. Bu veriler, BUEMS için sektörel bazda enerji talebi rakamlarını hesaplamada kullanılmıştır.

Baz senaryoda 2017 - 2047 yılları arasında enerji sektöründeki CO2 emisyonu miktarında 82% artış gözlenmiştir. Rüzgar ve güneş enerjisi alanında YEKA ihalelerinde öngörülen elektrik üretimi hedeflerin tutturulması durumunda, CO2 emisyonunun 2047 senesi içerisinde 15%'e kadar azalması öngörülmektedir. Bununla beraber, direkt emisyon azaltma senaryolarının toplam CO2 emisyonunu azaltmakta vergilendirme senaryolarına göre daha ucuz olduğu ve uzun vadede sektörel emisyon senaryolarına göre CO2 emisyonunu azaltmada daha iyi sonuçlar verdiği gözlenmiştir.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS

ac_invest	Annualized Investment Cost for each Technology
c	Conversion Technologies
ce	Electricity Production Technologies
cm	Cumulative Supply
cme	Cumulative Emissiocmen
CO2 emission	Total amount of carbon dioxide emission
coa_e_cap	coal fueled electricity power capacity
coa_e_cons	coal fueled electricity power generation
coa_e_gen	coal based electricity power generation
coa_supply	Total coal supply
cok_supply	Total coke supply
costinv	Discounted Annual Investment Cost
crf	Capital Recovery Factor
d	Demand Technologies
disanninv	Discounted Annualized Investment in Technologies
disanntcost	Annual Discounted Total System Cost
discount_c	Composite Discount
discount_c1	Composite Discount Component 1
discount_c2	Composite Discount Component 2
discount_c3	Composite Discount Component 3
disfuel	Discounted Net Expenditure on Fuel
disother	Discounted Other Expenditures Total
dissalv	Discounted Investment Salvage Cost
dot	Non-Transportation Sector Demand Technologies
dt	Transportation Sector Demand Technologies
E_COA_E_IMP	import coal to electricity conversion technologies
E_COA_E_MIN	mining coal to electricity conversion technologies
E_COACHP_E	coal combined heat&power existing conversion technologies

E_COACHP_N	coal combined heat&power new conversion technologies
E_COACO_20	coal-biomass mix 1 to electricity conversion technologies (year of commisioning-2020)
E_COACO_C1	coal-biomass mix 2 to electricity conversion technologies
E_COACO_C2	coal-biomass mix 2 to electricity conversion technologies
E_COAIG_20	integrated coal gasification conversion technologies (year of commisioning-2020)
E_COAIG_30	integrated coal gasification conversion technologies (year of commisioning-2030)
E_COAIG_C1	integrated coal gasification combined cycle conversion technologies with efficiency percentage %36
E_COAIG_C2	integrated coal gasification combined cycle conversion technologies with efficiency percentage %37
E_COAIG_C3	integrated coal gasification combined cycle conversion technologies with efficiency percentage %40
E_COAIGCH1	integrated coal gasification combined cycle with CO2 capture conversion technologies with efficiency percentage %33
E_COAIGCH2	integrated coal gasification combined cycle with CO2 capture conversion technologies with efficiency percentage %35
E_COAIGCH3	integrated coal gasification combined cycle with CO2 capture conversion technologies with efficiency percentage %36
E_COAIGCH4	integrated coal gasification combined cycle with CO2 capture conversion technologies with efficiency percentage %37
E_COAPF_20	pulverized coal to electricity conversion technologies (year of commisioning-2020)
E_COAPF_30	pulverized coal to electricity conversion technologies (year of commisioning-2030)
E_COAPF_C1	pulverized coal to electricity conversion technologies with efficiency value %35
E_COAPF_C2	pulverized coal to electricity conversion technologies with efficiency value %41
E_COAPF_C3	pulverized coal to electricity conversion technologies with efficiency value %45

E_COKCHP_N	coke to electricity via combined heat&power new conversion technologies
E_COKCHP	coke to electricity via combined heat&power existing conversion technologies
e	Energy Carriers
elc_prod	Total electricity generation
geo_e_cap	geothermal electricity power capacity
geo_e_cons	geothermal fueled electricity power generation
geo_e_gen	geothermal based electricity power generation
geo_supply	Total geothermal supply
hyd_e_cons	hydrogen fueled electricity power generation
hyd_e_gen	hydrogen based electricity power generation
hyd_supply	Total hydrogen supply
hydr_e_cap	hydro electricity power capacity
hydr_e_cons	hydro fueled electricity power generation
hydr_e_gen	hydro based electricity power generation
hydr_supply	Total hydro supply
ind	Industry Sector Technologies
invest_cost	Investment Cost for each Technology
k	Process Technologies
l	Technology Life
m	All Technologies
mth_e_cons	methanol fueled electricity power generation
nga_e_cap	natural gas fueled electricity power capacity
nga_e_cons	natural gas fueled electricity power generation
nga_e_gen	natural gas based electricity power generation
nga_supply	Total natural gas supply
nuc_e_cap	nuclear electricity power capacity
nuc_e_cons	nuclear fueled electricity power generation
nuc_e_gen	nuclear based electricity power generation
nuc_supply	Total nuclear supply
p	Process-Conversion-Demand Technologies

pet_e_cap	oil products fueled electricity power capacity
pet_e_cons	oil products fueled electricity power generation
pet_e_gen	oil products based electricity power generation
pet_supply	Total oil products supply
pridf	Period Discount Factor
pridisc	Periodic Discount Factor other than Investment
priinv	Periodic Discount Factor for the Investment
r_act	the Activity of a Process Technology
r_cap	the Total Installed Capacity of a Technology
r_em	Level of Emissions
res	Residential Sector Technologies
r_inv	the New Investment of a Process Technology
r_tsep	the Level of Supply-Resource Production
s	Supply Technologies
salvinv	Salvage Component of the Investment
ser	Service Sector Technologies
sex	Export Resource Technologies
sim	Import Resource Technologies
smn	Extraction Resource Technologies
sol_e_cap	solar electricity power capacity
sol_e_cons	solar fueled electricity power generation
sol_e_gen	solar based electricity power generation
sol_supply	Total solar supply
srn	Renewable Resource Technologies
t	Periods
totcost	Total Undiscounted System Cost
totemins	Total System Emission
tra	Transportation Sector Technologies
undanntcost	Undiscounted Annually Adjusted Total System Cost
undanntcost	Undiscounted Annually Adjusted Total System Cost
undcost	Undiscounted Total System Cost

undinv	Undiscounted Annual Investment Total in Technologies
v	Emission Type
wnd_e_cap	wind electricity power capacity
wnd_e_cons	wind fueled electricity power generation
wnd_e_gen	wind based electricity power generation
wnd_supply	Total wind supply
wod_supply	Total wood supply
wst_e_cons	waste fueled electricity power generation
wst_e_gen	waste based electricity power generation

1. INTRODUCTION

Need for energy is constantly increasing as globalization spreads, and is becoming a very important input for economic development. As energy resources are scarce, safe and sustainable supply of energy, efficient use, reduction of greenhouse gasses and environmental protection, price changes and instabilities in fuel prices, transformation from usage of fossil fuels to usage of renewable energy sources, have become strategically important for countries. Upon realizing the severity of this situation, nations try to conduct policies concerning accurate management of energy. Utilization of renewable energy resources have been started to become a widespread trend in recent years. The share of renewable energy and waste sources in electricity generation has been increased by 8.3% between years 1996 and 2016 in Turkey. According to International Energy Agency (IEA) data, the usage share of renewable energy technologies in electricity production has increased from 13.2 % in 2012 to 22 % in 2013 and the target percentage for the year 2020 is 26. [1, 2]

There is a number of ongoing studies to raise the usage of renewable energy sources such as wind, solar, hydro and geothermal, and to decrease usage of energy resources that have high amount of CO2 emissions such as coal, natural gas and gasoline. In the following part, we elaborate on some of the important arguments to conduct these studies.

The most important reason could be thought as global climate change. CO2 emission is a crucial factor for global warming, therefore reducing the use of energy types producing considerable amount of carbon gas is one of important ways to decelerate climate changes all over the world. According to Turkish Statistical Institute (TUIK) data, total amount of CO2 emission has been increased by 122 % in the period between 1990 and 2015 and energy sector has the biggest share in total emission amount 71.6 %. In addition, industry sector has 12.8 % and agriculture sector has 12.1 % of total amount of CO2 emission. [3]

Expiration date of main energy sources could be considered as another cause that direct countries towards renewable energy operations. Resources of coal, natural gas and gasoline have been decreasing considerably fast in recent decades, and governments have been started to evaluate alternative energy types to supply energy demands of their countries with taking geographical potential into account. Total amount of installed capacity for coal, liquid fuel and natural gas increased from 24 GW to 37 GW between 2006 and 2016 in Turkey. However, it has been supposed that there are 114 years of coal reserves by taking total coal production of the year 2015 into consideration. In addition to those facts, primary energy consumption in Turkey increased at a 5.1 % annual growth for the period of last 50 years. [4–6]

Another influential reason could be inexpensiveness of renewable energy resources comparing to common energy resources, because costs of operation and maintenance and supplying of raw materials for renewable energy is less than those of coal, natural gas and gasoline. Even if, the installation costs are higher for renewable energy technologies than thermal energy sources' facilities, usage of renewable energy has less cost in the long term, because renewable sources are less costly to supply.

The objective function of the BUEMS is minimizing total cost of for energy production while satisfying all sectors' demands properly. The main purpose of this project is to analyze usage of renewable energy sources and coal utilization in Turkey with taking all sectors and energy types into consideration and to draw a roadmap for next 30 years. In the BUEMS, time horizon will be considered as 5 years of periods and we will analyze the results for the years 2017, ..., 2047. For these 30 years the BUEMS will provide opportunities for forecasting future of renewable and coal energy sources technologies and taking required actions. Import and export processes for energy technologies will also be taken into consideration in the model. The model has different perspectives and inputs for analyzing the future of renewable and coal energy systems. There is a number of types for technologies and processes which are resource, production, conversion, consumption, and demand. Resource technologies (supply technologies) represent basic energy sources and all importation, exportation, mining and renewable technologies take part in this group. Production technologies are considered as energy production technologies for specific sector or demand by using specific resources. Conversion technologies are intermediate technologies which convert commodities to another energy carrier and arrange the energy type of energy carriers to yield input for other technologies. Consumption technologies show types of energy consumption processes of sectors. Demand technologies are separated into two parts as demand for primary energy sources and demand for process-conversion technologies. These technologies will be explained in detail in the master thesis. The table below shows the basic relations between technologies.

The model has different types of constraints to control the balance between variables and technologies. Energy balance constraints establish control that energy resources do not exceed the total supply amount for each energy resources. Demand constraints make sure that any type of demand for any energy resource is satisfied. There are capacity constraints for supply, process and conversion technologies. In this model capacity constraints are generally composed of upper, lower and fixed bounds for each specific energy type. Solar and wind energy technologies will be included in the mode as main renewable energy resources. Coal energy resources will be analyzed in two parts as domestic and imported. Production and process indices for these energy resources will be also explained in detail in. At first stage of the BUEMS, a number of sectors (residential, commercial, transport, industry, agriculture, power) will be included to system to examine the complete energy market reasonably. Electric and industry sectors will be the essential sectors for examining the future of renewable and coal energy technologies. Different upper, lower and fixed bound values for supply, capacity, production and investment technologies of renewable and coal energy resources will be used in scenarios to differentiate the model. At first stage terms and conditions of Renewable Energy Resource Zone (YEKA) tenders will be used in main scenarios. In addition to these data group government support for encouraging using coal in thermal power plants will be taken into consideration in scenarios for analyzing the behavior of coal tehnologies. Behaviors of other energy resources will be also monitored in the future years for each scenario and according to these results useful targets for renewable and coal energy technologies will be decided.

In the reference project, “Energy Economy and Environment Integrated Large Scale Modeling and Analysis of the Turkish Energy System”, all sectors were taken into consideration as a whole structure and detailed studies for each energy type are required to analyze energy utilizations and regulations for these technologies. By completion of this thesis a detailed model will be obtained for renewable energy sector in the Boğaziçi University Energy Modeling System BUEMS and further analysis and developments for sustainable and green energy technologies will be possible based on the results of the model.

2. LITERATURE REVIEW

Renewable energy technology usage and forecasting thermal energy sources have been becoming a more trending topic in recent years. In line with this issue, number of scientific studies in the literature that were done to answer the future of renewable energy and coal sources have been increasing in the last decades. There is a number of important studies in the energy literature that were benefited from different modeling techniques to draw a pathway for sustainable and clean energy technologies.

As a study on life cycle environmental, economic and social sustainability assessment of future electricity scenarios in Turkey up to 2050, Atılgan and Azapagic [7] presented by creating scenarios and assessed them for 19 sustainability indicators, using multi-criteria decision analysis to help identify the most sustainable scenarios. This study indicates that the fossil fuel dominated scenarios are environmentally the least sustainable for seven out of 11 impacts, including the global warming potential which increases up to four times on today's impact and opting for renewable-intensive pathways would halve the current global warming potential and reduce the use of fossil fuels by three times. In addition to those results, it shows that renewable and nuclear intensive scenarios outperform those dominated by fossil fuels, except for the very high preference for the economic criteria. However, their poor environmental and social performances makes them least sustainable overall. The renewable-nuclear intensive scenarios arefound to be the most sustainable options with respect to most of the environmental, economic and social impacts considered. Reducing the share of fossil fuels in the electricity mix would not only reduce significantly the environmental impacts, but also the costs. [7]

There is another study by Kılıçkaplan et al, that is concentrated on Turkey's energy transition towards 100 % renewable energy until 2050 by using an hourly resolved model. In this study, there are two scenarios: a power sector scenario and power sector plus desalination and non-energetic industrial gas demand (integrated) scenario. According to this study levelised cost of electricity increases slightly in the power scenario, from a fossil fuel based system in 2015 to a fully renewable energy-based system in 2050 by 3.8 %. The capacity mix in the power scenario for the assumptions of the year 2050 led to cost decrease by 19 %. In the integrated scenario, however, the costs decreases by 5 %, mainly due to the benefit of sector coupling. The model indicates that 100 % renewable energy system reduces energy import dependency and carbon emissions, while reducing the cost of energy supply. According to results of this study, Solar PV electricity emerges as the largest contributor to cover the growing energy demand of Turkey and supply about 43.2% of total demand by 2050. The second largest source of electricity is wind, contributing 10.3% of total demand by 2050. In addition, Turkey will decrease costs by more than 34 billlions euro each year by avoiding energy resource imports, as natural gas and coal consumption can be fully avoided in 2050 and corresponding CO2 emissions can reach an almost zero level. [8]

In another study by Günkaya et al, electricity generation depending on the resources and their shares are analyzed by taking environmental situation into consideration for Turkey. According to this study, the contribution of fossil fuels to electricity generation was almost 72% in 2012 (base year), it will have reached nearly 34% by the end of the 2023 (future year). Furthermore, the hydropower energy option is the third lowest option in electricity generation after the geothermal and solar energy options. However, geothermal and solar energy, which will only supply small portions (nearly 1.2%) of Turkey's remarkable total energy demand in 2023, will also have the smallest share in renewables. The contribution of planned hydroelectric power for electricity generation will be approximately 40% (154,000 GWh) of all natural resources by the end of 2023. This study also suggests that, if the government of Turkey wants to supply 30% of the country's electricity demand in 2023 from renewables, it also needs to use nuclear power to supply its increasing electricity demand and accommodate problems related to wind and solar energy. [9]

In addition to models mentioned above, a nonhomogenous discrete grey model were built to forecast eletricity consumption in Turkey. In this model, the results has indicated that the nonhomogenous discrete grey model has better forecasting assumptions than the grey model. [10]

There is another study by Boran et al that tried to explain the future of renewable energy resources. In this study, the evaluation of renewable energy resources for Turkey is accomplished using intuitionistic fuzzy Visekriterijumsko Kompromisno Rangiranje method in which criteria are expressed in both a quantitative and qualitative way for the first time in the literature. In the evaluation process, wind, hydro, solar, geothermal, and biomass are evaluated. Four main criteria – technological, environmental, sociological, and economic – are considered as main evaluation criteria and totally 12 subcriteria related to main criteria are also taken into consideration. Moreover, the sensitivity analysis has been conducted to identify which renewable energy resource is a better option under different circumstances. According to the results of this study, wind power is the first renewable energy option due to promising low-level emissions of GHGs as global warming is one of the main problems for developing countries. Moreover, wind power provides both reasonable prices and favorable social acceptance compared with other alternatives. Hydropower is the second option due to high water potential of Turkey; however, social acceptance is not favorable in the public eye due to resulting displacement of people and animals. Solar power has got the third, because of high investment cost and especially electricity is still not generated in an efficient way. When technological advances take place, solar power will become a very suitable option since the solar potential of Turkey is very high. [11]

In addition to studies that try to explain Turkey energy market, there are forecasting models and analyzes that concentrate on other countries' energy policies for future years. One of them also used the grey prediction models which are the GM (1,1) model, the NGBM (1,1) model, and the grey Verhulst model for theoritical derivation and scientific verification while forecasting renewable energy consumption in China. Results of this study have shown that the NGBM (1,1) model, and the grey Verhulst model have higher forecast accuracy than the original GM (1,1) model and these techniques can be applied for other countries' energy consumption prediction. [12]

In the study of Lee et al, bottom-up forecasting model technique was used to observe the development of South Korea government's plan for raising new and renewable energy development to 11 % by 2035. In addition to bottom-up model that includes each renewable energy variables, a competitive diffusion model, a logistic growth model, a linear regression model, and data from government planning and companies' planned projects were also used and the forecasts were classified and presented by renewable source and output type (i.e., electricity, heat, and transportation fuels). [13]

There is a study concentrating on renewable energy technologies on Cuba and in this study, the country's proposed energy policy to achieve 24% penetration of renewable energies in electricity generation by 2030 is analyzed. According to this study, in 2030 total electricity generation in Cuba will be 30,000 MW by the growth rate 57% and 7,200 MW of them will be provided with renewable energy sources. [14]

In another study by Weber et al, development of the renewable energy technologies in Europe is analyzed. In this study, a stochastic energy system model with endogenous cost-resource curves for renewable energy sources is used. According to results of this study, CO2 emissions can be reduced significantly with a reduction of demand. In line with that, abatement costs decrease, which lowers macroeconomic costs. Also, the extent of investments in conventional power plant capacity is dependent on total demand level. Fluctuating renewable energies have a low capacity credit and hence conventional back-up capacity is still necessary. Their absolute level is therefore still defined by total demand. [15]

There is a study about the future of renewable energy technologies in Europe. In this study, a scenario for a 100% renewable energy system in Europe by the year 2050 is analyzed. The transition from a business-as-usual situation in 2050, to a 100% renewable energy Europe is analysed in a series of steps. Each step reflects one major technological change. For each step, the impact is presented in terms of energy (primary energy supply), environment (carbon dioxide emissions), and economy (total annual socio-economic cost). According to results of this study, the cost of 100% scenario is approximately 10–15% higher than a business-as-usual scenario, but since the final scenario is based on local investments instead of imported fuels, it will create approximately 10 million additional direct jobs within the EU. [16]

There is a study which is concentrated on greenhouse gas emissions in California. In this study the CA-TIMES optimization model of the California Energy System (v1.5) is used to understand how California can meet the 2050 targets for greenhouse gas (GHG) emissions (80% below 1990 levels). This model represents energy supply and demand sectors in California and simulates the technology and resource requirements needed to meet projected energy service demands. The model includes assumptions on policy constraints, as well as technology and resource costs and availability. Multiple scenarios are developed to analyze the changes and investments in low-carbon electricity generation, alternative fuels and advanced vehicles in transportation, resource utilization, and efficiency improvements across many sectors. Results show that major energy transformations are needed but that achieving the 80% reduction goal for California is possible at reasonable average carbon reduction cost ($9 to $124/tonne CO2 at 4% discount rate) relative to a baseline scenario. [17]

In another study, TIMES – The Integrated MARKAL-EFOM (MARKet ALlocation Energy Flow Optimisation Model) System is used to design the low carbon roadmap for 2050 in Portugal. The results show that modelling Portugal as an isolated system can lead to underinvestment and underuse of the country's endowment of renewable energy sources in the longer term, which reduces the efficiency of investment. The modelling of Portugal as an interconnected energy system can therefore have a significant impact on the design of a sustainable electricity system and lead to improved investment efficiency with lower costs risk. [18]

Three MARKAL (MARKet ALlocation) family models are used to study China energy system's carbon mitigation strategies and corresponding impacts on the economy in another study. In this study, the endogenous demands in MARKAL MACRO and MARKAL ED enable them to partly satisfy carbon abatement constraints via energy service demand reductions, and the reduction levels for the 30 demand sectors from these two kinds of models for given carbon emission constraints are presented and compared. The impact of carbon mitigation on social welfare from MARKAL and MARKAL ED, and on GDP, investment and consumption from MARKAL-MACRO are evaluated. [19]

In study of Comodi et al, three 25-year energy scenarios developed with the TIMES model generator for Pesaro, a seaside municipality in central Italy are analyzed. It evaluates the effectiveness of local-scale energy policies in three sectors: households, transport, and the public sector (PS). Since the local energy demand is affected by summer tourism, seasonal consumption by holiday homes is also studied. Three scenarios were hypothesized: Business as Usual (BAU), Exemplary Public Sector (EPS), and Exemplary Municipality (EM). The EPS scenario models the exemplary role that recent European directives attribute to the PS in setting energy efficiency and technology penetration targets for itself; the EM scenario extends these targets to the household sector. [20]

3. BUEMS MODELING FRAMEWORK

BUEMS is a bottom-up modeling system which minimizes total energy system cost by taking observed and forecasted values of useful energy demand, defined technologies and parameters, resource availabilities, capacities and restrictions for the whole energy system into consideration. Main target of the model is to identify emission and cost implications of various renewable and coal focused energy policy options for Turkey providing guidance for policy makers and investors in long term.

As mentioned in the literature survey, the number of studies concentrated on the energy sector have been increased extensively in recent years and as a result, there are now various approaches and methodologies. In the meantime, the intensity of studies in the literature which are established to brighten the future of renewable energy technologies and utilization of coal sources have increased. There have been important forecasting and bottom-up models in the literature for analyzing renewable and coal-based energy markets, and the BUEMS will also be added to energy sector as a beneficial tool. Since, the model has a very detailed modeling system that includes all variables for energy market such as supply variables including trade variables, energy production and generation technologies, demand and consumption technologies of all sectors separately depending on different energy sources and so on. This complex structure of the model gives opportunity to the users to examine energy sector with considering every aspect of the market and to take decisions for future energy policies by evaluating the results of composed scenarios.

There are two main approaches in modeling framework which are differentiated according to their aggregation levels: bottom-up and top-down. In this thesis, BUEMS, which is built on a bottom-up modeling technique, is used to analyze energy market in detail, since this approach enables us to take every small component of the energy environment in Turkey into consideration and to evaluate all supply and demand technologies and sectors properly.

BUEMS is structured to reach minimum cost combination of energy technologies for diversely applied future scenarios of renewable energy technologies and coal resources, and to target minimum CO2 emission.

BUEMS applies the linear programming methodology to the system with taking constraints into consideration to reach minimum cost by meeting each demand at the end of each time period. In addition to this, BUEMS has the feature of making decisions by taking all knowledge of all possible future events in the consideration.

BUEMS has two main components: Technologies and commodities. The set of energy carriers compose of commodities that are generated or processed by technologies. There are number of energy carriers in the model which consist of coal, natural gas, petroleum, nuclear, hydropower, wind, solar, geothermal and hydrogen energy sources. [21]

Technologies are comprehensive ingredients of BUEMS. They can be defined as physical devices that transform a commodity type into another one by processing, converting, or transmitting. As mentioned in the definition above, every unit that converts one commodity to another is named as technology. Some examples are importation of a primary energy source, an air-conditioner that satisfies residential and commercial sectors' demand for cooling, or a passenger car with diesel engine used for transportation. Furthermore, every technology is regulated in the system by parameters. There are natural parameters for every technology such as investment cost, operating and maintenance cost, technology start year, salvage value, and efficiency. There are also parameters applied to specific technologies such as availability factor which is required just for the technologies that have the capacity to change under some circumstances.

Commodities are the other important ingredients of BUEMS. A commodity consists of any item that belongs to the sets of energy carriers, materials, emissions, monetary terms and energy services that is processed or produced by a technology in the model. Another key fact to remember is that when a commodity is processed by a technology, it should be renamed.

For example, whenever electricity is used to satisfy an end-use demand through a distribution technology, it is named as a separate commodity for every enduse sector.

There are three main technology classes in the model and all are explained in detail in later in this chapter. Figure below explains the relationships among them (see figure 3.1):

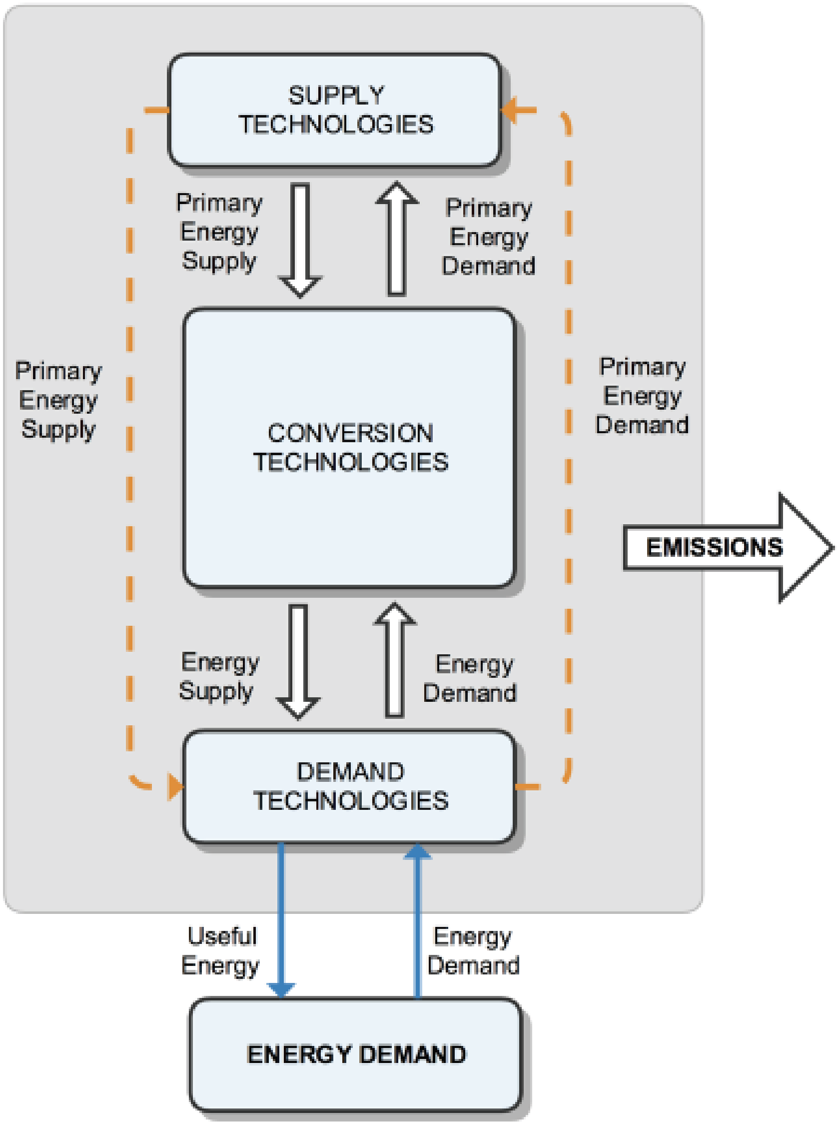

Figure 3.1. Relationship between energy technologies.
[22]

3.1. Technologies

3.1.1. Supply Technologies

Supply technologies are the providers of primary energy resources of the system. Primary energy carriers are introduced into the system by supply technologies at the beginning by two options (see figure 3.2).

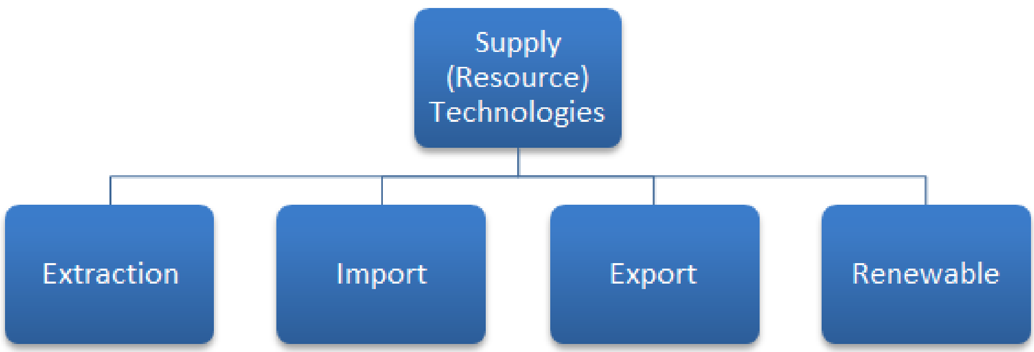

Figure 3.2. Supply technologies.

Domestic supply technologies are the first way to add primary energy sources. Extraction of primary energy sources and renewable energy (wind power, solar power, hydropower etc.) technologies are classified as the members of domestic class. Coal, natural gas, biomass and petroleum are important examples of primary energy. Furthermore, import of primary energy sources is another choice for supplying primary energy sources. There are important factors in the BUEMS that effects supply levels. Upper bound, lower bound and fixed bound for supply technologies are possible to set to control resource levels of primary energy sources. Decay and growth rates can also be used to control and arrange change amounts between periods for supply technology levels. In addition to these, cumulative capacity for specific supply technologies can be added to the model for restricted resources. Furthermore, there are unit cost and emission factor variables for supply technologies to calculate their economic and environmental influences on the model.

3.1.2. Conversion Technologies

Conversion technologies can be classified as intermediate steps between all commodities and energy carriers. They transform the type of commodities to convenient forms to provide energy source to another consuming or generating technology. Conversion technologies are seperated into two basic parts: electric generation and process (see figure 3.3).

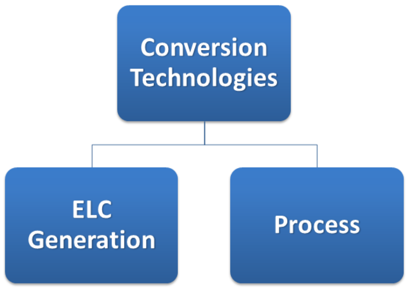

Figure 3.3. Conversion technologies.

The electricity generation technologies class includes all technologies that generate electricity. All conversion technologies besides electricity generation technologies are defined as processes. New investment levels, capacity levels and activity levels are decision variables for the BUEMS while making use of conversion technologies. In the BUEMS, new investments can only be added at the beginning of each time period for each technology and they are added to the existing capacity level to calculate the total capacity of each particular technology. New investments will be valid until end of the technologic life-time of each technology with previous existing capacity and there is a unit investment cost for each of them. Availabilty factor is the rate of usage for process technologies and these rate can be specified for each period and each technology seperately in the BUEMS. Baseload factor is another parameter that indicates the highest percentage of the baseload power plants in total electricity generation and this parameter also can be specified for each period and each technology seperately in the BUEMS. Residual capacity is another important variable for conversion technologies. This capacity variable only includes the predefined capacities that were invested prior to the start of the planning horizon. In addition to these parameters upper-bound, fixed-bound, and lower-bound levels can also be set for conversion technologies.

3.1.3. Demand Technologies

Demanding technologies build the final technology group of the model. They are one of the multiconnected parts of the model with conversion technologies. They can be related to both supply and conversion technologies. They can use primary energy resources directly or they can use the energy which is passed through conversion technologies. For example, coal can be used directly for heating in residential sector and electric that is generated by using coal sources can be used in air-contidioner system in service sector (see all five sectors in figure 3.4).

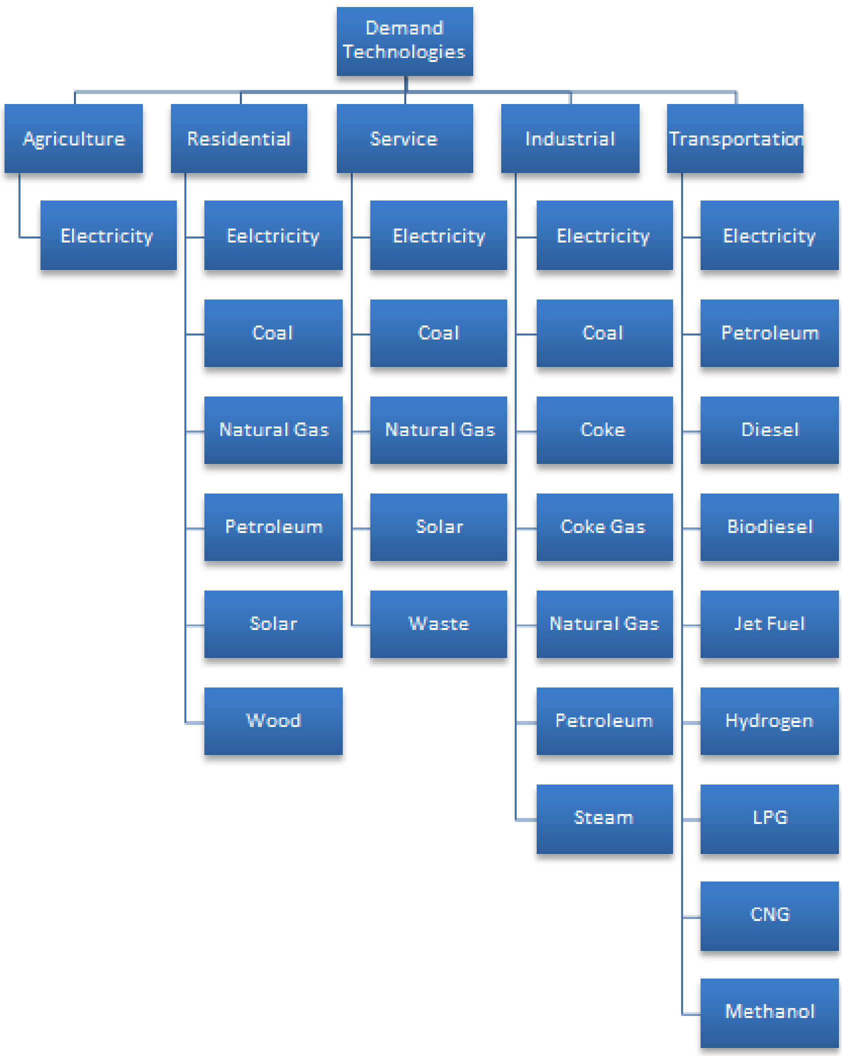

Figure 3.4. Demand technologies.

Demand requirements are defined with consumption units in the BUEMS rather than energy carriers. Therefore, there are conversion parameters that transform energy carriers into demand units. In addition, demand requirements can be composed exogenously in the system by the user and there can be investment levels for demand capacities in every period. In addition, capacity utilization factors and efficiency rate of input usage are attached to each demand technology to determine capacity levels in use and output levels resulting from this usage.

3.2. Model Structure: Sets, Parameters and Variables

In the BUEMS, all components of the energy sector are used to find the best solution. The main aim of the process observed from primary energy sources to final demand steps is to obtain minimum cost combination of energy sources and technologies by meeting the final energy demand. There is a number of parameters, variables and formulations which are composed with these smallest parts of the model. In the following section, these ingredients of the model will be defined and the logic behind the model will be explained clearly. Significant sets, parameters and variables of the BUEMS are decribed in the following with all abbreviations listed in the list of acronyms on page XVIII.

3.2.1. Objective Function

Objective function of the BUEMS is to minimize total cost. The sytem sums up all costs deriving from investments and consumption at the end of each period which is fixed to be 5 years in the current study. Total undiscounted cost is calculated by taking all of the costs due to consumption and usage of energy defined through model variables such as technologies, demands, fuel consumptions, and etc. In this thesis, values of "total undiscounted annually adjusted total system cost" (undanntcost) of the system for each period were analyzed to compare results of the applied scenarios.

$$mintotcost = \sum_t disanntcost(t)$$

where

- disanntcost(t): annual discounted total system cost
- totcost: total system cost (undiscounted)

3.2.2. Total Annual Cost

Total annual cost of the system is composed of total supply cost, total investment cost, and total operational cost.

$$mintotcost = \sum_t suppplycost(t) + operationalcost(t) + investmentcost(t)$$

- operationalcost(t) : total annual operational cost at period t (discounted to the base year)
- investmentcost(t) : total annual investment cost at period t (discounted to the base year)
- supplycost(t) : total annual supply cost at period t (discounted to the base year)

Operational cost is sum of fixed and variable operation and maintenance costs, operational cost for distribution of electricity, operation and maintenance costs of electricity transportation and operation and maintenance costs of LTH transportation for each technology of m.

$$operationalcost(t) = \sum_m fixom(m,t) * r\_cap(m,t) + edistom(m,t) * r\_act(m,t) + etranom(m,t) * r\_act(m,t) + dtranom(m,t) * r\_act(m,t) + varom(m,t) * r\_act(m,t) + capunit(m,t) * cf(m,t) * varom(m,t)) * r\_cap(m,t)/eff(m,t)$$

- fixom(m,t): fixed operation and maintenance cost per unit of capacity of technology m at period t
- r_cap(m,t): the total installed capacity of a technology m at period t
- edistom(m,t): unit operational cost for distribution of electricity for technology m at period t

- r_act(m,t): the activity of a process technology m at period t
- etranom(m,t): unit operational and maintenance cost for electricity transportation of technology m at period t
- dtranom(m,t): unit operational and maintenance cost for LTH transportation of technology m at period t
- varom(m,t): variable operation and maintenance cost per unit of activity for technology m at period t
- capunit(m,t): units of annual production activity for technology m at period t (This parameter is used to do unit conversion between capacity and activity of technologies (if capacity and activity units are different))
- cf(m,t): capacity utilization factor of tehcnology m at period t
- eff(m,t): efficiency rate

Supply cost is the total cost of providing primary energy sources to the system at a certain period including all of the transmission and distribution costs of energy carriers for each tehcnology of m . Annualization for supply cost is not required, because consumption of primary energy sources occurs at each period.

$$supplycost(t) = \sum_m scost(m,t) * r\_tsep(m,t)$$

- scost(m,t): unit supply cost of technology m at period t
- r_tsep(m,t): level of supply or resource production of technology m at period t

"Investment cost" can cover a year or a period. However, some costly investments such as the plantation of a thermal power station can take as long as a couple of periods. Under such circumstances, annualization of investment costs should be done first. All maintenance and repair expenses (regardless of it is fixed or variable) due to the use of each type of technology are analyzed under "Operational cost" title. "Investment cost" includes payment amount per one unit of capacity increase. Investment cost is distributed evenly throughout the lifespan of the technology with the help of "capital recovery factor (CRF). [22]

$$crf(p) = discrate(p)/(1 - (1 + discrate(p))^{(-life(p))}) \tag{3.1}$$

- crf(p): capital recovery factor of technology p
- discrate(p): discount rate of technology p
- life(p): lifetime of technology p

$$investmentcost(t) = \sum_m crf(m) * ((invcost(m,t) + edistinv(m,t) + etraninv(m,t) + dtraninv(m,t)) * rinv(m,t))$$

- crf(m): capital recovery factor of technology m
- invcost(m,t): investment cost per unit of new capacity addition of technology m at period t
- edistinv(m,t): unit investment cost for electricity distribution of technology m at period t
- etraninv(m,t): unit electricity transmission cost of technology m at period t
- dtraninv(m,t): unit LTH transmission cost of technology m at period t
- r_inv(m,t): the new investment of a process technology m at period t

3.2.3. Model Constraints

The BUEMS is defined as a bottom-up model based on a linear programming formulation where GAMS is used to obtain the optimum solution. The BUEMS has special constraints for based model and applied scenarios which are taken into consideration to control the levels of important variables and processes of the model. The figure below shows the classes of constraints which are helpful for avoiding invsible solutions for the BUEMS. [22]

3.2.3.1. Energy Balance Constraints. Energy balance constraints can be considered as energy source constraints or supply constraints. Each energy source has an energy

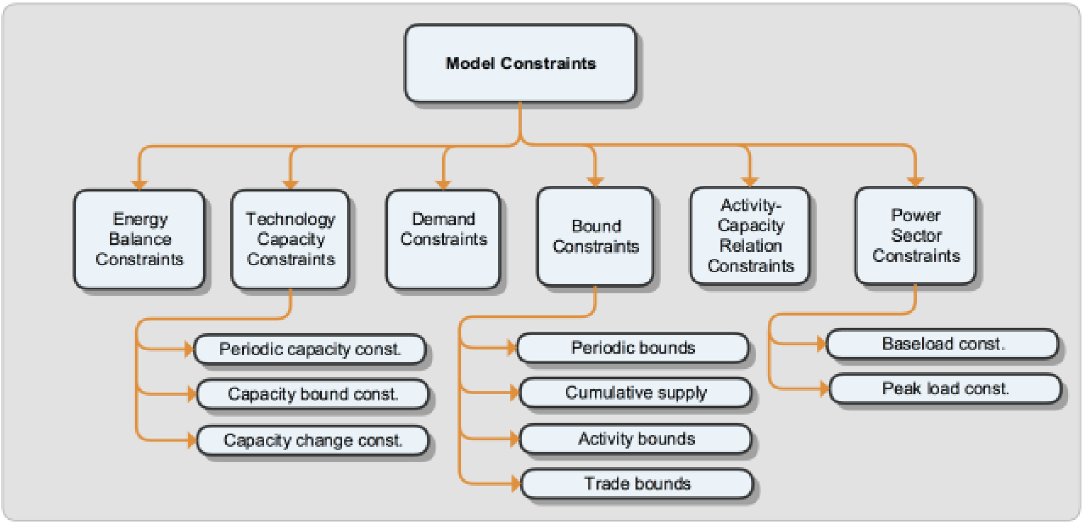

Figure 3.5. Constraint types of the model.
[22]

balance constraint and these constraints can guarantee that total level of usage of energy source can not exceed the total supply of that energy source. The equation below explains the logic that lies behind the this type of constraint and model user can observe that clearly, the total level of output generation should be bigger than the total level of input requirement for every technology activity.

$$\sum_m r\_tsep(m,t)+\sum_m outent(m,t)*r\_act(m,t) \geq \sum_m inpent(m,t)*r\_tsep(m,t)+ \sum_m inpent(m,t)*r\_act(m,t)+\sum_m inpent(m,t)*capunit(m,t)*cf(m,t)*r\_cap(m,t)/eff(m,t)$$

- r_tsep(m,t) : level of supply or resource production of technology m at period t
- outent(m,t) : level of output generation per unit of technology activity m at period t
- r_act(m,t): the activity of a process technology m at period
- inpent(m,t) : level of input requirement per unit of technology activity at period t
- capunit(m,t) : units of annual production activity for technology m at period t
- cf(m,t) : capacity utilization factor for tehcnology m at period t
- eff(m,t) : efficiency rate of technology m at period t

3.2.3.2. Technology Capacity Constraints. There are three types of technology capacity constraints in the BUEMS; periodic capacity constraints, capacity bound constraints, and capacity change constraints.

Periodic capacity constraints are used to control the total level of capacity for each period. This type of constraint can make sure that total level of previous investments which are still valid in current period and new added investments for that period should be equal to total capacity for each technology.

For process technologies (k) :

$$\sum_t r\_cap(k,t) = resid(k,t) + \sum_t (r\_inv(k,t) - r\_inv(k,t) * nyrper/life(k))$$

For conversion technologies (c) :

$$\sum_t r\_cap(c,t) = resid(c,t) + \sum_t (r\_inv(c,t) - r\_inv(c,t) * nyrsper/life(c))$$

For transportation demand technologies (dt) :

$$\sum_t r\_cap(dt,t) = resid(dt,t) + \sum_t (r\_inv(dt,t) - r\_inv(dt,t) * nyrsper/life(dt))$$

For non-transportation demand technologies (dot) :

$$\sum_t r\_cap(dot,t) = resid(dot,t) + \sum_t (r\_inv(dot,t) - r\_inv(dot,t) * nyrsper/life(dot)$$

- r_cap(m,t) : level of the total installed capacity of a technology m at period t
- resid(m,t) : residual capacity (This capacity only includes the predefined capacities that were invested prior to the start of the planning horizon)
- r_inv(m,t) : level of the new investment of a process technology m at period t
- nyrsper : number of years per period t
- life(m) : useful lifetime of the technology m

Capacity change constraints are used to control the amount of increase or decrease in the caapcity level of a technology between consecutive time periods. There are decay and growth rates in the BUEMS which are defined to related technologies to prevent unexpected rises and declines in each period and control the level of new investments and expenditure of resources for these technologies.

r_cap(m,t+1) $\geq$ r_cap(m,t)*$decay(m, t + 1)^{(nyrsper)}$

r_cap(m,t+1) $\leq$ r_cap(m,t)*$growth(m, t + 1)^{(nyrsper)}$

- r_cap(m,t): level of the total installed capacity of a technology m at period t
- decay(m,t): maximum decay rate of capacity for technology m between consecutive periods
- growth(m,t): maximum growth rate of capacity for technology m between consecutive periods

The third type of technology capacity constraints is capacity bounds constraints. BUEMS gives user the capability of restricting the level of technology capacities by composing Excel files and uploading them to the GAMS code. Users can decide upper, lower or fixed levels for significant technologies by using this method. For example: if minimum capacity of a technology is decided by govenrment as an future enegy policy, a lower bound can be set to make sure that technology will not be less than that certain amount for a future period.

3.2.3.3. Demand Constraints. Demand constraints are defined in the BUEMS for each demand technology seperately and these constraints make sure that every demand for every period is met properly by supply and conversion technologies.

$\sum_m outent(m,t) * capunit(m,t) * cf(m,t) * r\_cap(m,t) \geq demand(m,t)$

- outent(m,t) : level of output generation per unit of technology activity m at period t
- r_cap(m,t): level of the total installed capacity of a technology m at period t
- capunit(m,t) : units of annual production activity for technology m at period t
- cf(m,t) : capacity utilization factor for technology m at period t
- demand(m,t) : level of demand of technology m at period t

3.2.3.4. Bound Constraints. There are constraints similar to technology capacity constraints for an activity or a commodity. These constraints give opportunity to user to set a lower, upper or fixed bound for an activity or a commodity for a certain period. There are four types of bound constraints in the BUEMS.

First type of bound constraints is periodic bound. This bounds are used to define a minimum/maximum limit or a fixed value for a level of a technology in a certain period. There are three ways to benefit from these constraints.

For supply levels of supply technologies :

$$\text{r\_tsep(m,t)} \leq \text{bound\_m\_upper(m,t)}$$

$$\text{r\_tsep(m,t)} \geq \text{bound\_m\_lower(m,t)}$$

$$\text{r\_tsep(m,t)} = \text{bound\_m\_fix(m,t);}$$

For activity level of process and capacity technologies :

$$\text{r\_act(m,t)} \leq \text{bound\_m\_upper(m,t)}$$

$$\text{r\_act(m,t)} \geq \text{bound\_m\_lower(m,t)}$$

$$\text{r\_act(m,t)} = \text{bound\_m\_fix(m,t)}$$

- r_act(m,t): the activity of a process technology m at period
- r_tsep(m,t) : level of supply or resource production of technology m at period t
- bound_m_upper(m,t) : upper bound on the capacity/activity level of a technology m at period t
- bound_m_lower(m,t) : lower bound on the capacity/activity level of a technology m at period t
- bound_m_fix(m,t) : fixed bound on the capacity/activity level of a technology m at period t

Another type of bound constraints is cumulative supply limit. The BUEMS contains resources having finite amount of supply level in the time horizon such as thermal energy sources. By using cumulative supply limit constraints, user can keep this situation under control.

$$\sum_t r\_tsep(s,t) * nyrsper \leq cum(s,cm)$$

- r_tsep(s,t) : level of supply or resource production of technology s at period t
- nyrsper : number of years per period
- cum(s,cm) : cumulative (overall supply) resource limitation on supply technology s

Trade bounds is the third type of bound constraints. This constraints is applied to ensure that, import amount for a technology composes a defined percentage of total supply level for a certain period.

$$\sum_p r\_tsep(p,t) \leq bounds(p,t) * \sum_p r\_tsep(p,t)$$

- r_tsep(p,t) : level of supply or resource production of technology p at period t
- bounds(p,t) : scenario constraints

3.2.3.5. Activity – Capacity Relation Constraints. These constraints make sure that any activity for a technology should be below the total capacity for a certain period. Because capacity and activity can have different unit type, a unit conversion parameter is added to the equation below.

r_act(m,t) $\leq$ capunit(m,t)* af(m,t)*r_cap(m,t)

- r_act(m,t): the activity of a process technology m at period
- r_cap(m,t): level of the total installed capacity of a technology m at period t
- capunit(m,t) : units of annual production activity for technology m at period t
- af(m,t): annual availability factor of the technology m at period t

3.2.3.6. Power Sector Constraints. Power sector constraints are used to set control on electricity production by deciding baseload and peak load levels.

Setting a minimum level for electricity production at night for a certain period is held by setting baseload constraints in the BUEMS. The main aim of usage of these constraints is to prevent fluctuations for electricity demand.

$$\sum_m outelc(m,t)*qhr\_n(m,t)*r\_act(m,t)*baseload("ELC",t)) \geq \sum_m qhr\_n(m,t)* outelc(m,t)*r\_act(m,t)$$

- r_act(m,t): the activity of a process technology m at period
- outelc(m,t): level of electricity generation per unit of technology activity m at period t
- qhr_n(m,t): fraction of the year represented by time-of-day segment (night)
- baseload(”ELC”,t): the highest percentage of the baseload power plants in total electricity generation at period t

There are some time periods in the model in which electricity demand has its maximum level, in other words peak value. Therefore, some amount of capacity should be always available in such cases. By the usage of peak load constraints, these maximum demand periods can be kept under control.

4. OVERVIEW OF TURKISH ENERGY RESERVES

In this chapter, current situation of the energy sources around the world and Turkey will be presented and an overview of the amounts and percentages related to them will be shown. After the law 4628 was passed in 2001, liberalization process has started to develop in Turkey in energy sector. As a result of these developments, the share of government in electricity production has started to decrease.

4.1. Thermal Energy Sources

The three most important thermal energy sources of the BUEMS are coal, natural gas and oil.

According to the International Energy Agency report of 2017, total energy consumed around the world are sourced around 33% by coal sources. This percentage also is corresponded to 40% of the total electricity generation. The most important countries contributing coal production are China, the USA, India, Indonesia, Australia and South Africa according to the World Energy Agency report of 2016. In Turkey, coal is one of the most important energy sources like worldwide. According to MENR, the reserves of lignite are 15.6 billion tons with lignite production reaching 50.4 million tons in 2015, and the reserves of hard coal are 1.3 billion tons and hard coal production was 1.4 million tons in 2015 in Turkey. MENR has also reported that hard coal imports have increased by 97.5% between 2005 and 2015 due to growing demand and because of increasing trend of importation Turkish government has targeted to increase the usage of domestic coal in electricity generation. According to the International Energy Agency Energy Policies of IEA Countries Report 2016, in Turkey, electricity sector consumes 68% of coal supply, industry sector consumes 16.8% of coal supply, agriculture sector consumes 9.7% of coal supply and households consumes 5.5% of coal supply.

Turkish government has been studying on an incentive process to increase usage of domestic coal sources. This incentive process offers tax exemptions, support for investment loans and priority for new investments. In addition to those privileges, govenrment also gives purchasing guarantee with the cost of 201 TL / MWh for domestic coal based produced electricity.

Natural gas is another important source for the energy need of countries. According to the last World Energy Council Report, 22% of total energy consumed around the world are provided with natural gas sources. According to Energy Market Regulatory Authority (EMRA) Natural Gas Report 2017, Turkey import natural gas mostly from five countries which are Russia, Iran, Azerbaijan, Algeria, Nigeria and percentages are 51.93%, 16.74%, 11.85%, 8.36% and 3.76% respectively. MENR indicates that Turkey's producible reserves of natural gas were 18.8 billion m3 as the end of 2016 and natural gas supply of Turkey is almost completely provided by imports. According to EMRA Natural Gas Report 2017 55,250 million sm3 natural gas were imported from various countries in 2017 and the amount of domestic production declined by 3.58% in 2017 compared to 2016.

Oil is one of the important energy sources for the world. According to the last World Energy Council Report, 32.9% of total energy consumed around the world are provided with oil sources. According to the IEA, oil demand will increase because of Organisation for Economic Co-operation and Development (OECD) countries between 2016 and 2022, while oil demand for non-OECD countries will decline because of using fuel-saving technologies and slower economic growth.

4.2. Renewable Energy Sources

In this part, current situation of renewable energy technologies will be explained.

Total installed capacity hydro power, wind power and geothermal power in Turkey was 27,033 MW, 6,195 MW and 885 MW respectively according to MENR data in 2017. According to the government's Energy Efficiency Strategy Paper 2012-2023, the share of renewable energy in the country's electricity production is planned to be 30% in 2023 and the amount of energy consumed per GDP in Turkey in the year 2023 is targeted to decrease at least 20% compared to year 2011. According to IEA statistics, the amount of energy consumed per GDP has decreased 10% in 2015 compared to year 2011.

Wind power is one of the most significant renewable energy technologies in the world. According to the Global Wind Energy Council Statistics Report 2017, total wind power capacity of the world was 539,581 MW in 2017 and China is the leader country in this area followed by the USA and Germany. Capacity projections of TEIAS indicates that installed capacity of wind power will be 9,993 MW in 2021 in Turkey. Figure below shows wind power potentials in Turkey. (see figure 4.1) [23]

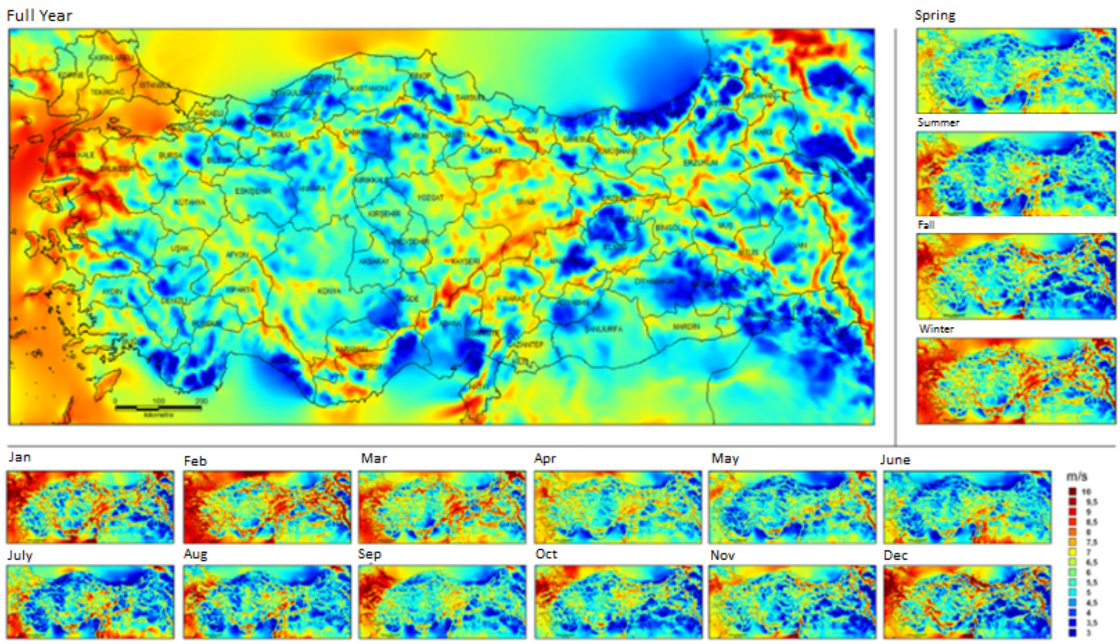

Figure 4.1. Wind speed potentials in Turkey for the height of 100 m

Solar power in another important element of renewable energy group. According to IEA, global installed solar power capacity has reached to 300 GW in 2016. According to the TEIAS, the installed capacity of licenced solar energy plants has reached to 13.9 MW, and unlicensed solar power plants' installed capacity has reached to 2,464 MW in 2017. Figure below shows solar power potentials in Turkey.(see figure 4.2) [24]

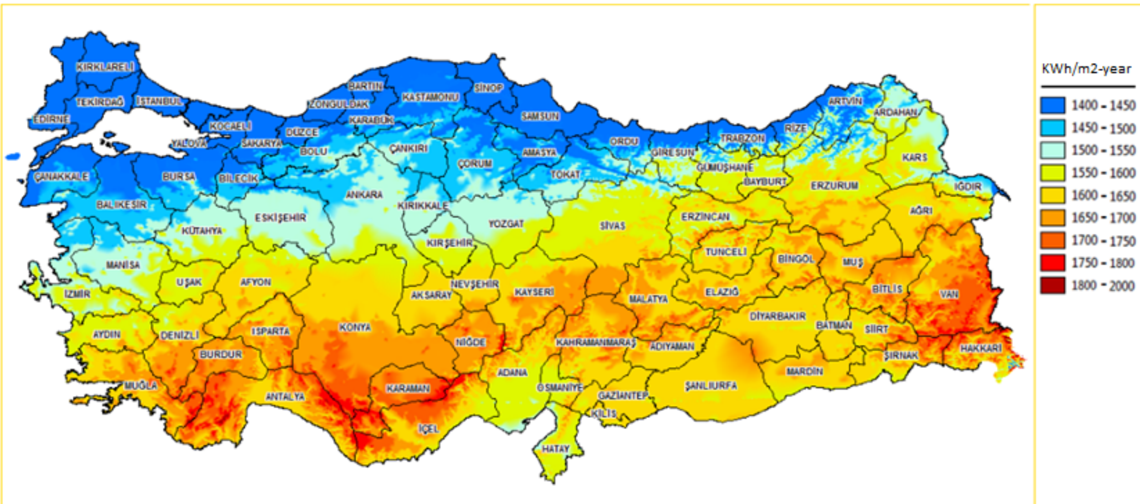

Figure 4.2. Solar power potentials in Turkey

Hydro power is another important renewable energy technology. According to the IEA, 17% of the world's electricity was sourced from hydropower with having 1,700 GW installed capacity in 2016 and China is the leader country in this area.According to the MENR report, total installed capacity of hydro power in Turkey was 27,033 in 2017.

Geothermal energy is one of the important renewable technologies. IEA report indicates that total capacity of geothermal energy was 13 GW in worldwide and Turkey is one of the important players in this energy type with Indonesia, the Philippines and Mexico. According to TEIAS data, the total geothermal installed capacity of Turkey was 885 GW in 2017.

According to the existing legislations (YEKDEM) [25] purchasing guarantees are given at 13.3 $ cent/kWh for solar power based electricity andat 7.3 $ cent/kWh for wind power based electricity. However, it is envisaged to remove the guaranteed feedin tariffs and reduce cost via tenders. A new investment process for renewables was introduced by the Turkish government in 2017 based on tenders for renewable energy resource zones called YEKA. The following YEKA tenders were held so far:

A Turkish - South Korean consortium won the solar power tender of 20 March 2017 with the price 6.99 $ cent/kWh. According to this tender, a solar power plant will be built in Karapınar (Konya) region with 1,000 MW capacity and a factory will be built to produce solar PV modules with capacity 500 MW/year. The rate of domestically produced equipments in this capacity will be 65%. Furthermore, according to YEKA solar power tender, it is claimed that solar power based electricity production will increase 1.7 billion kilowatt hour in every year starting from 2022. According to the laws, government gives purchasing guarantee for solar power based produced electricity with 13.3 $ cent/kWh and this price is increasing for rising domestical producing rate.

A Turkish - German consortium won the wind power tender of 3 August 2017 with the price 3.48 $ cent/kWh. According to this tender, wind power plants will be built in 5 different areas (Kayseri-Niğde, Sivas, Edirne-Kırklareli-Tekirdağ, Ankara-Çankırı-Kırıkkale, Bilecik-Kütahya-Eskişehir) with 1,000 MW of total capacity and each area will have 50 MW capacity at least. A factory will be built to produce to produce number of 300 - 450 wind turbines (each with 2.3 MW capacity at least). The rate of domestically produced equipments in this factory will be 65%. In addition, according to YEKA wind power tender, it is claimed that wind power based electricity production will increase 3 billion kilowatt hour in every year starting from 2022.

New tenders will be held in 2019 for wind and solar power. A new tender announcement for wind power is made inviting bids to be submitted until 7 March 2019. According to this tender, four wind power plants in Balıkesir, Çanakkale, Aydın and Muğla shall be built and each plant have 250 MW capacity, and this tender has a price ceiling 5.5 $cent/kWh. A new tender announcement for solar power is also made inviting bids to be submitted until 31 January 2019. According to this tender, three solar power plants shall be built in Şanlıurfa, Hatay and Niğde with total capacity of 1,000 MW, and this tender has a price ceiling 6.5 $ cent/kWh.

5. MODEL CALIBRATION

In this thesis, Turkey energy market data from 2012 - 2017 are taken into consideration to calibrate the BUEMS. Electricity generation, installed capacity and sectoral energy consumption levels for the years 2012 and 2017 are calibrated according to the data from TEIAS and MENR and lower bounds for installed capacities are set for the year 2022 according to TEIAS Electricity Generation Capacity Production Report (2017-2021).

Important parameters' definitions and values are listed in following section.

5.1. Input Data

Periods : Periods are the time horizons of the BUEMS. Periods are structured in 5-years time intervals and the model provides the results for end of each 5 year period starting in 2012 until 2057.

Cumulative supply limit : The cumulative supply limits are used to control the supply amounts of resources in the BUEMS. The cumulative supply limits are zero for all supply technologies in the base model excluding following technologies: imported solid biomass, imported coal, imported coke, imported heavy fuel oil, imported liquid hydrogen, imported jet resource, imported keresone, imported light fuel oil, imported lpg, imported methanol, imported natural gas, imported oil, imported petroleum, imported natural uranium, extraction of domestic hard coal, domestic asphaltite coal, domestic lignite coal, domestic coke, wood, natural gas, oil, bio-waste, wheat, solid waste, and renewables (geothermal, hydropower,solar, tidal, wave, wind).

Lifetime of technologies : Lifetime of technologies shows the depreciation time for each technology and a technology will be no longer available for usage at the end of this time horizon if any investments are made. In other words, it indicates the usage period of a specific technology. (see table 5.1)

Table 5.1. Lifetime of important process and electricity generation technologies

Technology	Lifetime
Coal - Agriculture	50
Coal - Electricity	50
Coal - Industry	50
Coal - Residential	50
Coal - Service	50
Natural gas - Agriculture	40
Natural gas - Electricity	40
Natural gas - Industry	40
Natural gas - Residential	40
Natural gas - Service	40
Coke - Electricity	50
Coke - Industry	50
Electricity generation - coal (mining)	35
Electricity generation - coal (import)	35
Electricity generation - coke	20
Electricity generation - geothermal	40
Electricity generation - hydro	40
Electricity generation - natural gas	20
Electricity generation - solar	20
Electricity generation - wind	25

Supply cost : Supply cost is the total cost of providing primary energy sources to the system at a certain period including all of the transmission and distribution costs of energy carriers for each tehcnology. (see table 5.2)

Table 5.2. Supply costs (Million $ / PJ)

Technology	2017	2022	2027	2032	2037	2042	2047
Coal (mining 1)	1.02	1.29	1.13	1.06	1.03	1.03	1.06
Coal (mining 2)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Coal (mining 3)	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Coal (import 1)	1.40	1.77	1.98	2.06	2.07	2.07	2.07
Coal (import 2)	1.50	1.19	1.19	1.13	1.19	1.25	1.31
Coke (import)	2.38	3.04	3.37	3.51	3.54	3.57	3.71
Coke (mining 1)	1.80	1.43	1.43	1.35	1.43	1.50	1.58
Coke (mining 2)	1.99	2.53	2.81	2.92	2.95	2.98	3.01
Natural gas (mining 1)	1.85	1.85	1.85	1.85	1.85	1.85	1.85
Natural gas (import 1)	5.07	6.11	6.73	7.16	7.64	7.64	7.64
Natural gas (import 2)	5.79	6.98	7.69	8.18	8.73	8.73	8.73
Natural gas (import 3)	6.15	7.41	8.17	8.69	9.27	9.27	9.27
Natural gas (import 4)	6.51	7.85	8.65	9.21	9.82	9.82	9.82
Natural gas (import 5)	6.88	8.29	9.13	9.72	10.37	10.37	10.37
Natural gas (import 6)	7.23	8.72	9.61	10.22	10.91	10.91	10.91
Petroleum (import)	7.79	5.67	6.09	6.37	6.80	7.08	7.50
Renewables	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Investment cost for capacity addition : Investment cost is the cost of adding new technologies or extending capacities of the existing technologies. Residual capacities do not have any investment cost since they are put into the model at the beginning of the planning horizon. (see table 5.3)

Fixed O&M cost : This parameter is used to calculate the fixed operation and maintenace cost for related technologies. Fixed operation and maintenance cost is applied on capacities for each technology.(see table 5.3)

Variable O&M cost : This parameter is used to calculate the variable operation and maintenace cost for related technology activities. Variable operation and maintenance cost is applied on technology activities which are calculated differently according to the technology type (energy conversion technology or demand technology).(see table 5.3)

Table 5.3. Investment and operation and maintenance costs for the year of 2017 (Million $ / GW)

Technology	Investment	Fixed O&M	Variable O&M
Electricity generation - coal (mining)	750	14	0
Electricity generation - coal (import)	750	20	0
Electricity generation - coke	781	1	2
Electricity generation - geothermal	750	20	0
Electricity generation - hydro (small)	850	85	0
Electricity generation - hydro (large)	800	80	0
Electricity generation - natural gas	389	1	2
Electricity generation - solar	965	0	0
Electricity generation - wind (off-shore)	1140	45	0
Electricity generation - wind (on-shore)	805	27	0

Residual capacity : This variable shows the existing capacity of each technology prior to the beginning of related period. The difference of installed capacity value and residual capacity value gives the new investments for the related period.

Availability factor : This parameter is used to calculate available amount of each technology to be used in activities for related periods.(see table 5.4)

Table 5.4. Availability factor of important electricity generation technologies

Technology	Availability factor
Electricity generation - coal (mining)	0.73
Electricity generation - coal (import)	0.73
Electricity generation - coke	0.55
Electricity generation - geothermal	0.70
Electricity generation - hydro	0.40
Electricity generation - natural gas	0.57
Electricity generation - solar	0.13
Electricity generation - wind (off-shore)	0.30

Capacity utilization factor : The activity level of a demand technology is a particular proportion of the capacity variable and it is represented by capacity utilization factor. This factor gives the share of capacity that is active in the related period. And this parameter is different than annual availability factor which gives the maximum share of the available capacity in the related period for energy conversion technologies.

Technical efficiency : This parameter shows the efficiency rate (of input usage) of demand technologies. There is no assigned efficiency rate parameter for energy conversion technologies. These technologies' efficiency rate is determined by their input/output ratio.

5.1.1. Base Scenario

5.1.1.1. Supply Levels. Energy supply levels of BUEMS are calibrated with the data taken from MENR. Coal and natural gas supply levels are fixed according to the data from Coal Market Report and Electricity Generation Company (EUAS) Sector Report respectively.(see table 5.5 and table 5.6)

Table 5.5. Domestic and import coal supply levels in 2012 and in 2017 in Turkey (PJ)

Coal Type	2012	2017
Domestic Coal	715.9	535.9
Lignite	644.8	477.3
Hard Coal	46.1	37.7
Asphaltites	25.1	20.9
Import Coal	929.5	929.5
Hard Coal	803.9	916.9
Petroleum Coke	117.2	
Coke	8.4	12.6

Table 5.6. Domestic and import natural gas supply levels in 2012 and in 2017 in Turkey (PJ)

Natural Gas Type	2012	2017
Domestic Natural Gas	15.7	8.3
Import Natural Gas	1549.1	1651.8

Table 5.7. Levels of import natural gas supply in 2012 and in 2017 in Turkey (PJ)

Country	2012	2017
Russia	836.5	781.3
Iran	294.3	318.8
Algeria	154.9	158.6
Azerbeijan	123.9	251.1
LNG	93.0	90.9
Nigeria	46.5	51.2

5.1.1.2. Installed Capacity Levels. According to TEIAS data, total installed capacity was 57,059 for year the 2012 and this number has increased to 81,555 MW in 2017. In BUEMS installed capacity levels of 2012 and 2017 are fixed by taking these values and distributions of these numbers to sources into consideration.(see table 5.8 and table 5.9) [6]

Table 5.8. Installed capacities in 2012 in Turkey (MW)

Energy Source	Installed Capacity
Hard Coal + Imported Coal + Asphaltite	4382.6
Lignite	8193.3
Fuel Oil + Diesel Oil + LPG + Naphtha	1285.5
Natural Gas	14116.4
Natural Gas + Liquid	6282.2
Natural Gas + Liquid + Solid	245.4
Solid + Liquid	353.2
Renewables and Wastes	168.8
Hydropower	19609.4
Wind	2260.6
Geothermal	162.2

In addition to studies on the past data of installed capacity levels, TEIAS has published two reports which indicate the future of installed capacity levels in worst case and best case scenarios. Total installed capacity level will increase to 108,045 MW in year of 2021 according to the best case scenario. Furthermore, this number will be 103,433 in the same period according to the worst case scenario. In BUEMS, worst case scenario values for installed capacity levels are taken into account as lower bounds of installed capacities for year 2022. [6]

Table 5.9. Installed capacities in 2017 in Turkey (MW)

Energy Source	Installed Capacity
Fuel Oil + Naphtha + Diesel oil	303.6
Domestic Coal (Hard Coal + Lignite + Asphaltite)	9872.6
Imported Coal	8793.9
Natural Gas + LNG	23063.7
Renewables + Wastes + Waste Heat + Pyrolytic Oil	575.1
Multi Fuel Fired (Solid + Liquid)	682.9
Multi Fuel Fired (Liquid + Natural Gas)	3433.6
Geothermal	884.7
Hydropower	27033.7
Wind	6195.2
Solar	13.9
Solar (Unlicenced)	2463.8

5.1.1.3. Energy Consumption by Sectors. Energy consumption values of BUEMS for the years 2012 and 2017 are taken from National Energy Balance Tables published by MENR. Following tables show the values for electricity, industry, residential and service sectors. [26]

Table 5.10. Electricity sector energy consumption levels in Turkey (PJ)

Enery Source	2012	2017
Hard Coal	287.6	436.6
Lignite	378.7	424.5
Asphaltite	8.2	27.7
Natural Gas	797.5	621.4
Petroleum	31.0	25.6
Hydro	208.3	242.1
Wind	21.1	55.9

Table 5.11. Industry sector energy consumption levels in Turkey (PJ)

Energy Source	2012	2017
Hard Coal	155.4	172.0
Lignite	87.4	66.3
Asphaltite	5.4	2.5
Coke	245.6	138.4
Coke Gas	13.4	18.3
Natural Gas	319.3	363.2
Electricity	323.9	384.0

Table 5.12. Residential&Service sector energy consumption levels in Turkey (PJ)

Energy Source	2012
Hard Coal	207.5
Lignite	104.4
Asphaltite	4.0
Natural Gas	368.4
Electricity	338.1

5.1.1.4. Energy Generation. Electricity generation values of BUEMS for the years of 2012 and 2017 are fixed according to the data taken from TEIAS. Following tables show electricty generation by sources for the years 2012 and 2017. [6]

Table 5.13. Turkey electricity generation by resources in 2012 (PJ)

Energy Source	2012
Hard Coal + Asphaltite	14.8
Imported Coal	105.2
Lignite	124.9
Fuel Oil	3.5
Diesel Oil	2.4
Natural Gas	376.2
Hydropower	208.3
Geothermal	3.2
Wind	21.1

Table 5.14. Turkey electricity generation by resources in 2017 (PJ)

Energy Source	2017
Hard Coal + Imported Coal	205.3
Lignite	145.9
Liquid Fuels	7.1
Natural Gas	389.4
Hydropower	210.4
Geothermal + Wind + Solar	95.6

5.1.2. Policy and Emission Reduction Scenarios of the Model

In this thesis, five policy scenarios are added to the model besides from base model to display the future of renewable energy technologies and coal utilization in Turkey energy market. YEKA tenders of wind and solar power technologies are taken into account for renewable energy scenarios in the model. In addition to the policy scenarios, percent reduction scenarios and tax scenarios are applied to display the results in the manner of CO2 emission and marginal abatement cost. Definitions of these scenarios and their assumptions which are applied to the model to analyze results of each scenario are shortly explained below:

Policy Scenarios

- Wind : 54 PJ of increase in wind power generation ("wnd_e_ gen" variable) is added to the model for each 5 year period starting from 2022.
- Solar : 30.6 PJ of increase in solar power generation ("sol_e_ gen" variable) is added to the model for each 5 year period starting from 2022.
- Wind&Solar: 54 PJ of increase in wind power generation ("wnd_e_ gen" variable) and 30.6 PJ of increase in solar power generation ("sol_e_ gen" variable) are added to the model for each 5 year period starting from 2022.
- Coal 1: The growth of coal usage for electrivity generation is restricted so as not to increase more than 5% per annum starting from 2022.
- Coal 2: Usage of imported coal in electricity production has been removed starting from the period 2022 to observe the market dynamics while encouraging usage of domestic coal resources.

Percent Reduction Scenarios

- Total10: Total CO2 emissions are reduced by 10% from base emissions beginning from 2022.
- Total20: Total CO2 emissions are reduced by 20% from base emissions beginning from 2022.
- Total30: Total CO2 emissions are reduced by 30% from base emissions beginning from 2022.
- Sector10: Sectoral CO2 emissions are reduced by 10% each from base emissions beginning from 2022.
- Sector20: Sectoral CO2 emissions are reduced by 20% each from base emissions beginning from 2022.

- Sector30: Sectoral CO_2 emissions are reduced by 30% each from base emissions beginning from 2022.

Tax Scenarios

- Tax20: 20$ tax per ton of CO_2 emission is applied to all energy conversion and relevant demand technologies.
- Tax30: 30$ tax per ton of CO_2 emission is applied to all energy conversion and relevant demand technologies.
- Tax40: 40$ tax per ton of CO_2 emission is applied to all energy conversion and relevant demand technologies.
- Tax50: 50$ tax per ton of CO_2 emission is applied to all energy conversion and relevant demand technologies.

6. RESULTS

The main aim of the BUEMS is to minimizing total system cost by using linear programming technique by supplying every sector's total demand for each time period. There are five demanding sector in the model; agriculture, residential, service, industry and transportation. These sectors use different energy types for their requirements. These sectors and energy types will be explained in detail in the sectors part.

As explained before, the BUEMS has an important availability for users that is differing the model for usage, in other words it has flexibility for different scenarios creation for analyzing future of various energy technologies. In conclusion part of this master thesis, the results of scenarios which are based on the changing important variables for verifying renewable energy and coal resources will be presented in the policy scenarios part. In addition to the policy scenarios, results of the percent reduction scenarios will be displayed. In order to analyze the future of renewable energy technologies and coal reserves in Turkey energy market six different scenarios (Based, Wind, Solar, Wind&Solar, Coal1 and Coal2) were created in the BUEMS. The GAMS codes fordifferent model runs and Excel files including scenarios' results will be shared in the master thesis CD.

6.1. Base Scenario Results

In the base scenario which is also called as business as usual scenario, the energy market has been evaluated with the observed values (for past years of model) and current estimations of the data set for future years. Data set of the reference project "Energy Economy and Environment Integrated Large Scale Modeling and Analysis of the Turkish Energy System" ,TEIAS and MENR data have been used to build base scenario of the BUEMS. [6, 22]

6.1.1. Important Parameters of Base Scenario

In the base scenario, 25 - 30% of the total supply amount for the years 2012 – 2027 has been consisted of coal sources (coal and coke), and this rate has gradually increased to 65% for future years of the model. This increase can be seen on the figure below. On the other hand, total amount of wind and solar power for primary energy supply was observed around 1% of the total supply in the base scenario. (see figure 6.1)

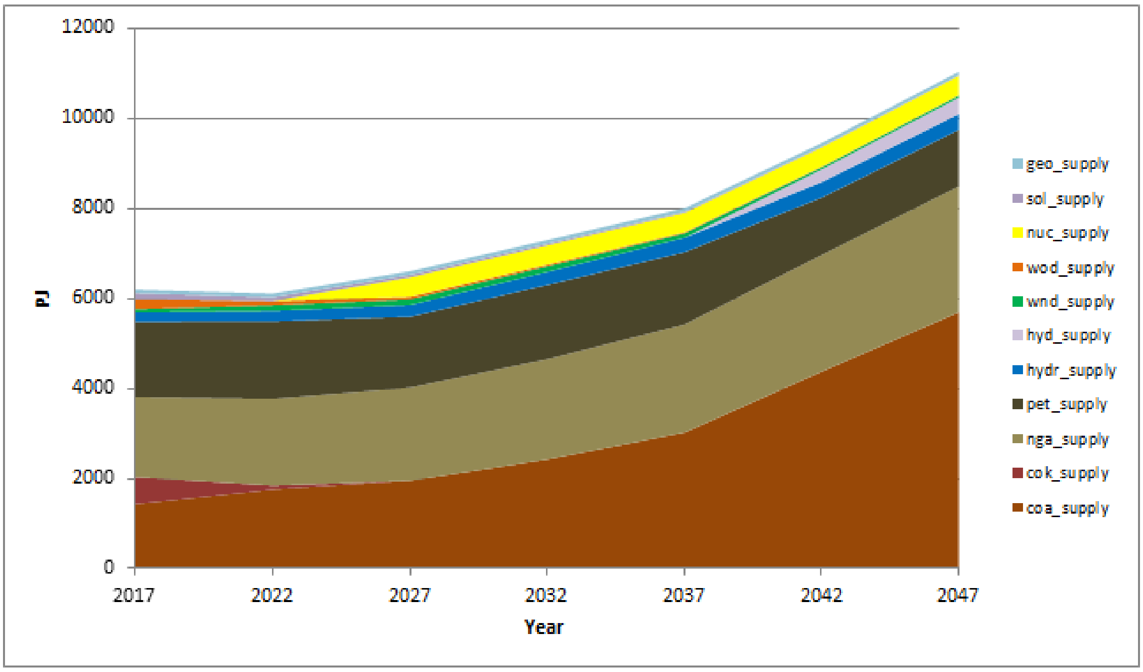

Figure 6.1. Primary energy supply by sources in base scenario.

Installed capacity values are another decisive data set that are used for analyzing forecasting results of the model. Proportion of coal fueled power in total installed capacity is between 24% in 2017 and rises to 41% in 2047. On the other hand, the total installed capacity amount of wind and solar power has composed the 10 - 15% of the total amount for early years of the model and it has decreased to 1% toward last years of the model. (see figure 6.2)

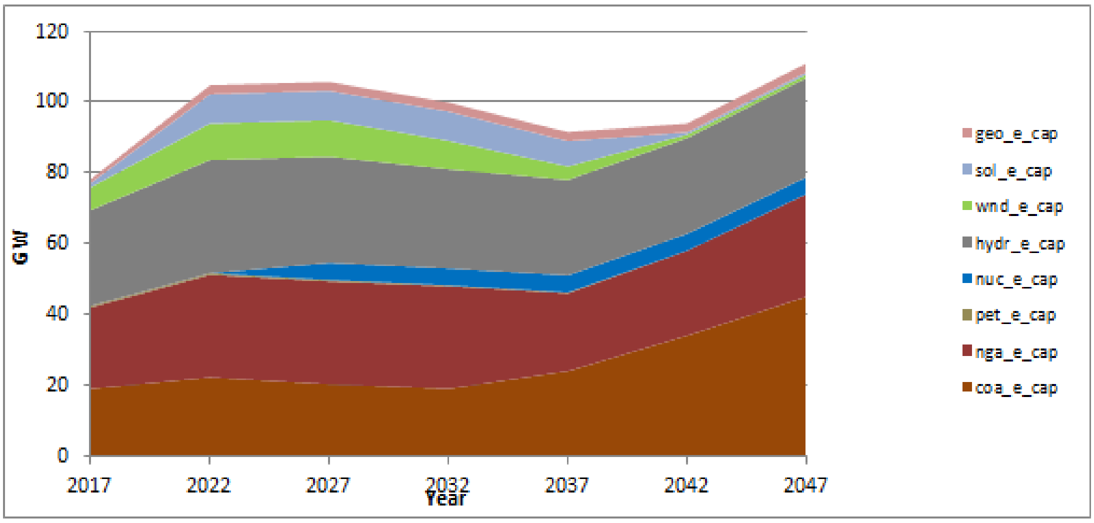

Figure 6.2. Installed capacities of technologies in base scenario.

Electricity generation is another important indicator for the model. 25 – 35% of total electricity generation has been provided with coal based sources in the early periods of the model, and this percentage has increased to 70% in the lately years in base scenario. On the other side, wind and solar based sources has constituted around 10% of total electricity generation at the beginning and this rate has decreased to 2% in 2047.(see figure 6.3)

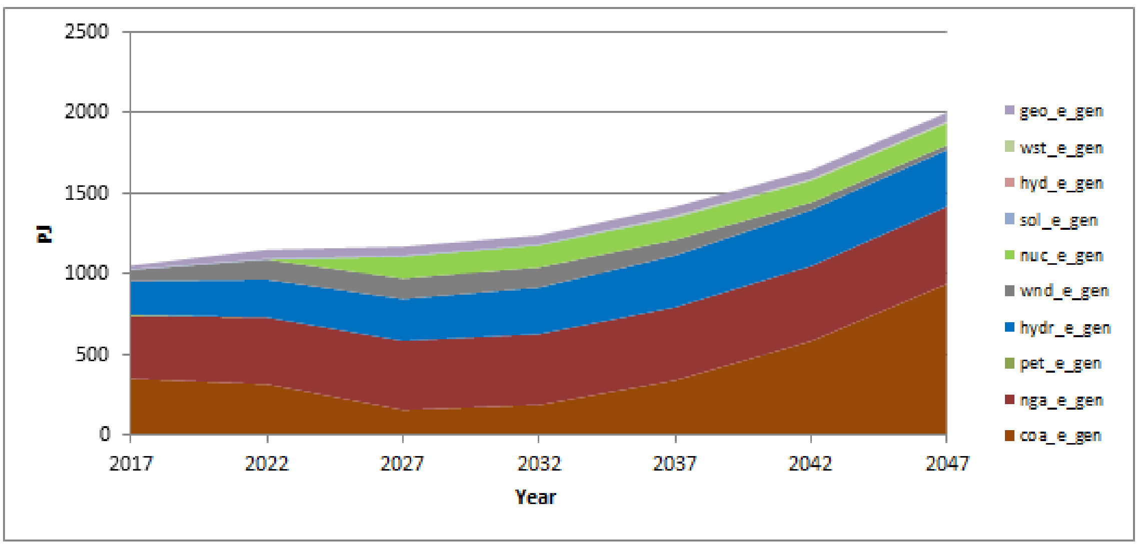

Figure 6.3. Electricity generation technologies and amounts in base scenario.

There are important parameters in the BUEMS to compare the results of the scenarios. These are total electricity production, total undiscounted annual cost and total amount of CO2 emission. These parameters are appeared as result of the model run with the variables mentioned above at the end of the running process in each time. The table below displays the values for these parameters in base scenario for years 2012 and 2017 (see table 6.1) :

Table 6.1. Values of significant variables in base model

Variables	2012	2017
Undiscounted Annually Adjusted Total System Cost (million $)	52491	80417
Total electricity production (PJ)	860	1054
Total amount of CO2 emission (million tons)	315	383

Results of the base scenario has shown that, usage of coal sources will escalate in current situation for Turkey while renewable energy technologies will be rarely used. As a result of increase in thermal energy sources, total CO2 emission amount for energy market will rise and environmental problems will be seen more often if any precaution will be taken by government and private companies.

6.1.2. End Use Sectors

As mentioned before, there are five demanding sectors in the BUEMS. Each of them have various demand technologies in the system for different energy sources and the model aims to meet every sector's demand for each period while minimizing the total system cost. The figures in the following sections show that energy consumption for demanding sectors is not affected by changing scenarios, in other words in each scenario required amount of energy can be provided to demand technologies of sectors.

6.1.2.1. Agriculture Sector. Agriculture sector is on of the important production areas of Turkey and has around 8% share in GDP. In this model only electricity consumption of agriculture sector has been taken into consideration (it is shown as elc_a_cons in model and excel files including results of the scenarios). [27]

In BUEMS, agriculture sector has only electricity consumption technology and it can be said that from the graphic, electricity consumption of agriculture sector increases exponentially over the years.(see figure 6.4)

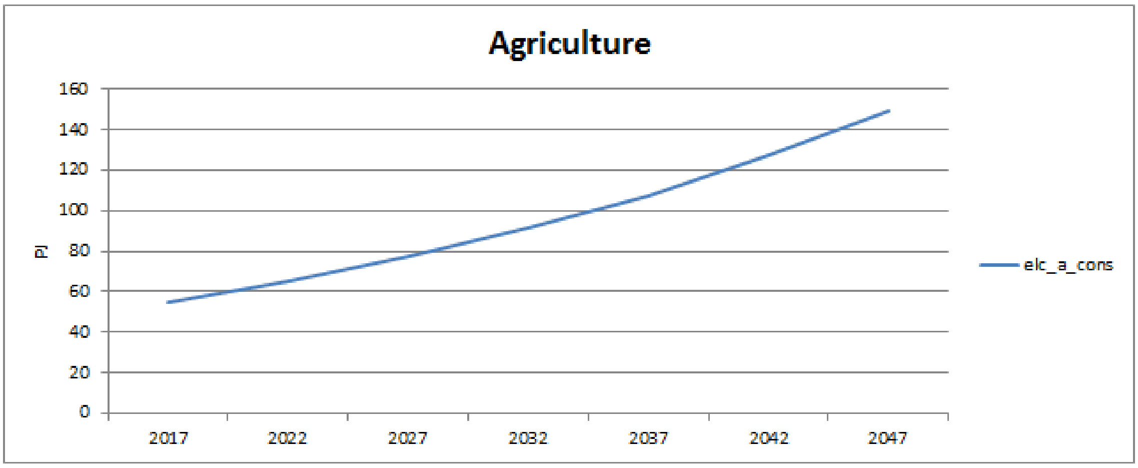

Figure 6.4. Energy consumption of agriculture sector for each scenario.

6.1.2.2. Residential Sector. Residential sector has grown in last decades in Turkey because of increasing number of constructions and investments.

In the BUEMS, residential sector has eight different demanding technologies that represent electricity, coal, natural gas, oil products, solar power, wood, low temperature heat and hydrogen power consumptions (these consumptions are shown by the abbreviations elc_r_cons, coa_r_cons, nga_r_cons, pet_r_cons, sol_r_cons, lth_r_cons and hyd_r_cons respectively in the model and excel files including results of the scenarios)

Electricity energy is the most important energy source for residential building. Residential sector is has an important share in electricity consumption. According to TUIK data, around 51 GW of the total electricity consumption that corresponds to 22.2% in total in 2016 has been derived from households. [1]

Following figure show the energy consumption of residential sector for different scenarios (details of each scenario will be explained in detail in scenarios part):(see figure 6.5)

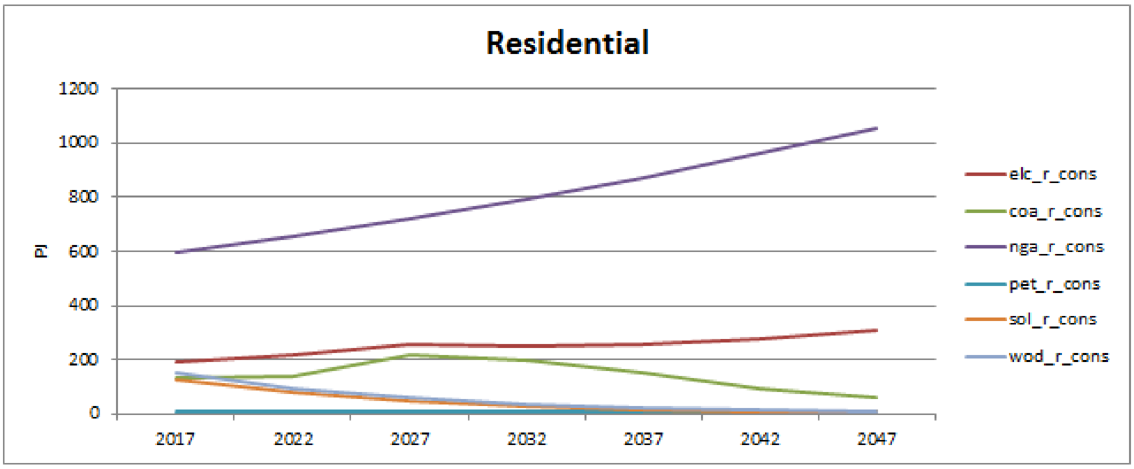

Figure 6.5. Energy consumption of residential sector for each scenario.

Electricity consumption of residential sector has increased in every period besides from the period between 2027 - 2032. In addition to this situation, increase of electricity consumption has increased towards the end of the time horizon (between 2047 - 2057). Consumption of natural gas has shownan exponential growth. On the other hand, consumption of coal has decreased in the future years for residential sector although it has an important rate in the first years of the model.

It can be concluded from the graphic, electricity and natural gas consumption represent similar behaviors for all scenarios and consumptions for these two energy resources increases towards future years of the model, while direct use of coal, petroleum, solar energy and wood loses its significance for residential sector.(see figure 6.5)

6.1.2.3. Service Sector. Service sector is another important sector of the model, because it includes various types of buildings and services and energy consumption technologies as a result of this diversification. Commercial buildings and government offices are included to the service sector in the BUEMS and their energy demand technologies are used as variables. Electricity, coal, natural gas, solar power, hydrogen power and waste consumptions are the demand technologies of service sector in the model (these consumptions are shown by the abbreviations elc_s_cons, coa_s_cons, nga_s_cons, sol_s_cons, hyd_s_cons and wst_s_cons respectively in the model and excel files including results of the scenarios).

Similar to the residential sector, the biggest portion of energy consumption for service sector is electricity energy consumption. According to TUIK data, around 52 GW of the total electricity consumption that corresponds to 22.7% in total in 2016 has been derived from commercial buildings and govenrment offices. [1]

Following figure show the energy consumption of service sector (details of each scenario will be explained in detail in scenarios part):

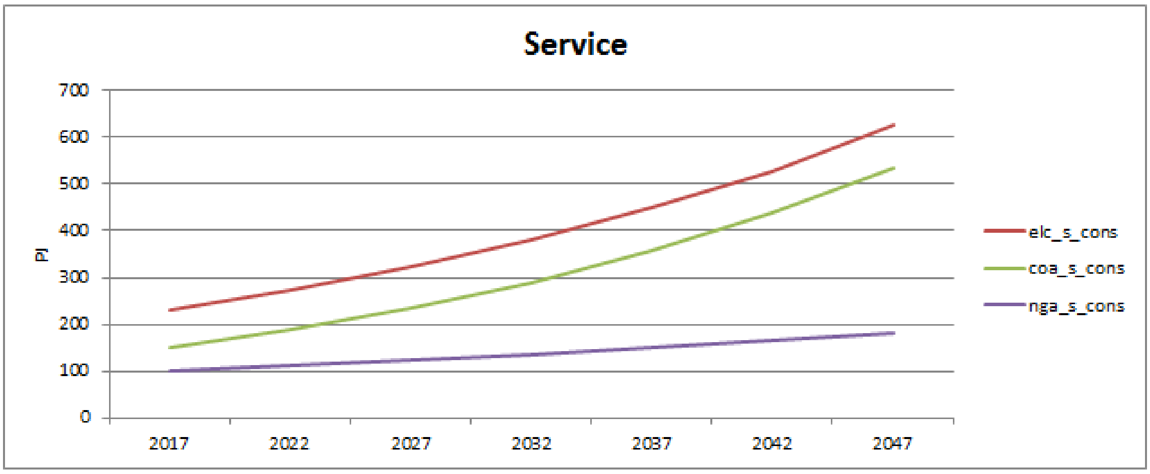

Figure 6.6. Energy consumption of service sector for each scenario.

In the base scenario, electricity and consumption of service sector have increased in every period besides from the period between . In addition to this situation, consumption of natural gas has increased decreasingly for service sector in the future years in the current situation. (see figure 6.6)

The figure above indicates that, electricity consumption for service sector will become the most important energy source for demanding technologies in the future and consumption amount of electricity energy in each scenario display an exponential growth for next forty years. On the other hand, coal consumption has been observed higher for service sector and it has been also used directly to produce energy.

6.1.2.4. Industry Sector. Industry sector is the most important sector of the model with regard to the total amount of energy demand. Industry sector holds the 50% of the total energy consumption among all sectors. Chemicals and fertilizers industry, food industry, steel industry, glass and non-metal minerals industry, pulp and paper industry, ceramic industry, primary aluminum industry and cement industry constitutes the important amount of industry sector demand in the model. Because of industry sector has many parts, its energy consumption range is aggregated by number of resources such as electricity, coal, coke, coke gas, natural gas, oil products, blast furnace gas, hydrogen power, syn gas, waste and steam (these consumptions are shown by the abbreviations elc_i_cons, coa_i_cons, cok_i_cons, nga_i_cons, pet_i_cons, bfg_i_cons, hyd_i_cons, syn_i_cons, wst_i_cons and stm_i_cons respectively in the model and excel files including results of the scenarios).

Electricity is the most important energy source for industry sector. Electricity energy comprises the 15% of the total energy consumption for industry sector until 2057. Furthermore, industry sector consumption has been the most considerable amount in total electricity consumption for Turkey for last 40 years. According to TUIK values, 47% (108 GW) of the total electricity consumption was originated from industry sector in 2016. [1]

Following figures shows the energy consumption of industry sector (details of each scenario will be explained in detail in scenarios part):

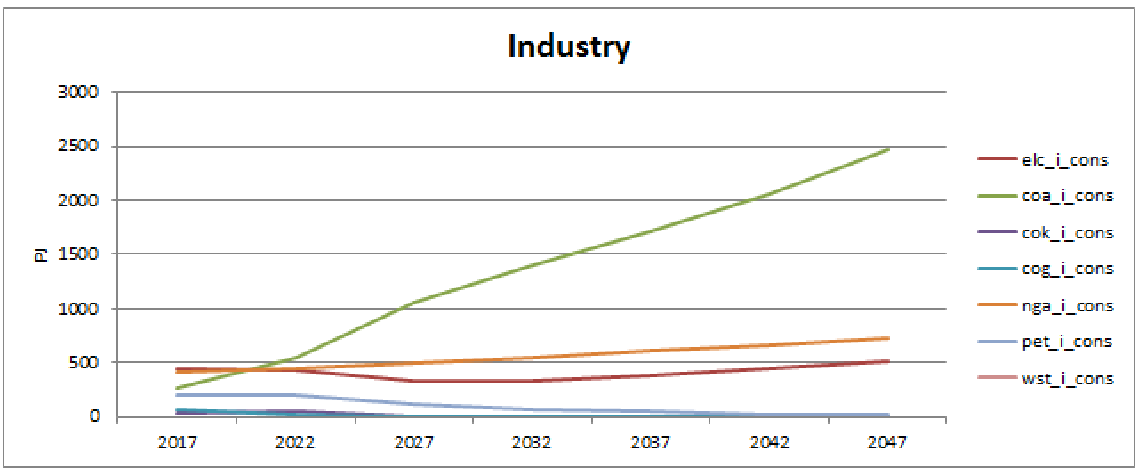

Figure 6.7. Energy consumption of industry sector for each scenario.

The graphic for industry sector shows that coal will be the most important energy source for industry sector in future and natural gas and electricity will be the alternative sources to meet required energy for industrial operations. (see figure 6.7)

<u>6.1.2.5. Transportation Sector.</u> Transportation sector is another sector of the model. Since, electric and hydrogen car technologies are expected to be common in Turkey from 2037, these two energy sources will be important for the transportation sector. On the other hand, because of the variety of transportation vehicles and fuels, transportation sector has ten different demand technologies in the model which are electricity, oil products, cng, diesel, bio diesel, jet fuel, hydrogen, methanol, ethanol and lpg (these consumptions are shown by the abbreviations elc_t_cons, pet_t_cons, cng_t_cons, die_t_cons, biod_t_cons, jet_t_cons, hyd_t_cons, mth_t_cons, eth_t_cons and lpg_t_cons respectively in the model and excel files including results of the scenarios).

Energy consumption amounts for transportation sector in each scenario are equal in each scenario and the following figure shows the changes for future years (see figure 6.8).

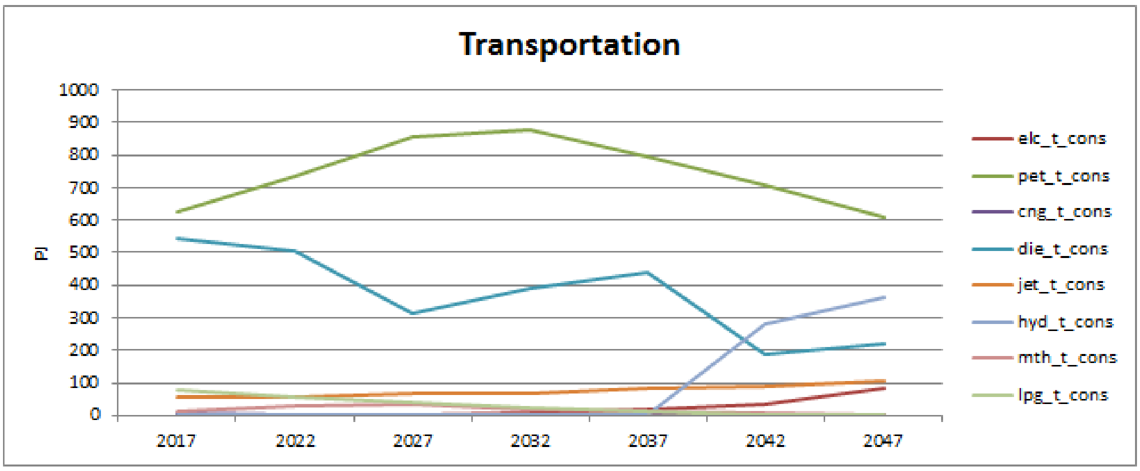

Figure 6.8. Energy consumption of transportation sector for each scenario.

The main change for transportation sector is adding hydrogen and electricty technologies in to the sector starting. As a result of new entering technology, usage of natural fuel sources like petroleum and diesel are decreasing in the future years.

6.2. Policy Scenarios

The BUEMS is built with bottom-up method as mentioned before. This characteristic provides user with changing variables and creating different scenarios and various versions for analyzing the future of the energy market in different ways. In this thesis, five policy scenarios are generated to evaluate the results of investments in renewable energy technologies and policies applied for controlling domestic coal sources. These scenarios are named as; wind, solar, wind & solar, coal 1 and coal 2. In the following parts of this chapter all scenarios and observations of them will be explained in detail.

6.2.1. Wind Scenario

In the wind scenario, YEKA tenders for improving wind power technologies was taken into consideration to build the model and examine the possible cases of energy market if the developments are concentrated on wind power. According to YEKA values, it is claimed that wind power based electricity production will increase to 3 billion kilowatt hour annually starting from 2022. In the model, each period has 5 years of time zone. Therefore, 15 billion kilowatt hour (54 petajoule) of increase for "wnd_e_gen" variable is added to the model by 5-year constraints and whole system has been run to analyze scenario results. [28]

In the wind scenario, percentage of wind power sources in total supply is definitely above of which in the base scenario as expected. It has increased to 4% of total in the lately periods. Wind and solar power has increased their percentage in total amount of primary energy supply while coal sources has been used less (46%) with respect to base scenario.(see figure 6.9)

Installed capacity for wind and solar power has inreased their share by the year of 2047 of the model in wind scenario and installed capacity of coal sources is lower from the amount in base scenario (23% in wind scenario, 41% in base scenario).

Renewable sources has composed 48% of total installed capacity in wind scenario, while they has 29% in base scenario.(see figure 6.10)

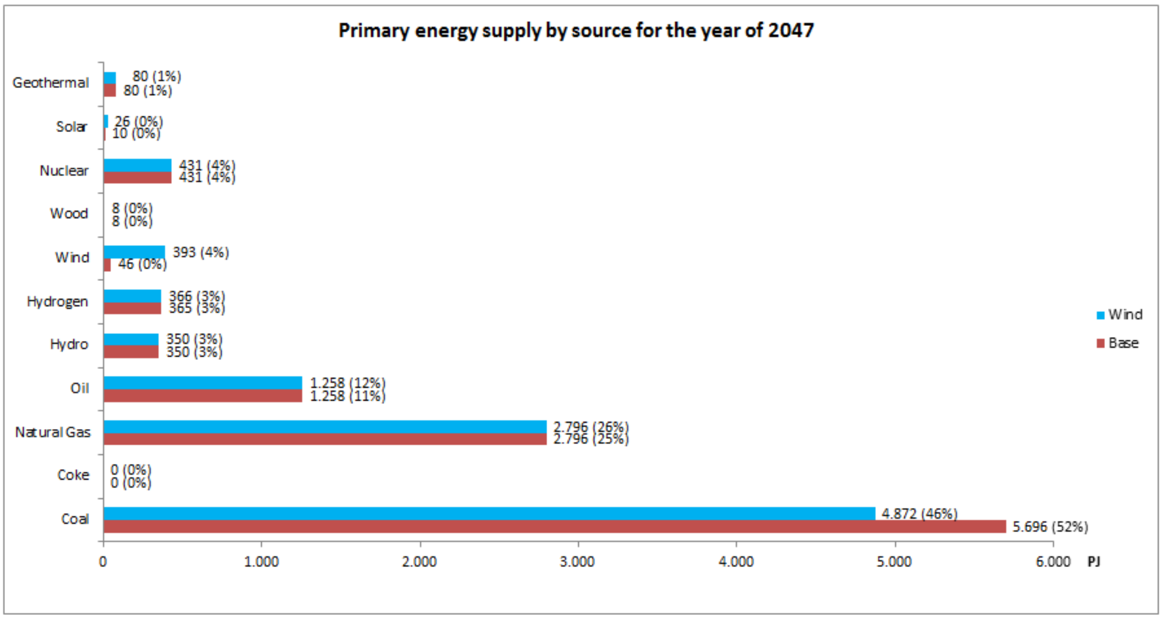

Figure 6.9. Primary energy supply by sources in wind scenario and base scenario for the year of 2047.

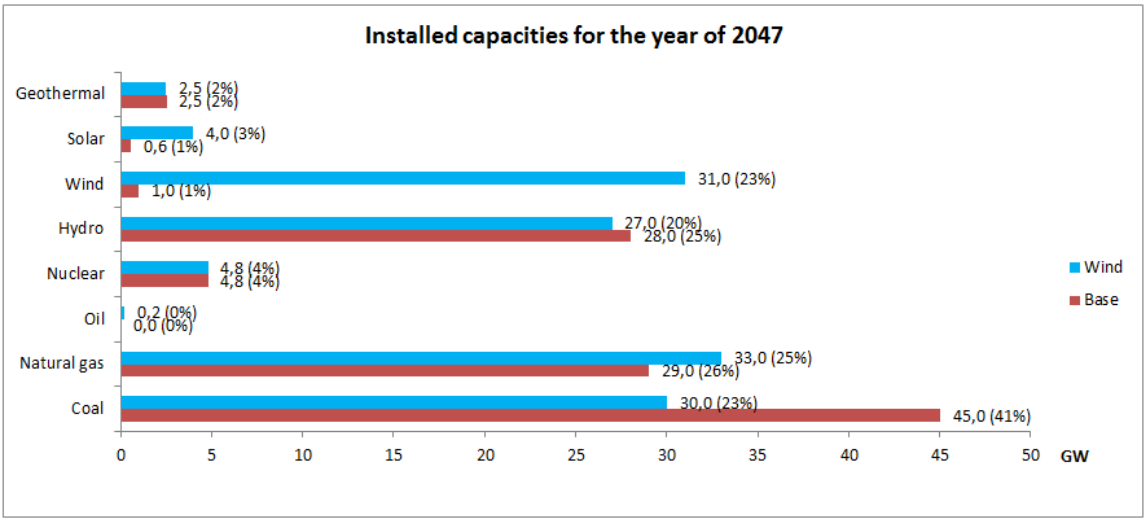

Figure 6.10. Installed capacity amounts and percentages in wind scenario and base scenario for the year of 2047.

The situtation in electricity generation is similar to which in installed capacity progress. While wind and solar power has increased their shares in total, the level of coal based and coal fueled processes has decreased. Share of wind power based electricity generation has increased to 20% from 1% and percentage of coal based generation has decreased to 27% from 47%. (see figure 6.11)

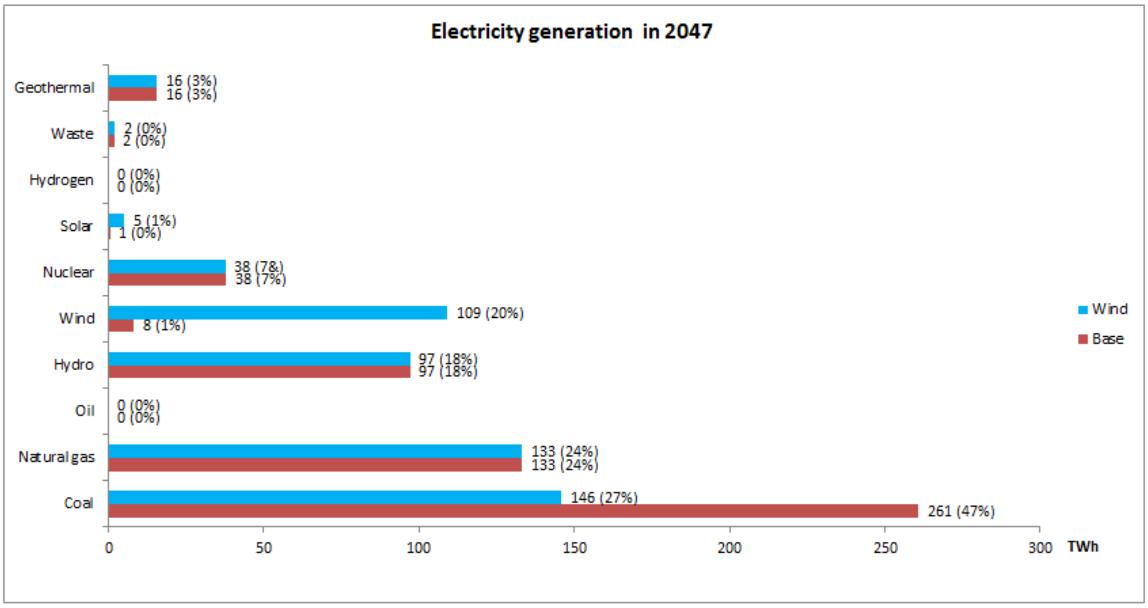

Figure 6.11. Electricity sector generation variables in wind scenario and base scenario for the year of 2047.

6.2.2. Solar Scenario

In the solar scenario, YEKA tenders for improving solar power technologies was included to the model to observe the future of energy market if the developments are focused on solar power. According to YEKA values, it is claimed that solar power based electricity production will increase 1.7 billion kilowatt hour in every year starting from 2022. In the model, each period has 5 years of time zone. Therefore, 8.5 billion kilowatt hour (30.6 petajoule) of increase for "sol_e_gen" variable is added to the model by 5-year constraints and whole system has been run to observe scenario results. [29]

In the solar scenario, share of solar power sources in total supply has increased more than five times at the end of simulation with respect to the share of it in the base scenario. Solar power has increased their percentage (from 0.1% to 2%) in total amount of primary energy supply while coal sources has been used less (from 52% to 49%) with respect to base scenario by the period of 2047.(see figure 6.12)

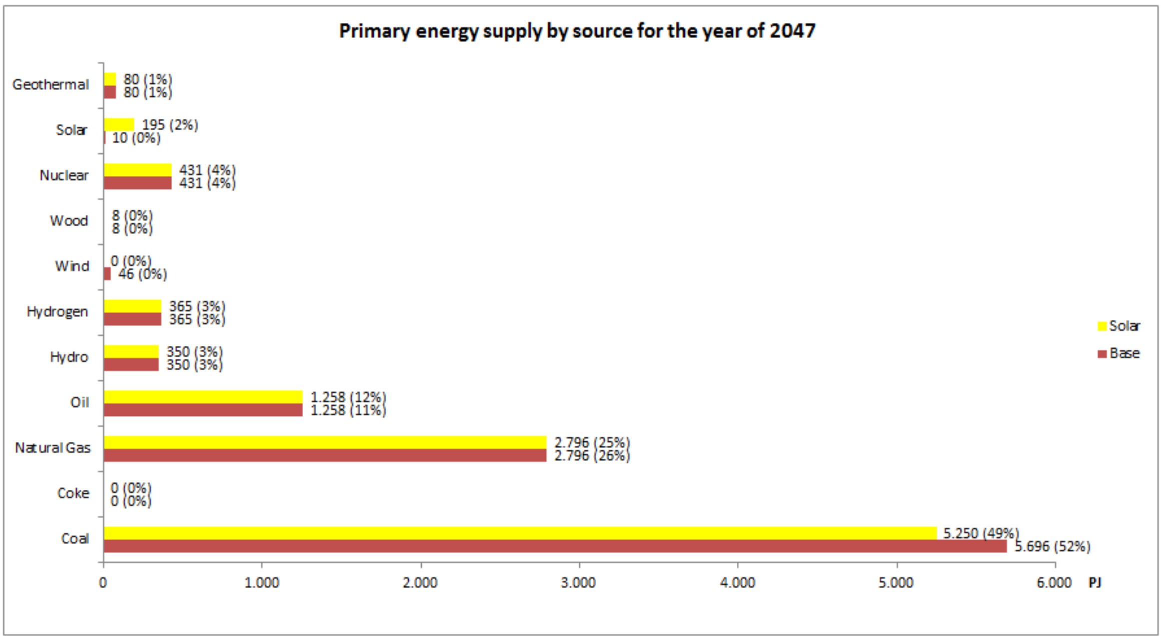

Figure 6.12. Primary energy supply by sources in solar scenario and base scenario for the year of 2047.

In solar scenario, wind and solar power sources has more installed capacities than based and wind scenario. Share of solar power sources installed capacities has raised to 32% from 1% in total. On the other hand, coal sources have less installed capacity (it has decreased to 25% from 41%) than base scenario, because model has been directed to benefit from renewable energy sources.(see figure 6.13)

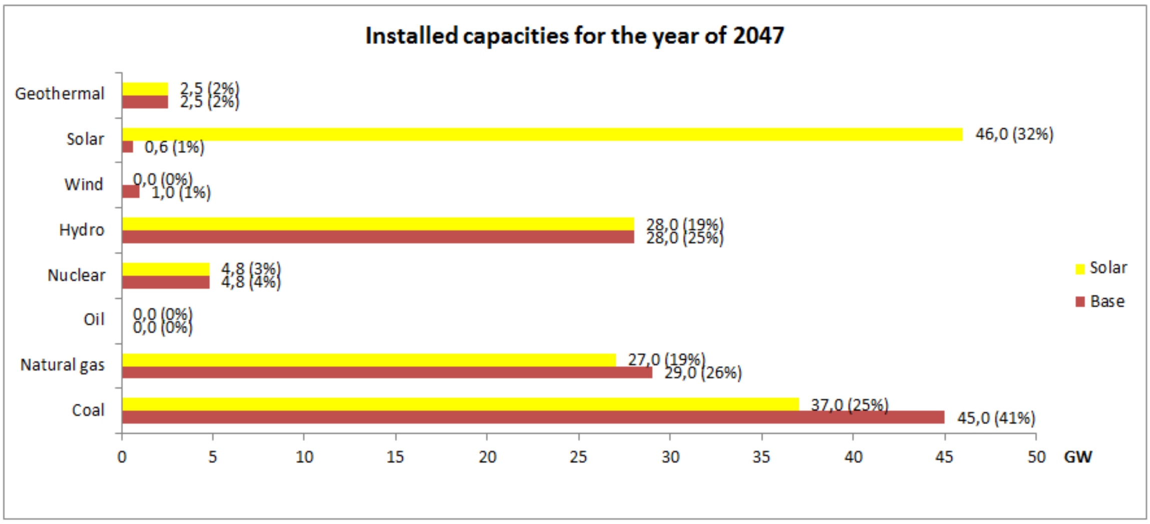

Figure 6.13. Installed capacity amounts and percentages in solar scenario and base scenario for the year of 2047.

The change in amounts for renewable energy technologies in electricity generation are similar to which in installed capacity progress. While wind and solar power has increased their shares in total, the level of coal based and coal fueled processes has decreased. Share of solar power based electricity generation has increased to 10% and percentage of coal based generation has decreased to 37% from 47%.(see figure 6.14)

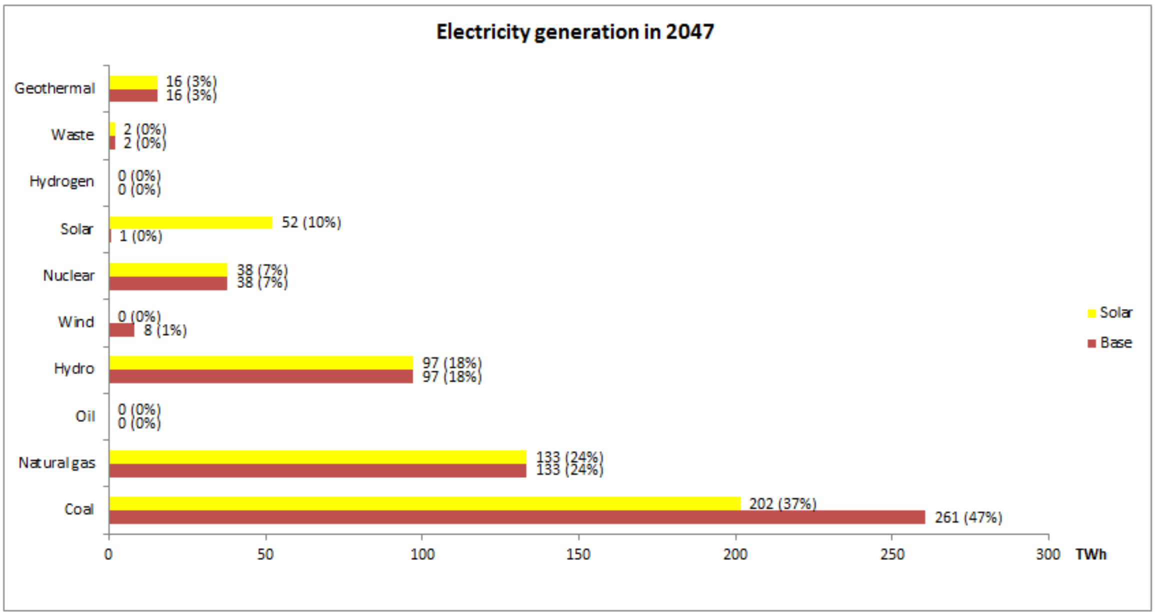

Figure 6.14. Electricity sector generation variables in solar scenario and base scenario for the year of 2047.

6.2.3. Wind&Solar Scenario

The investments for wind and solar power technologies in previous scenarios are combined in wind&solar scenario. 15 billion kilowatt hour (54 petajoule) of increase for “wnd_e_gen” variable and 8.5 billion kilowatt hour (30.6 petajoule) of increase for “sol_e_gen” variable are added to the model by 5-year constraints and whole system has been run to observe scenario results. As a result of these investments shares of wind and solar power in total primary energy supply has raised and decay in share of coal resources has appeared. Sum of wind and solar power has composed the 6% of the total supply in this scenario, while this percentage is only 0.3% in base scenario for the year 2047. In addition, share of coal reserves in primary energy supply has fallen to 47% from 52%. (see figure 6.15)

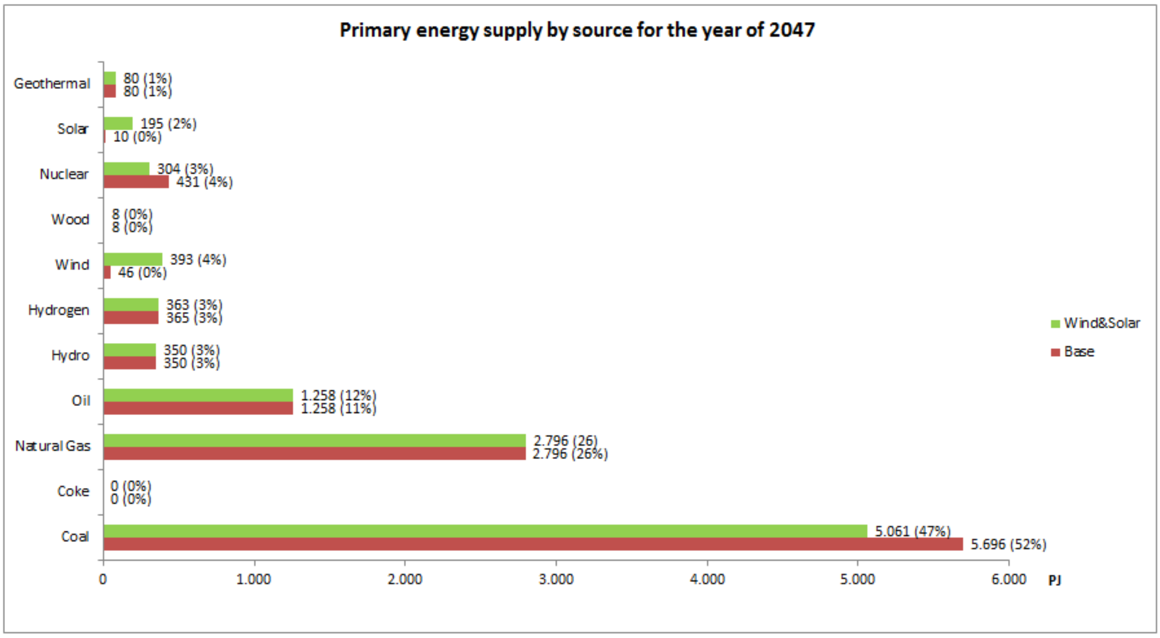

Figure 6.15. Primary energy supply by sources in wind&solar scenario and base scenario for the year of 2047.

Installed capacity for renewable energy sources has also increased and their share in electricity generation and electricity production has raised while coal sources’ percentage has gone down below the level of which in base scenario.

Total installed capacity for wind and solar power has raised their percentage from 2% to 45% and at the same time, installed capacity share of coal resources has decreased 15% from 41% for the year 2047.(see figure 6.16)

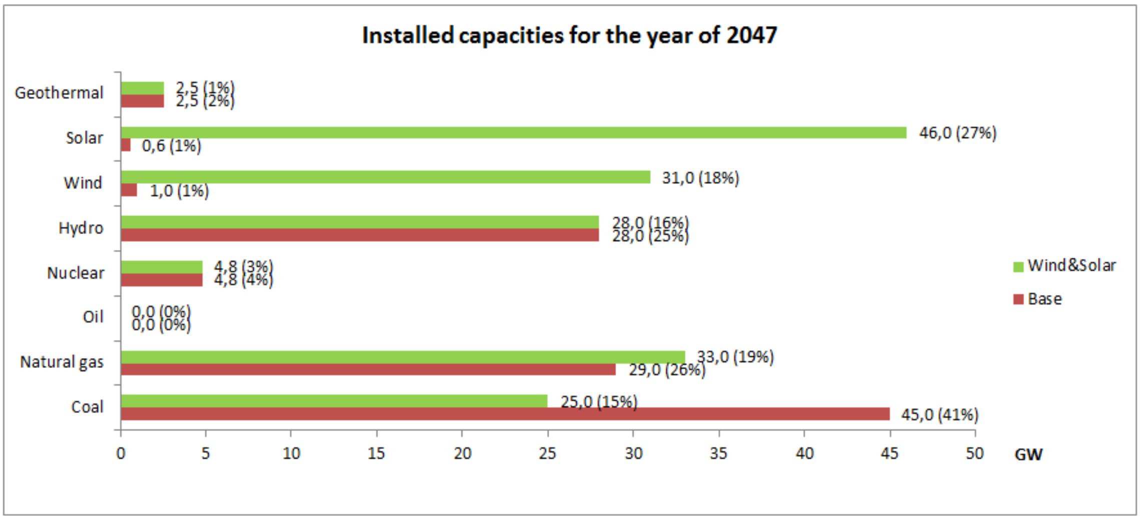

Figure 6.16. Installed capacity amounts and percentages in wind&solar scenario and base scenario for the year of 2047.

Similar to the situations in previous scenarios, electricity generation shares of wind, solar and coal sources has shown the analogous behaviors with installed capacity level changes. In electricity generation, wind and solar power based generation has increased their share from 1% to 29% in total and coal based electricity generation has decreased to 20% from 47% by the year of 2047. (see figure 6.17)

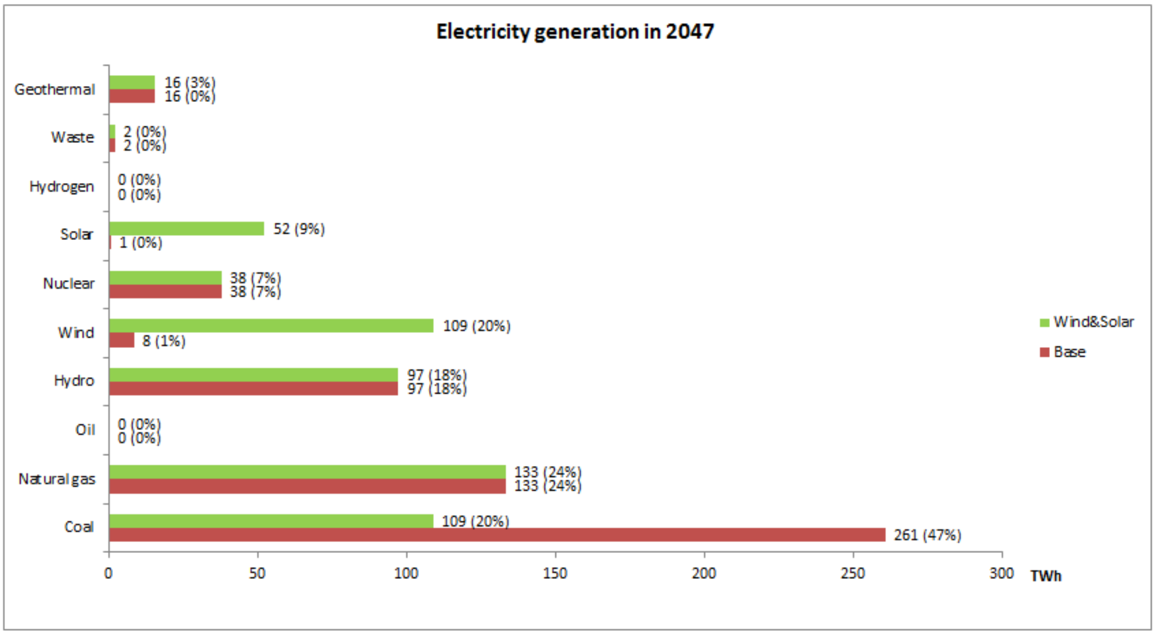

Figure 6.17. Electricity sector generation variables in wind&solar scenario and base scenario for the year of 2047.

6.2.4. Coal 1 Scenario

Coal resources of the model are separated into two according to trade options; export and import. In addition to these trade options, there is one important progress for coal supply which is mining. In Coal 1 scenario, the main aim is to analyze the dynamics of energy market by controlling total coal using for future periods.

In the base scenario, total coal usage in electricity production has shown an annual increase rate of 5% between 2017 and 2057. However, the increase rates between consecutive 5-year periods have been varied from 6% to 60%. In order to prevent this irregularity, 5-year constraints for all coal technologies has been added to the model. These constraints make sure that consumption amount of all coal technologies in electricity production cannot be more than 1.27 times of the value in previous period (5% annual increase rate = 27% 5-year increase rate). The figure below shows the changes in levels of primary energy sources. Since, increase rate for coal using is restricted, the model has directed to alternative energy sources for primary energy supply. Petroleum and natural gas sources has increased their share to 38% from 36% in total, while share of renewable energy sources has increased to 6% from 4% by the year of 2047.(see figure 6.18)

Renewable sources have increased their share in total installed capacity to 33%, while total installed capacity for coal sources has decreased to 36% because of applied constraints to prevent unstable growth of coal usage in electricity production.(see figure 6.19)

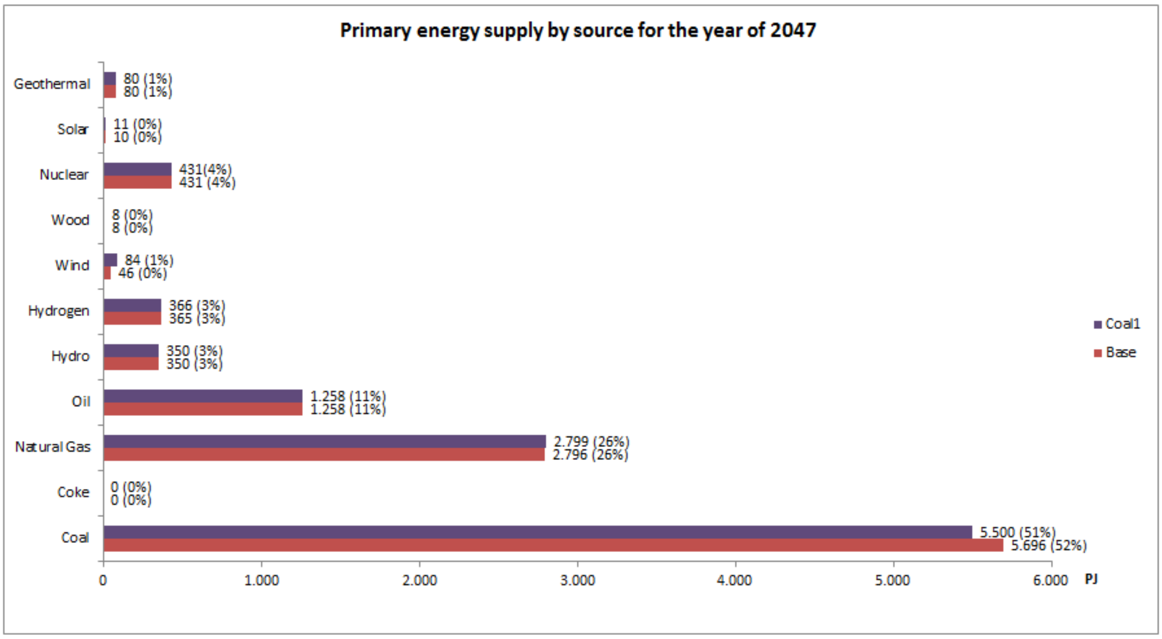

Figure 6.18. Primary energy supply by sources in coal 1 scenario and base scenario for the year of 2047..

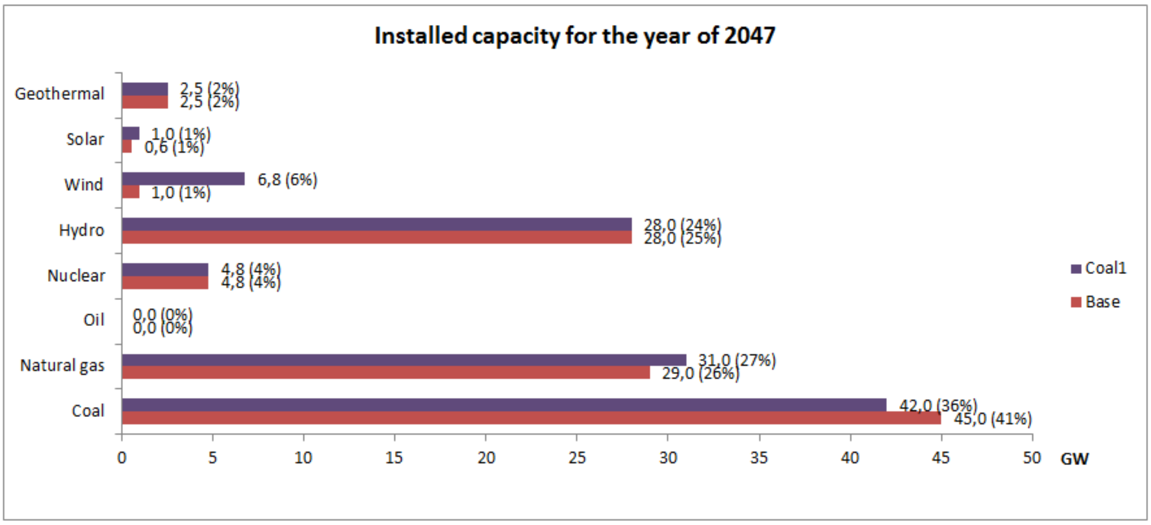

Figure 6.19. Installed capacity amounts and percentages in coal 1 scenario and base scenario for the year of 2047.

Percentage of electricity generation from renewable sources has raised to 25%, because of the restricted usage of coal in Coal 1 scenario. In base scenario, their total share is 21%. On the other hand, coal based electricity generation has decreased to 44% while it is 47% in base scenario for the period of 2047.(see figure 6.20)

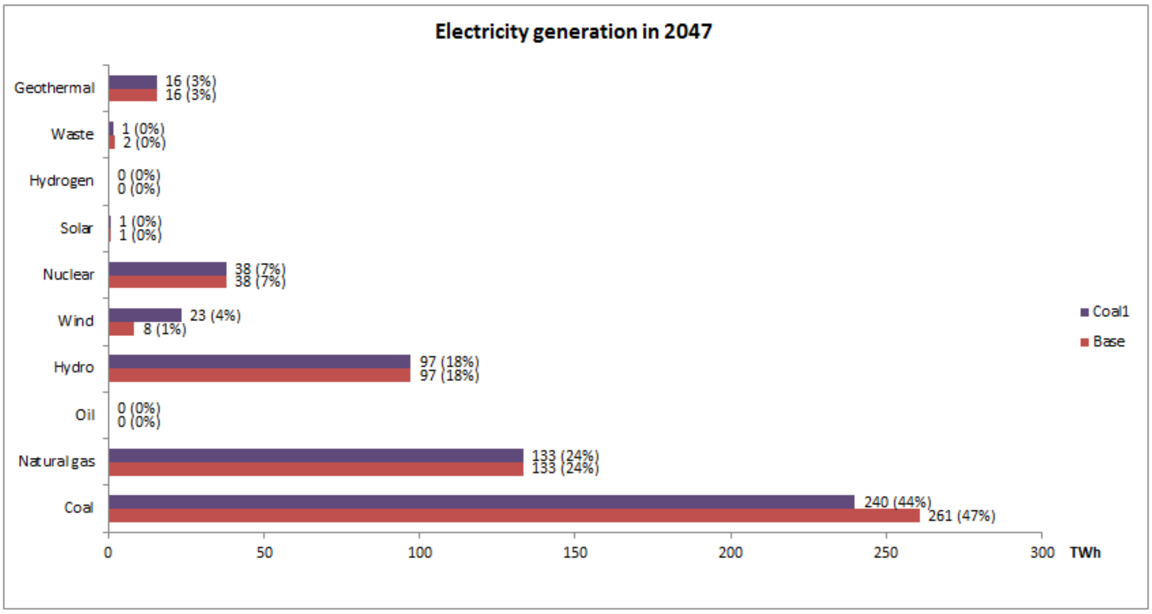

Figure 6.20. Electricity sector generation variables in coal 1 scenario and base scenario for the year of 2047.

6.2.5. Coal 2 Scenario

In Coal 2 scenario, usage of imported coal in electricity production has been removed starting from the period 2022 to observe the market dynamics while encouraging usage of domestic coal resources. Similar to the previous scenario, renewable sources has increased their share.(see figure 6.21)

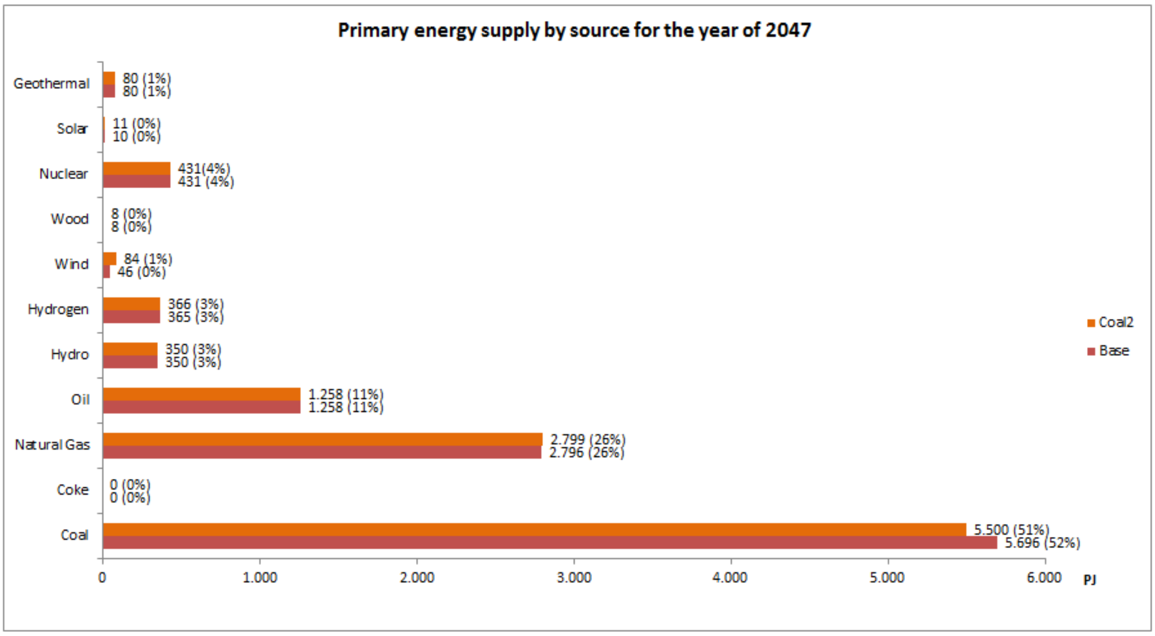

Figure 6.21. Primary energy supply by sources in coal 2 scenario and base scenario for the year of 2047.

Total installed capacity for coal sources has decreased because of the limitations on the coal technologies. On the other hand, installed capacity of renewable energy sources has increased and reached to 33% of total capacity in 2047 (this share is 29% for base scenario).(see figure 6.22)

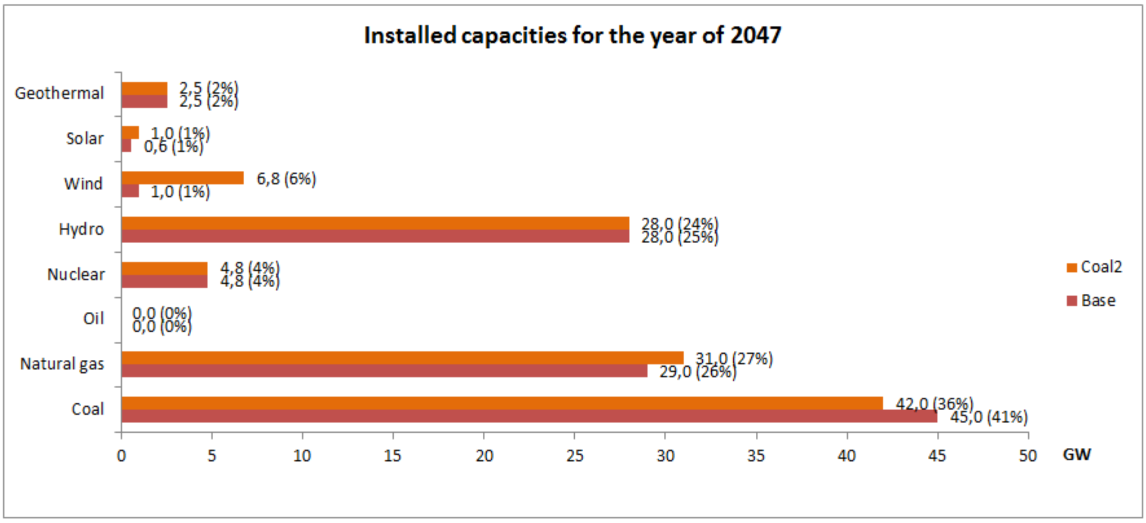

Figure 6.22. Installed capacity amounts and percentages in coal 2 scenario and base scenario for the year of 2047.

Renewable energy based electricity generation has raised to 26%, because of the decreasing installed capacity of coal sources in Coal 2 scenario. In base scenario, their total share is 21%. On the other hand, coal based electricity generation has decreased to 44% while it is 47% in base scenario for the year of 2047.(see figure 6.23)

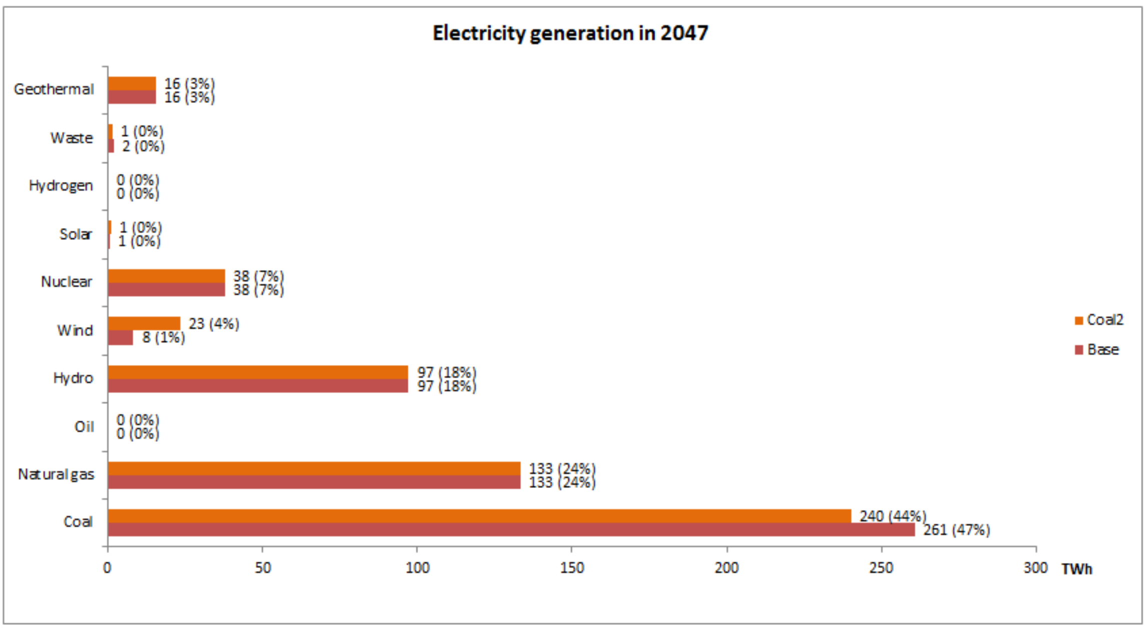

Figure 6.23. Electricity sector generation variables in coal 2 scenario and base scenario for the year of 2047.

6.3. Percent Reduction Scenarios

One of the important targets of this thesis is to control and reduce the amount of CO2 emission in Turkey for the future. In order to analyze this situation, six percent reduction scenarios are applied to the model and results are compared with the results of the base scenario and policy scenarios. In the BUEMS, total CO2 emission of the system is composed with the emission of agriculture, industry, residential, service and transportation sectors and electricity generation. In this part, 10%, 20% and 30% reduction scenarios and their results will be presented. This upper bounds for total CO2 emission amount are decided by the percentages of CO2 emission amounts in the base scenario.

These percent reduction scenarios and their applications are explained below :

Total10: 10% reduction constraints are applied to the model to restrict the total CO2 emission amount of the system beginning from 2022.

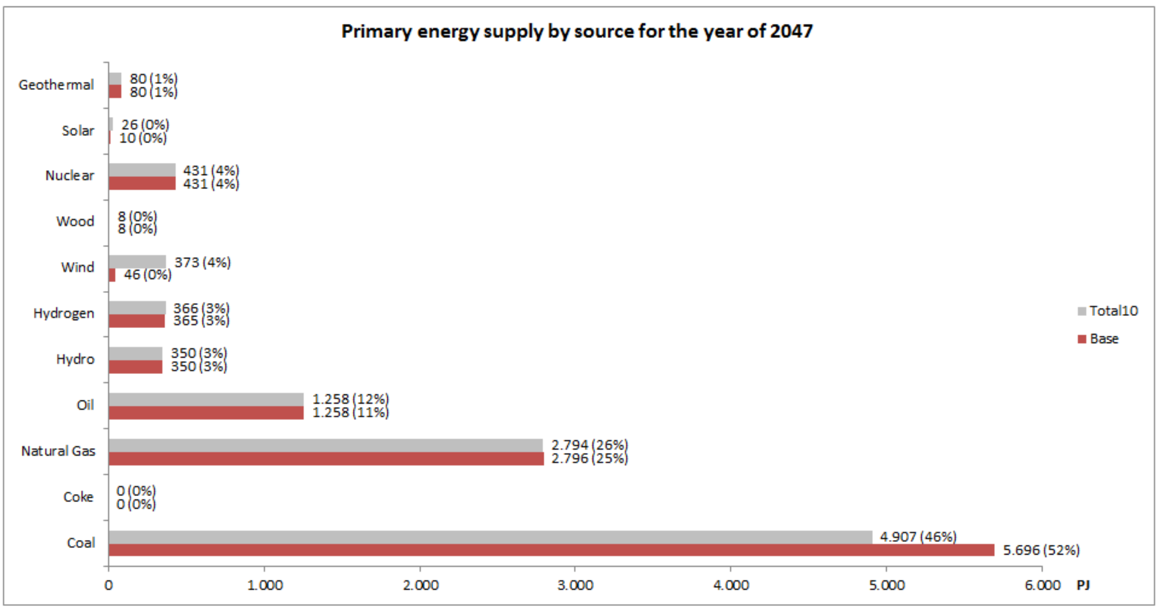

Figure 6.24. Primary energy supply by sources in Total10 scenario and base scenario for the year of 2047.

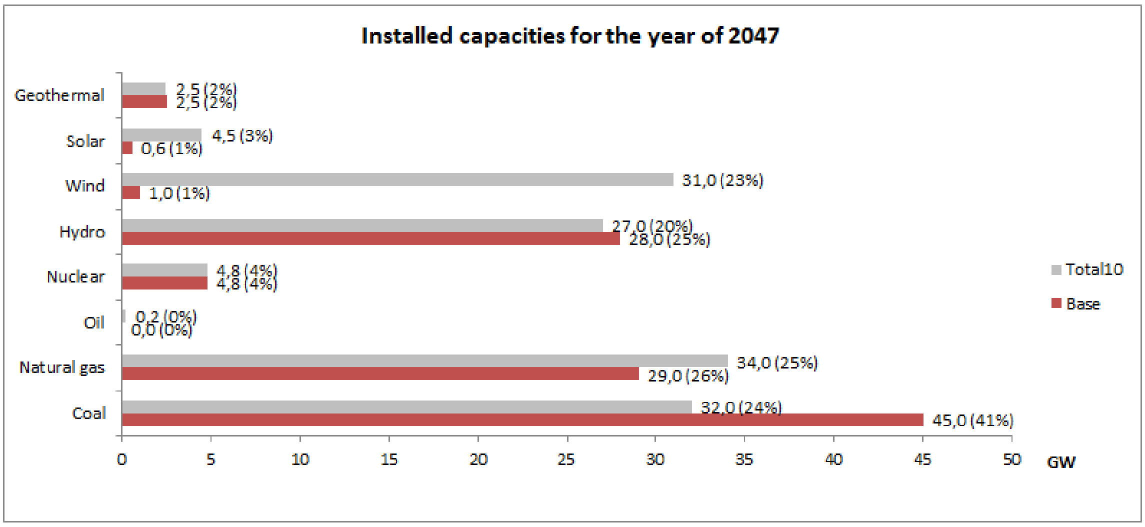

Figure 6.25. Installed capacity amounts and percentages in Total10 scenario and base scenario for the year of 2047.

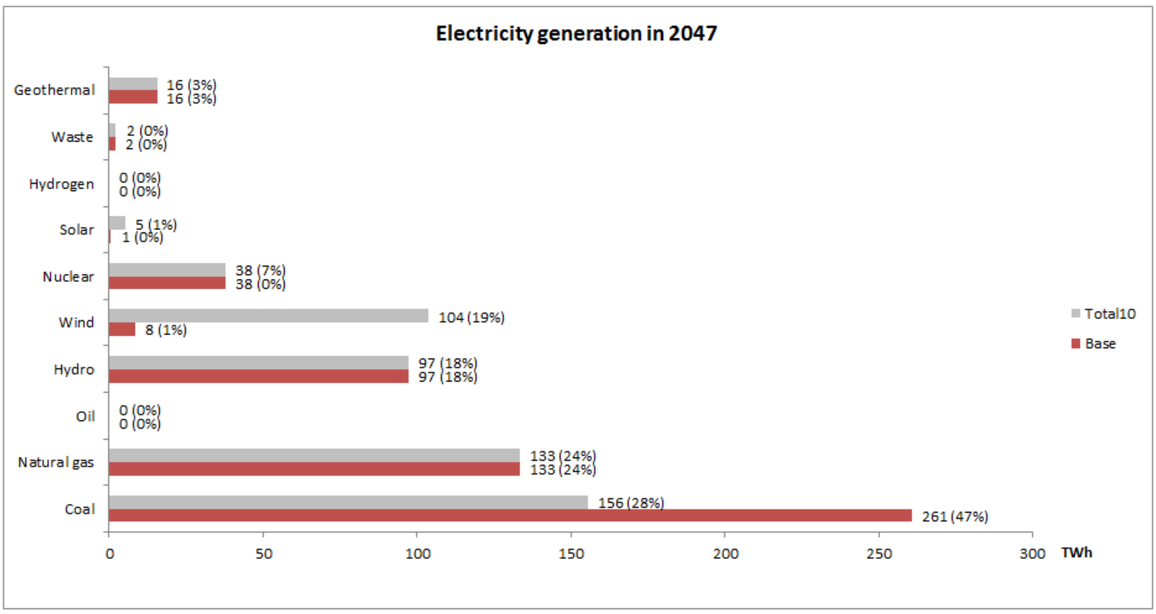

Figure 6.26. Electricity sector generation variables in Total10 scenario and base scenario for the year of 2047.

Total20: 20% reduction constraints are applied to the model to restrict the total CO2 emission amount of the system beginning from 2022.

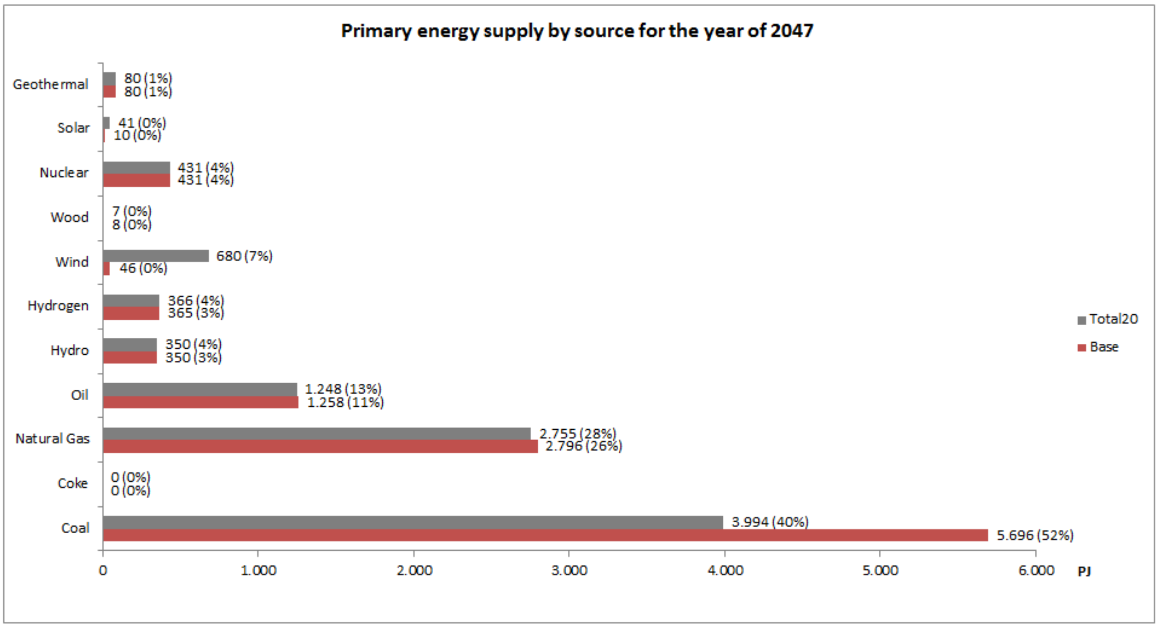

Figure 6.27. Primary energy supply by sources in Total20 scenario and base scenario for the year of 2047.

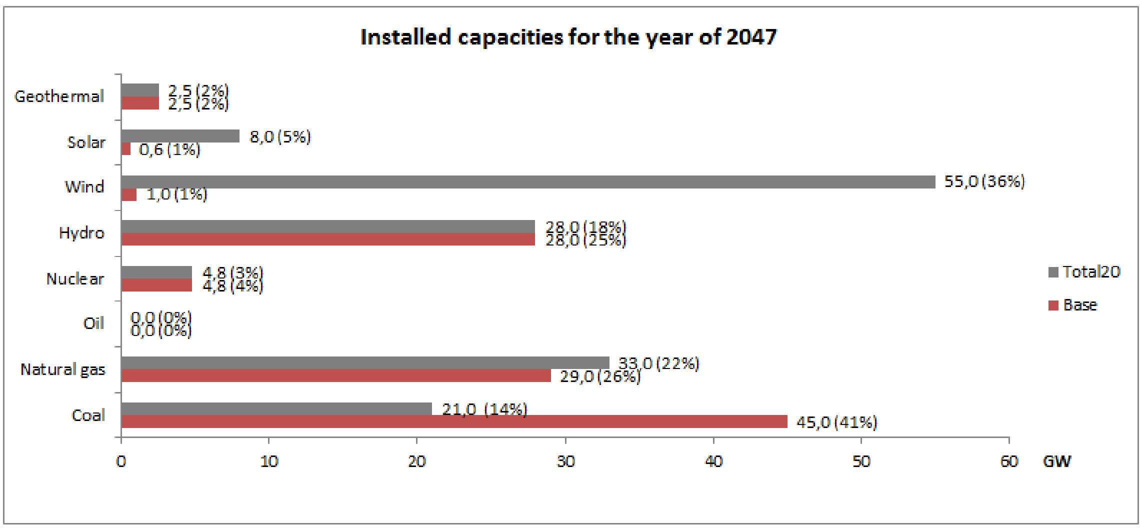

Figure 6.28. Installed capacity amounts and percentages in Total20 scenario and base scenario for the year of 2047.

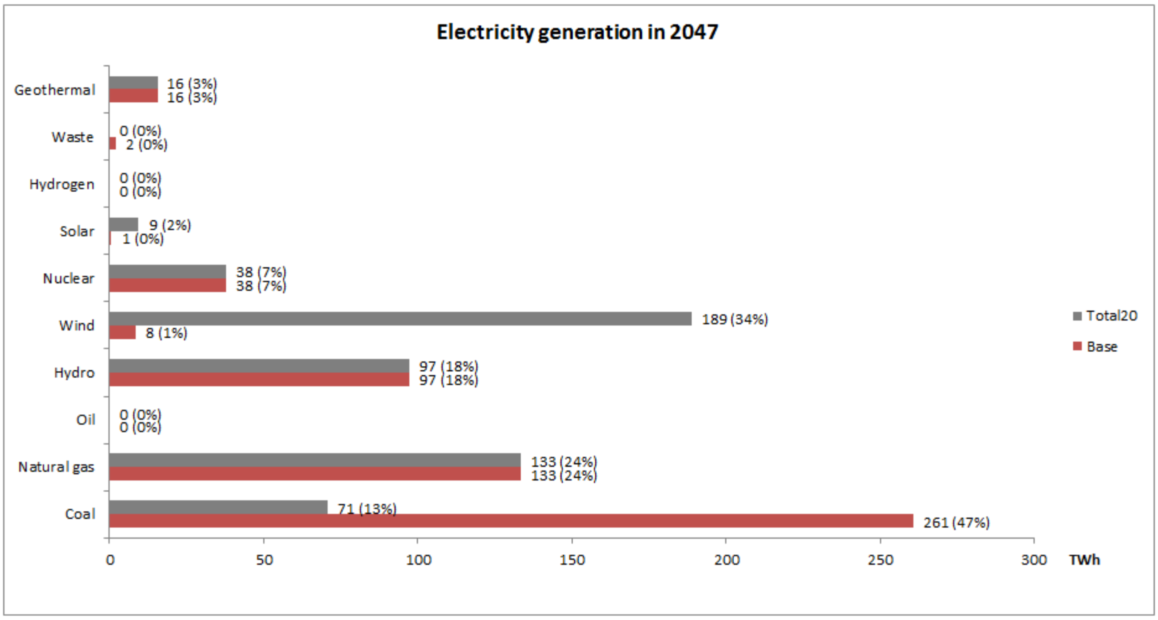

Figure 6.29. Electricity sector generation variables in Total20 scenario and base scenario for the year of 2047.

Total30: 30% reduction constraints are applied to the model to restrict the total CO2 emission amount of the system beginning from 2022.

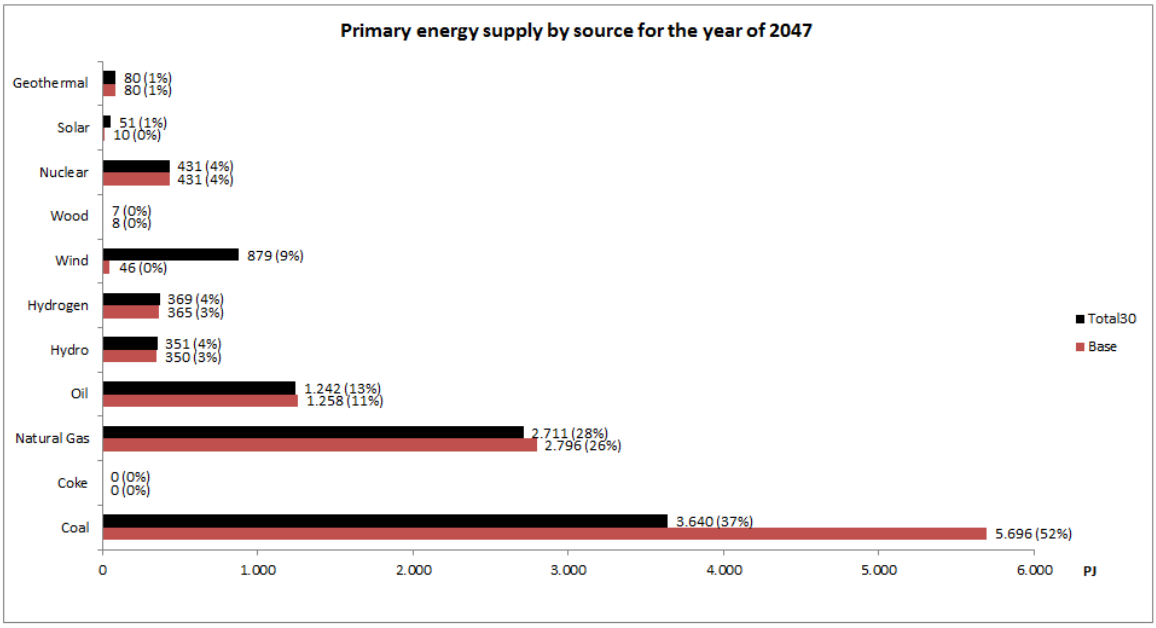

Figure 6.30. Primary energy supply by sources in Total30 scenario and base scenario for the year of 2047.

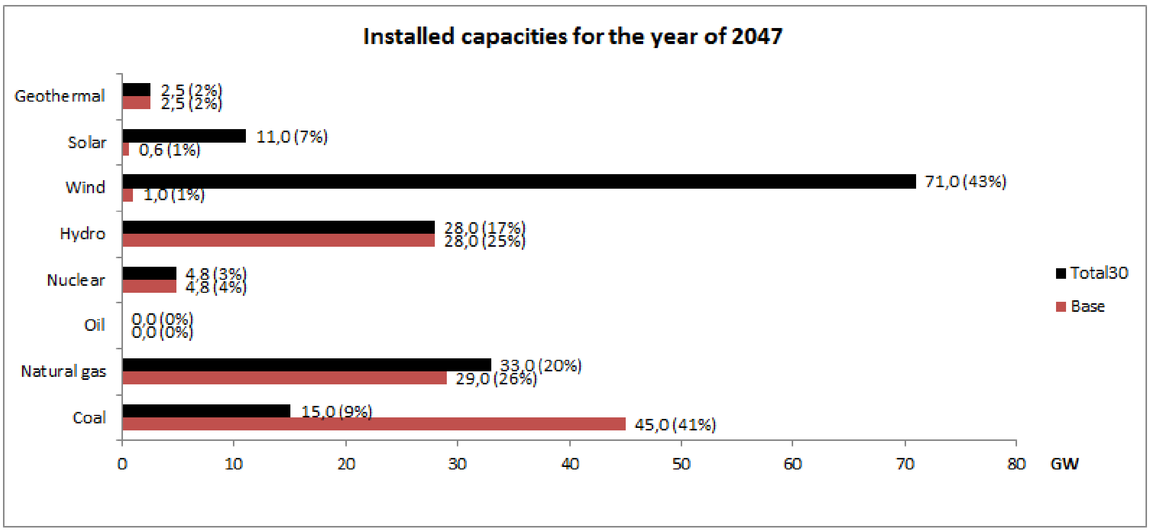

Figure 6.31. Installed capacity amounts and percentages in Total30 scenario and base scenario for the year of 2047.

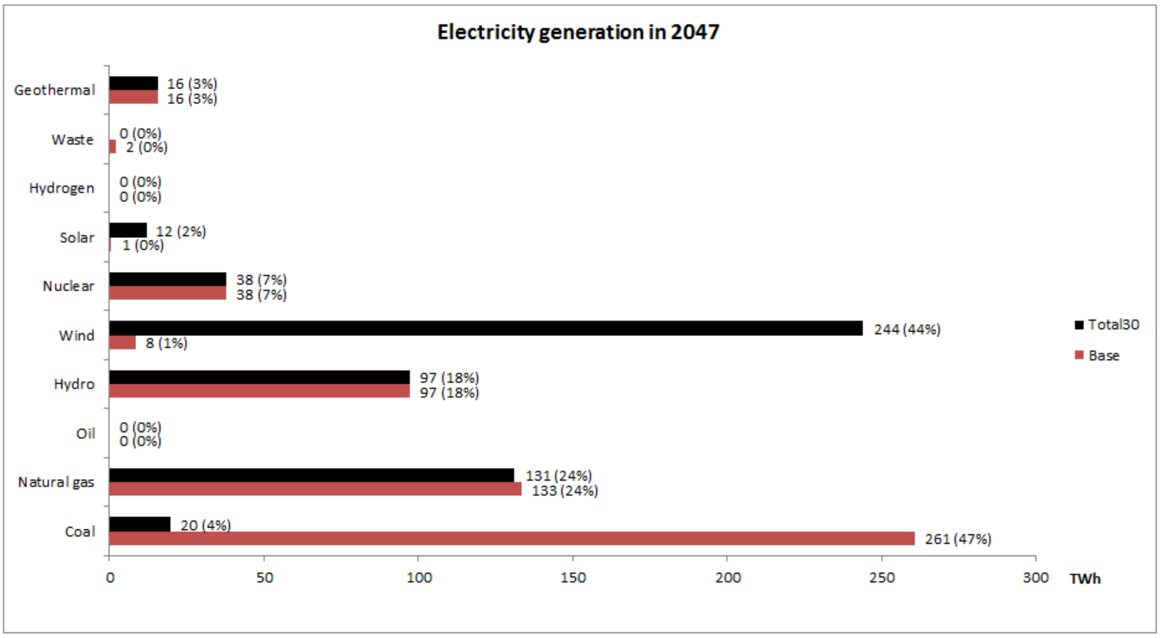

Figure 6.32. Electricity sector generation variables in Total30 scenario and base scenario for the year of 2047.

Sector10: 10% reduction constraints are applied to the model to restrict the CO2 emission amount of each sector separately beginning from 2022.

Sector20: 20% reduction constraints are applied to the model to restrict the CO2 emission amount of each sector separately beginning from 2022.

Sector30: 30% reduction constraints are applied to the model to restrict the CO2 emission amount of each sector separately beginning from 2022.

Situation of the total amount of CO2 emission and unit cost of emission decreasing are the most significant variables comparing to the base scenario in percent reduction scenarios. These variables are useful for analyzing that whether percent reduction scenarios could be alternative to policy scenarios for emission reduction or not.

Change in total CO2 emission levels for all policy and percent reduction scenarios comparing to the base scenario are displayed in the following table:

Table 6.2. Change in total CO2 emission levels in policy and percent reduction scenarios

Scenarios	2017	2022	2027	2032	2037	2042	2047
Wind	0%	0%	0%	-6%	-8%	-9%	-11%
Solar	0%	0%	-1%	-4%	-4%	-7%	-9%
Wind&Solar	0%	-1%	-4%	-9%	-11%	-13%	-15%
Coal 1	0%	0%	0%	-5%	-2%	-1%	-1%
Coal 2	0%	0%	-1%	-6%	-3%	-2%	-3%
Total10	-1%	-10%	-10%	-10%	-10%	-11%	-18%
Total20	-2%	-25%	-20%	-20%	-20%	-22%	-27%
Total30	-4%	-30%	-30%	-30%	-30%	-30%	-32%
Sector10	-8%	-9%	-11%	-8%	-9%	-7%	-7%
Sector20	-13%	-14%	-16%	-16%	-16%	-15%	-14%
Sector30	-19%	-21%	-24%	-24%	-24%	-22%	-21%

According to the Table 6.2, it can be concluded that restriction for total amount of the system gives better results than restriction for each sector separately for the environment. 30% reduction scenario for the total CO2 amount has the best results in association with emission decreasing target. In this scenario, total amount of CO2 emission has decreased 32% by the year 2047.

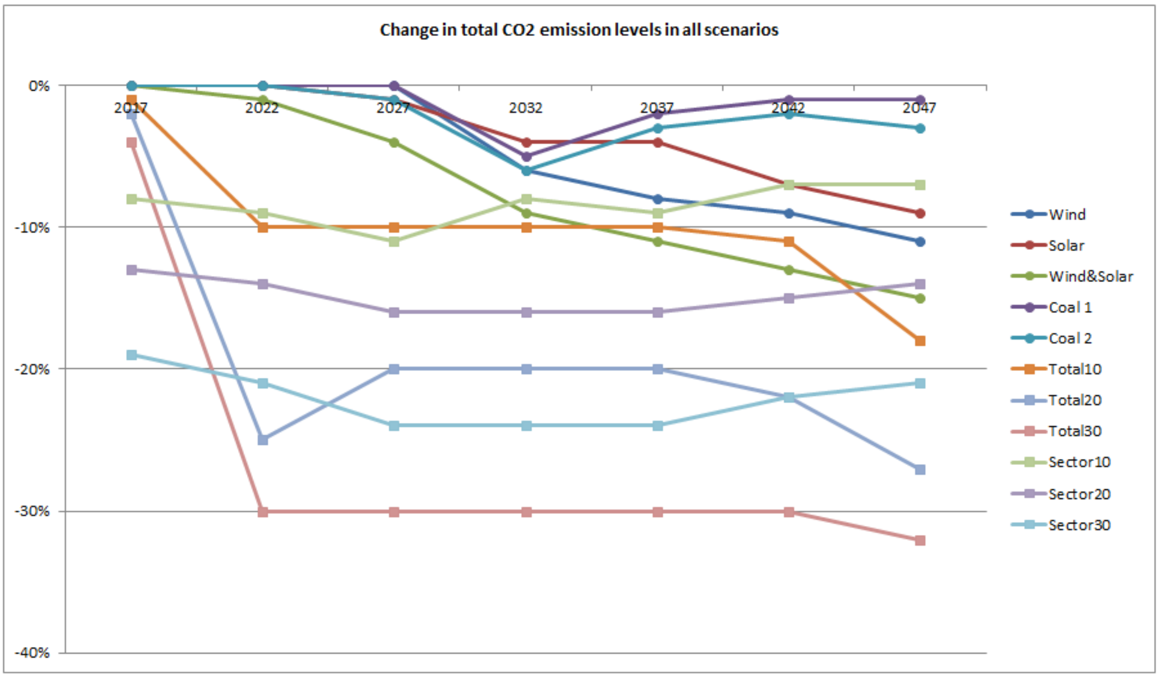

Figure 6.33. Change in total CO2 emission levels in policy and percent reduction scenarios.

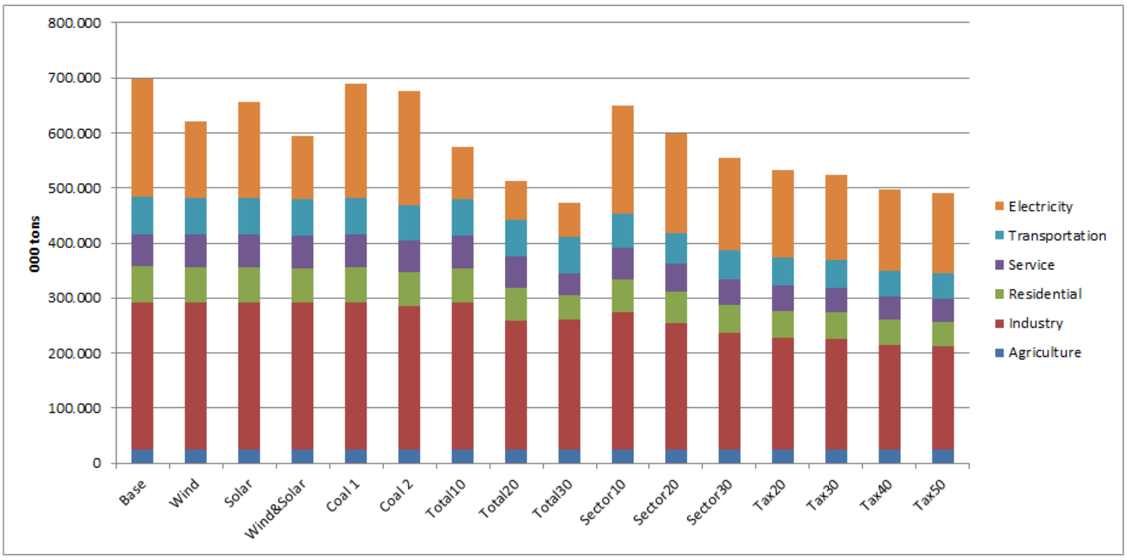

Figure 6.34. CO2 emission levels in base, policy, percent reduction and tax scenarios.

Unit cost of decreasing CO2 amount for each scenario are shown in the following table (in $/ton) :

Table 6.3. Cost of decreasing CO2 amount per unit in policy and percent reduction scenarios ($/ton)

Scenarios	2022	2027	2032	2037	2042	2047
Wind	39	90	21	45	33	31
Solar	71	151	74	88	64	50
Wind&Solar	49	77	49	50	62	51
Coal 1	111	44	16	18	61	98
Coal 2	68	50	15	13	27	27
Total10	30	29	26	29	66	36
Total20	40	47	37	24	46	32
Total30	85	100	86	69	67	48
Sector10	41	56	128	130	178	164
Sector20	33	38	64	68	88	81
Sector30	27	26	43	46	58	54

According to the Table 6.3, it can be concluded that, 20% reduction scenario that applied to whole system has lower cost for reducing CO2 emission among all percent reduction scenarios in the long term.

6.4. Tax Scenarios

There is an alternative policy for government to reduce total CO2 emission amount in the energy sector which is the taxation for each unit CO2 emission. Government can control the total CO2 amount in the energy sector by this kind of economic "punishment" and decrease the environmental pollution for the next years. In this part of the thesis, taxation of 20$, 30$, 40$ and 50$ per ton of CO2 are applied and their results are analyzed. This scenarios will be named as Tax20, Tax30, Tax40 and Tax50 respectively in the following parts.

Change in total amount of CO2 emission and unit cost of emission decreasing are important variables in these scenarios for comparing these scenarios with the base scenario. Following tables show the values for of these variables in each scenario.

Table 6.4. Change in total CO2 emission levels in tax scenarios

Scenarios	2017	2022	2027	2032	2037	2042	2047
Tax20	1%	-9%	-6%	-10%	-14%	-19%	-24%
Tax30	0%	-10%	-8%	-13%	-17%	-20%	-25%
Tax40	-1%	-11%	-10%	-16%	-20%	-24%	-29%
Tax50	-2%	-14%	-13%	-19%	-22%	-25%	-30%

According to results on the Table 6.4, it can be observed that, applying direct punishment for CO2 emission is more efficient than percent reduction scenarios in the matter of decreasing CO2 amounts in general. Futhermore, tax scenarios give better results than reduction scenarios for sectors (Sector10, Sector20, Sector30). In addition, Tax50 scenario and Total30 scenario can be alternative for each other, because they give similar results for decreasing CO2 emission in future.

According to results on the Table 6.5, unit cost for decreasing CO2 emission is higher for tax scenarios comparing to other scenarios as expected, because there is a fixed cost for each ton of CO2 emission in thse scenarios and this situation increases the total cost. Although the tax scenarios gives close results with total percent reduction

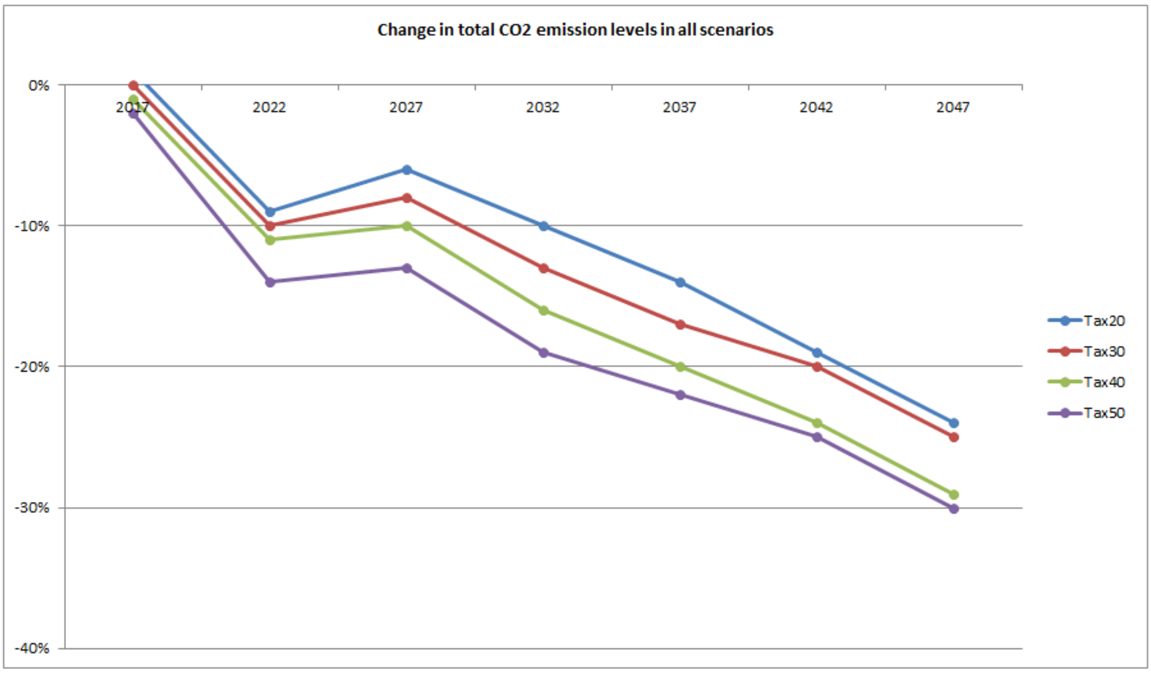

Figure 6.35. Change in total CO2 emission levels in all scenarios.

Table 6.5. Cost of decreasing CO2 amount per unit in tax scenarios ($/ton)

Scenarios	2022	2027	2032	2037	2042	2047
Tax20	235	353	196	145	126	102
Tax30	296	360	220	175	160	125
Tax40	345	378	238	183	180	148
Tax50	350	372	245	206	205	167

scenarios in terms of total amount of CO2 reduction, tax scenarios are more expensive than total percent reduction scenarios. As the tax rate increases, the unit cost of emission reduction rises.

6.5. Energy Consumption and Production

As mentioned in the previous, main aim of building the BUEMS is to find a cost-effective optimal solution for the future years of energy market while supplying all demands of sectors. In this master thesis, the model is used to forecast the use of renewable energy technologies and coal resources in particular. Following figures and explanations show the results of each applied scenario and try to draw a roadmap for optimum investments for required energy technologies.

Following figures show the total amount of electricity production for every scenario and differences of the scenarios besides from base scenario (wind, solar, wind&solar, coal 1, coal 2) with base scenario as percentages for each period of the model.

Table 6.6. Total electricity generation in base and policy scenarios (PJ)

Scenarios	2017	2022	2027	2032	2037	2042	2047
Base	295	323	328	348	397	461	552
Wind	295	323	343	351	403	463	552
Solar	295	331	344	357	402	456	545
Wind&Solar	295	322	354	370	419	471	557
Coal 1	295	324	327	375	405	466	555
Coal 2	295	324	330	379	406	466	555

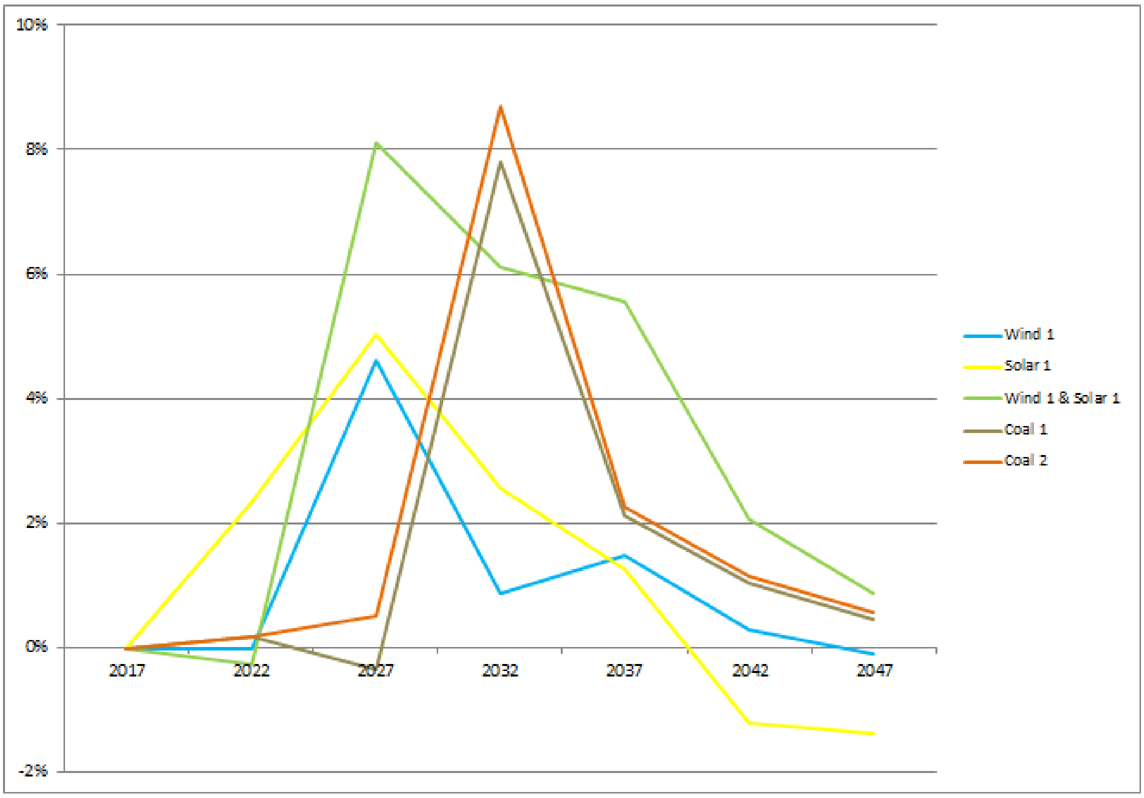

Figure 6.36. Change in total electricity production levels.

The results show us that electricity production processes of the applied scenarios are following similar paths with respect to base scenario.(see table 6.6) and figure 6.36) This situation can also be explained with following figures which show energy consumption of the sectors in each scenario as electricity and non-electricity energy types.

Table 6.7. Total electricity consumption of the end use sectors in base and policy scenarios (PJ/Year)

Scenarios	2017	2022	2027	2032	2037	2042	2047
Base	928	987	1001	1063	1208	1408	1686
Wind	928	987	1045	1068	1218	1415	1687
Solar	928	987	1032	1076	1217	1414	1690
Wind& Solar	928	960	1064	1114	1270	1460	1727
Coal 1	928	987	1001	1123	1232	1431	1708
Coal 2	928	983	1000	1118	1232	1431	1708

Total electricity consumption levels in alternative scenarios are almost at the same level with base scenario, hence in alternative scenarios electricity production shows similar behaviors with the base scenario and it can be concluded that decreasing usage of coal does not affect the electricity production for the future.(see table 6.7)

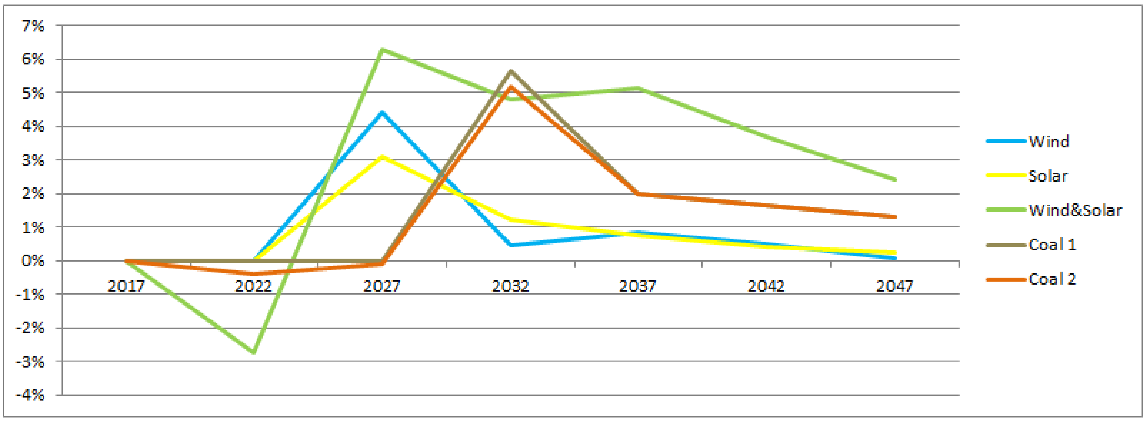

Figure 6.37. Changes in total electricity consumption levels.

Electricity consumption levels show an increase for the year 2027 in renewable energy scenarios with the effect of new investments, but at the end of the time horizon all scenarios come to the level of base scenario.(see figure 6.37)

Table 6.8. Total non-electricity consumption of the end use sectors in base and policy scenarios (PJ/Year)

Scenarios	2017	2022	2027	2032	2037	2042	2047
Base	3799	4124	4632	5204	5677	6204	6978
Wind	3800	4127	4557	5184	5657	6192	6972
Solar	3800	4124	4575	5175	5658	6194	6972
Wind&Solar	3800	4164	4513	5106	5574	6142	6937
Coal 1	3800	4138	4613	5112	5634	6178	6961
Coal 2	3804	4143	4616	5120	5634	6178	6961

As mentioned above, electricity consumption rises for renewable scenarios in 2027 and as a result of that, direct use of non-electricity energy sources decreases as seen in the figure. In addition to that, non-electricity consumption for all policy scenarios also show same behavior with base scenario in future.(see figure 6.38)

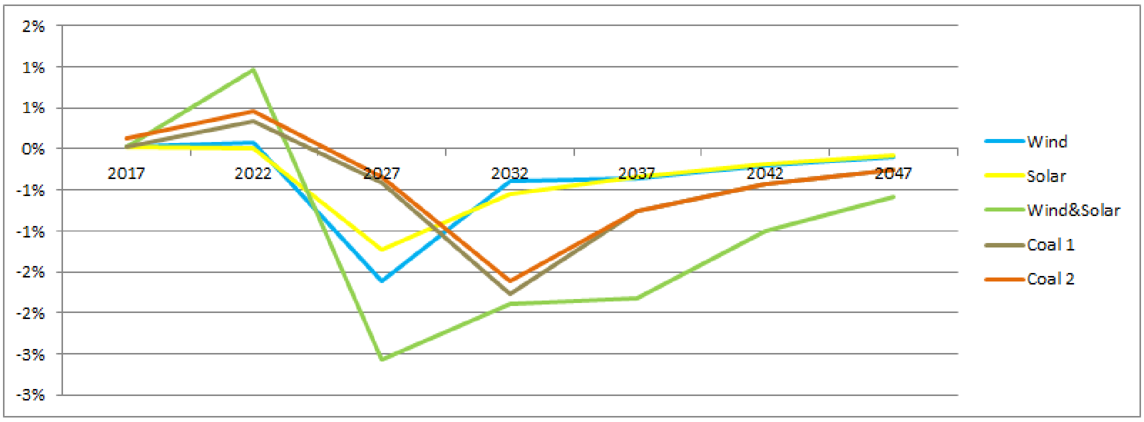

Figure 6.38. Changes in total non-electricity consumption levels in base and policy scenarios

The graphics above show that, demanding sectors are using electricity energy more in the scenarios (wind, solar, wind&solar, coal 1, coal 2) for a 5 year (2027 - 2032) and these sectors are using alternative energy sources in their operations less in this period, in other words non-electricity energy sources. Therefore, we can say that, electricity and non-electricity energy sources for demanding sectors are backing up each other to prevent lack of energy for related operations of sectors.(see figure 6.37 and figure 6.38)

6.6. Total System Cost and CO2 Emission

Undiscounted annual total cost is another important indicator for analyzing the possible results of the. The most important target of the model is minimizing total cost while satisfying all demands of the sectors. Following figure shows the undiscounted annual total cost for scenarios in million $ for each period.

Base scenario has the minimum total cost among all scenarios, because in base scenario there is no restriction for coal usage or new investments for alternative technologies. Since, operating cost of using current coal resources is lower than renewable technologies, base scenario has the highest coal usage and minimum total cost between all applied scenarios. According to YEKA tenders, cost of wind power for new investments is 3.48 cent/kwh, while investments of solar power cost 6.99 cent/kwh. These costs are comparable with the costs in the model. Total cost of the wind&solar scenario is the highest between all scenarios, because this scenarios includes all investments for solar and wind power technologies. Solar scenario is the second highest scenario according to total cost, and wind scenario is the third highest scenario, because cost of solar power is higher than wind power according to the YEKA tenders. Coal 2 and coal 1 scenarios are following this scenarios according to the total cost level.(see table 6.9 and figure 6.39) [28, 29]

Table 6.9. Undiscounted total annual cost for base and policy scenarios (million $)

Scenarios	2017	2022	2027	2032	2037	2042	2047
Base	80417	91296	100009	109210	123580	134870	152970
Wind	80417	91302	100190	109800	125430	136670	155350
Solar	80417	91331	100850	110550	125340	137550	156050
Wind&Solar	80410	91345	101220	111210	126480	139420	158250
Coal 1	80433	91304	100080	109600	123760	135160	153440
Coal 2	80433	91321	100110	109660	123780	135180	153450

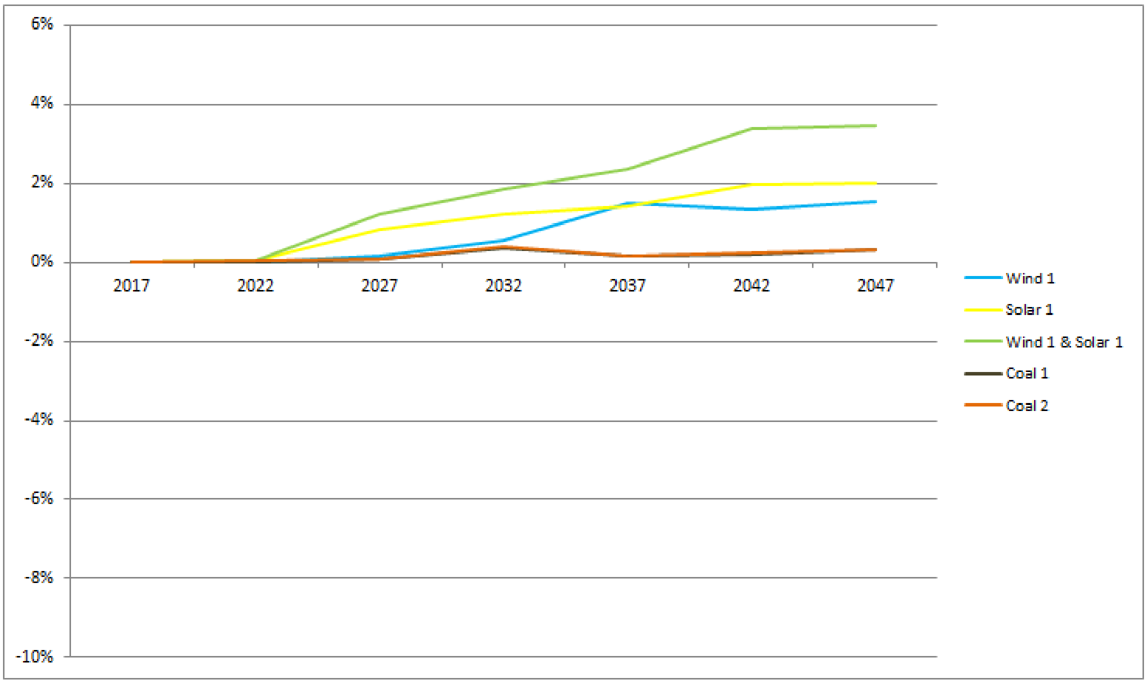

Figure 6.39. Changes in undiscounted total annual cost levels for all scenarios with respect to base scenario.

To minimize environmental pollution deriving from increasing amount of CO2 emission is another significant issue in this master thesis. Consumption of natural resources which causes high amount of CO2 emission should be limited and decreased and sustainable and green energy technologies should be more widespread to avoid environmental air pollution in the future. This idea will be supported by following figures and explanations.

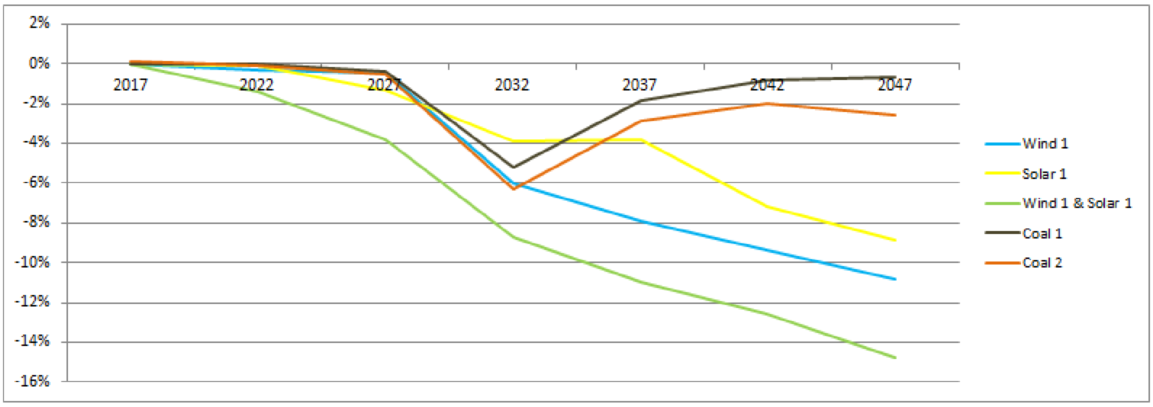

Figure 6.40. Changes in total CO2 emission levels for all scenarios with respect to base scenario.

Each of alternative scenarios has lower CO2 emission level with regard to base scenario, because of less usage of thermal energy sources. Wind & solar scenario has the lowest emission level and looks like the best scenario for a healthy environment as expected, because all renewable investments are taken into consideration in this scenario and a more"green" energy market is composed. (see figure 6.40)

CO2 intensity tables below show the rate of total CO2 emission/total energy supply and total CO2 emission deriving from electricity production/total electricity generation for each policy scenario and period. These tables also show that, wind&solar scenario which has minimum intensity values is the best scenario for the environment. Furthermore, in alternative scenarios (wind, solar, wind&solar, coal1 and coal2) total CO2 emission decreases with respect to the current situation in the future years. (see table 6.10 and table 6.11)

Table 6.10. CO2 intensity of base and policy scenarios for each period (total CO2 emission/total energy supply) (thousand tons/PJ).

Scenarios	2017	2022	2027	2032	2037	2042	2047
Base	62	66	62	64	66	62	63
Wind	62	66	62	61	62	58	59
Solar	62	66	61	86	64	58	59
Wind&Solar	62	64	59	68	59	55	55
Coal 1	62	65	61	59	63	60	60
Coal 2	62	66	62	59	63	60	60

Table 6.11. CO2 intensity of base and policy scenarios for each period (total CO2 emission arising from electricity generation/total electricity generation) (thousand tons/PJ).

Scenarios	2017	2022	2027	2032	2037	2042	2047
Base	133	104	68	71	79	91	107
Wind	134	104	65	50	50	58	71
Solar	133	101	64	58	65	72	91
Wind&Solar	133	97	60	44	43	49	57
Coal 1	133	104	68	70	88	83	105
Coal 2	133	104	69	82	90	94	100

Following table shows the unit cost for decreasing total CO2 emission in each scenario. Since wind&solar scenario has the highest total cost as mentioned above, it has also the biggest unit cost for emission decreasing.(see table 6.12)

Table 6.12. Cost of decreasing total CO2 emission/unit for policy scenarios ($/ton).

Scenarios	2022	2027	2032	2037	2042	2047
Wind	-19	90	21	45	33	31
Solar	71	151	74	88	64	50
Wind&Solar	9	77	49	50	62	51
Coal 1	111	44	16	18	25	28
Coal 2	68	50	15	13	27	27

7. SENSITIVITY ANALYSIS

In this chapter of the master thesis, 16 different scenarios are applied to the model and their effects on change in total electricity production and total cost will be analyzed. These scenarios are listed below:

Sensitivity scenarios for useful energy demand:

Demand +10 : All sectors' demands for electricity and non-electricity energy technologies are increased 10% for each period.

Demand -10 : All sectors' demands for electricity and non-electricity energy technologies are decreased 10% for each period.

Demand +20 : All sectors' demands for electricity and non-electricity energy technologies are increased 20% for each period.

Demand -20 : All sectors' demands for electricity and non-electricity energy technologies are decreased 20% for each period.

Sensitivity scenarios for operational and maintenance costs:

Cost +10 : Fixed and variable operational and maintenance costs are increased 10% for each period.

Cost -10 : Fixed and variable operational and maintenance costs are decreased 10% for each period.

Cost +20 : Fixed and variable operational and maintenance costs are increased 20% for each period.

Cost -20 : Fixed and variable operational and maintenance costs are decreased 20% for each period.

Sensitivity scenarios for efficiency of renewables:

Ren eff +10 : 10% increased efficiency for all renewable energy technologies.

Ren eff -10 : 10% decreased efficiency for all renewable energy technologies.

Ren eff +20 : 20% increased efficiency for all renewable energy technologies.

Ren eff -20 : 20% decreased efficiency for all renewable energy technologies.

Sensitivity scenarios for investment cost of renewables:

Ren inv +10 : 10% increased investment cost for all renewable energy technologies.

Ren inv -10 : -10% decreased investment cost for all renewable energy technologies.

Ren inv +20 : 20% increased investment cost for all renewable energy technologies.

Ren inv -20 : -20% decreased investment cost for all renewable energy technologies.

Ren inv +50 : 50% increased investment cost for all renewable energy technologies.

Ren inv -50 : -50% decreased investment cost for all renewable energy technologies.

Table 7.1. Change in total electricity generation levels in policy and sensitivity analysis scenarios

Scenarios	2022	2027	2032	2037	2042	2047
Demand +10%	13.0%	7.0%	5.0%	7.0%	9.0%	9.0%
Demand -10%	-15.2%	-8.8%	-7.4%	-8.0%	-9.8%	-9.4%
Demand +20%	18.0%	10.1%	15.7%	18.1%	19.2%	19.9%
Demand -20%	-15.2%	-8.8%	-10.6%	-17.1%	-19.1%	-19.5%
Cost +10%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cost -10%	-2.7%	-1.3%	-0.2%	-0.4%	-0.2%	-0.1%
Cost +20%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
Cost -20%	-2.7%	-1.3%	0.6%	0.5%	0.2%	0.2%
Ren eff +10%	0.0%	1.1%	0.8%	0.4%	0.2%	0.1%
Ren eff -10%	0.0%	-0.6%	-0.6%	-0.2%	-0.1%	-0.1%
Ren eff +20%	0.0%	2.2%	1.7%	0.8%	0.4%	0.2%
Ren eff -20%	0.0%	-2.8%	-2.9%	-1.0%	-0.5%	-0.3%
Ren inv +10%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ren inv -10%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ren inv +20%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ren inv -20%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ren inv +50%	0.0%	-1.4%	-2.9%	-1.0%	-0.5%	-0.3%
Ren inv -50%	0.0%	0.0%	0.7%	0.1%	0.2%	0.2%

According to Table 7.1, it can be concluded that, total electricity production is more sensitive to the change in demand amounts rather than other scenarios. In addition to this, changing investment cost of renewable energy technologies in small percentages (10%, 20%) does not have a major effect on electricity generation. On the other hand, changing investment cost of renewable energy technologies by +/-50% changes total electricity generation.

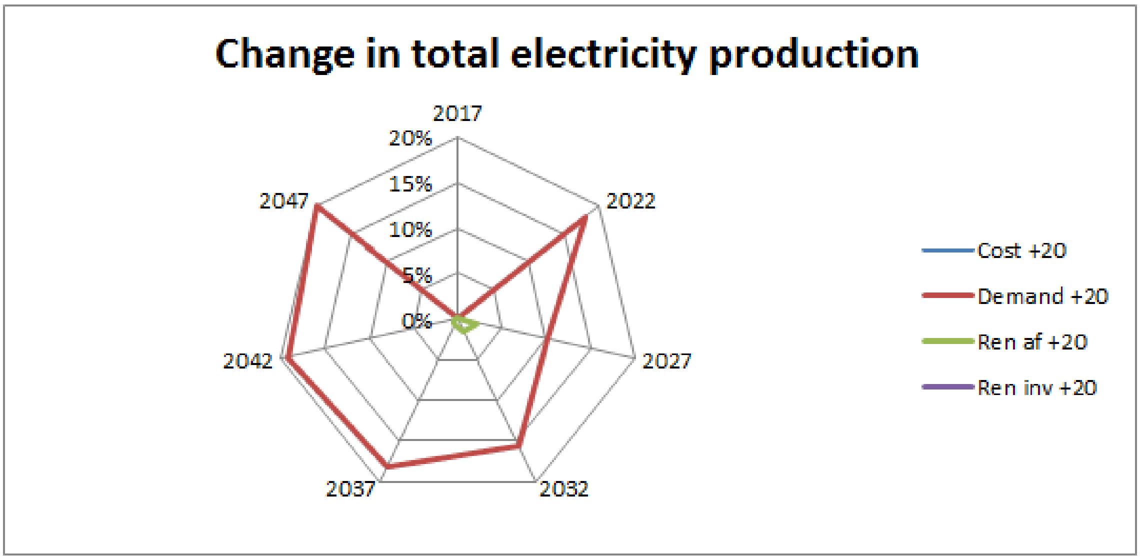

Figure 7.1. Changes in total electricity production

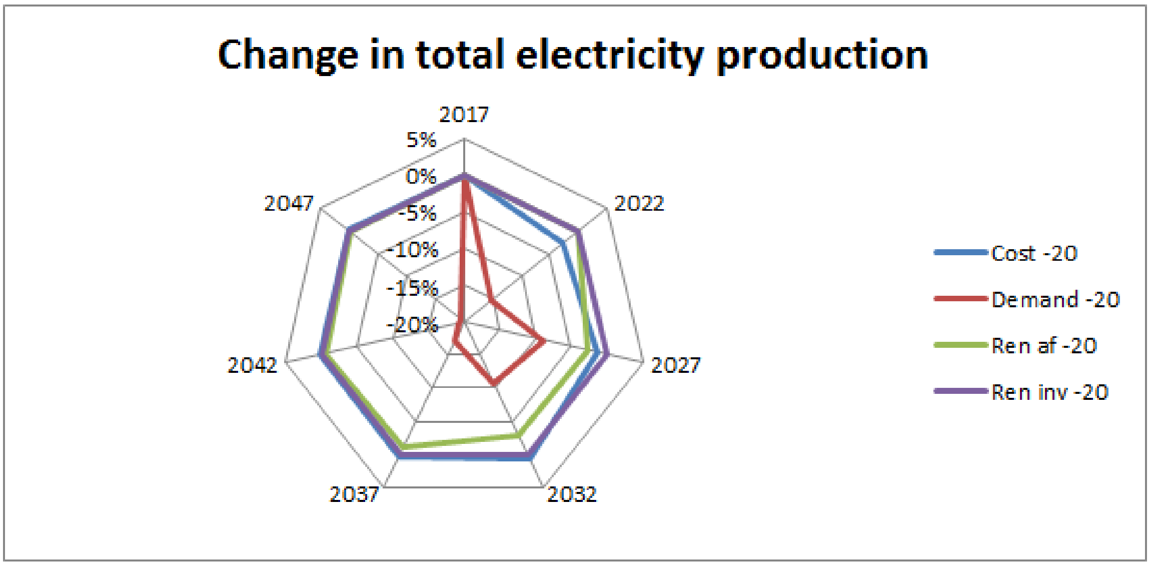

Figure 7.2. Changes in total electricity production

Table 7.2. Change in total cost levels in policy and sensitivity analysis scenarios

Scenarios	2022	2027	2032	2037	2042	2047
Demand +10%	0.0%	7.0%	8.0%	8.0%	8.0%	8.0%
Demand -10%	-6.9%	-7.0%	-7.4%	-8.0%	-8.1%	-8.3%
Demand +20%	16.2%	15.1%	15.4%	16.2%	16.5%	16.8%
Demand -20%	-12.3%	-13.6%	-14.8%	-16.0%	-16.4%	-16.4%
Cost +10%	0.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Cost -10%	-2.6%	-2.5%	-2.5%	-2.4%	-2.4%	-2.3%
Cost +20%	5.3%	5.4%	5.4%	4.9%	4.9%	4.6%
Cost -20%	-5.2%	-5.1%	-5.2%	-4.9%	-4.9%	-4.7%
Ren eff +10%	0.1%	0.1%	0.0%	-0.2%	-0.2%	-0.2%
Ren eff -10%	0.0%	0.1%	0.0%	0.3%	0.3%	0.4%
Ren eff +20%	0.0%	0.1%	0.0%	-0.3%	-0.3%	-0.4%
Ren eff -20%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%
Ren inv +10%	0.3%	0.4%	0.3%	0.1%	0.0%	0.0%
Ren inv -10%	-0.1%	0.0%	-0.1%	-0.3%	-0.2%	-0.1%
Ren inv +20%	0.5%	0.6%	0.4%	0.2%	0.1%	0.1%
Ren inv -20%	-0.3%	-0.2%	-0.3%	-0.4%	-0.3%	-0.2%
Ren inv +50%	1.1%	1.1%	0.8%	0.6%	0.4%	0.2%
Ren inv -50%	-1.0%	-0.8%	-0.9%	-0.9%	-0.5%	-0.4%

According to Table 7.2, total system cost is more sensitive to the change in demand amounts rather than other scenarios.

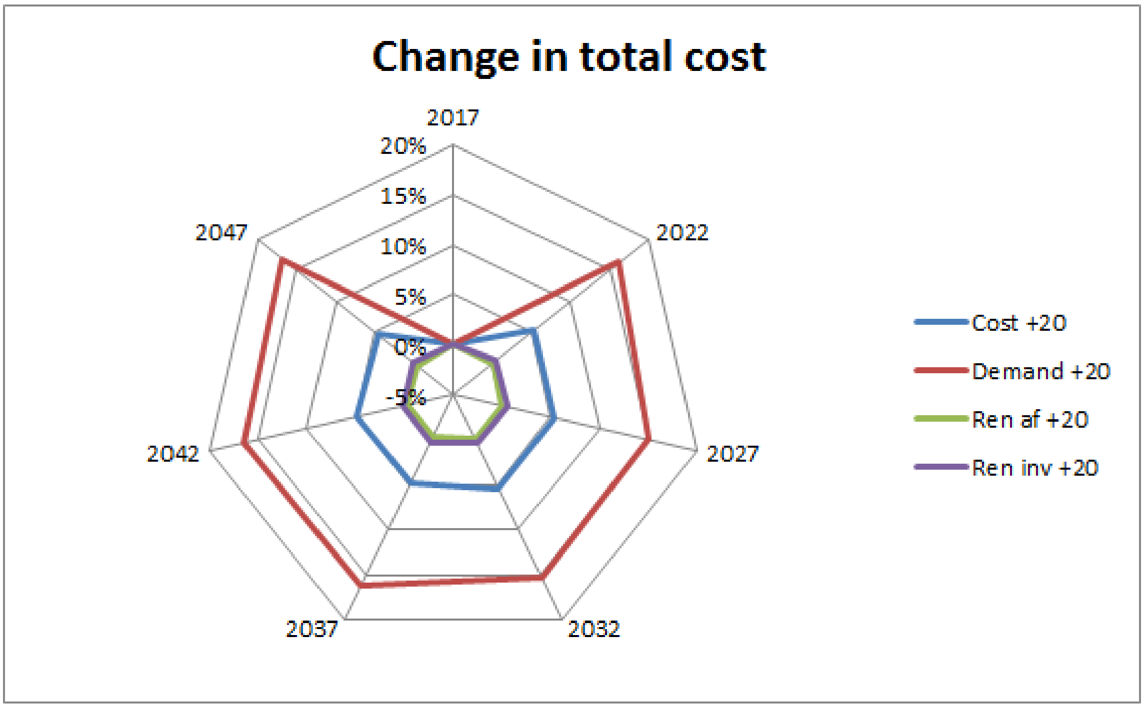

Figure 7.3. Changes in total cost

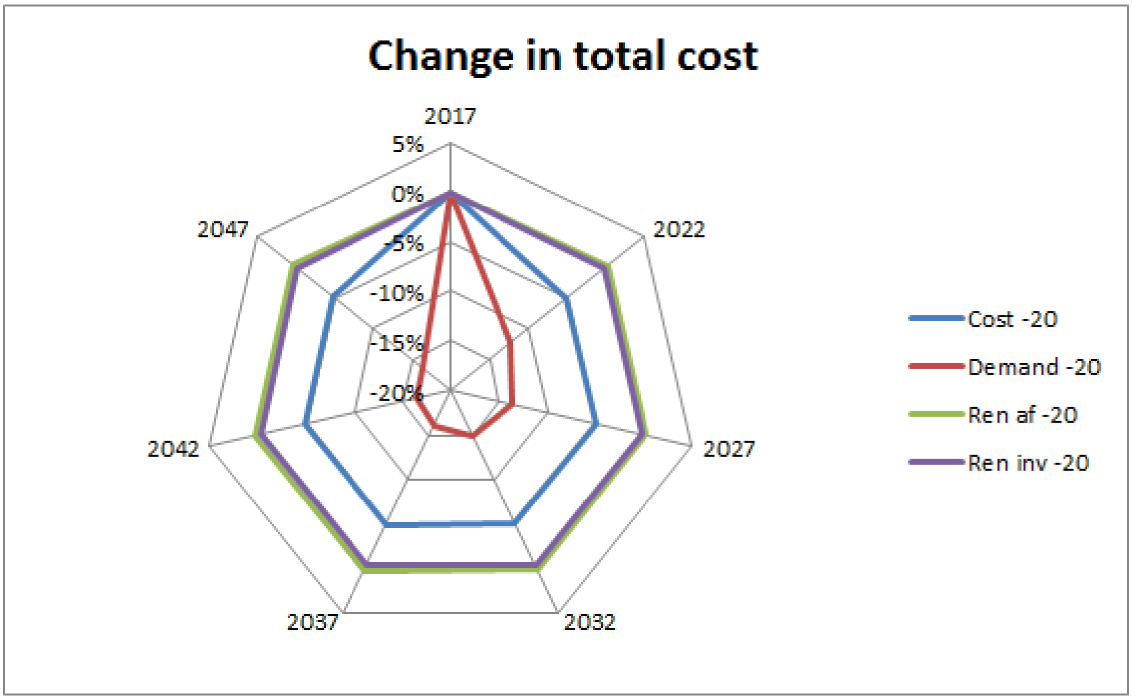

Figure 7.4. Changes in total cost

8. CONCLUSIONS

The main target of this thesis is to evaluate the diffusion prospects for renewable energy technologies and utilization of coal reserves in Turkey under various policy assumptions and to draw a road map for decision-makers. For this purpose, the Boğaziçi University Energy Modeling System BUEMS is calibrated under various scenarios and results are elaborated to evaluate energy and environmental policy implications on Turkey's energy sector until 2047.

BUEMS is a technologically detailed linear optimization model yielding cost-minimizing allocations of energy technologies to satisfy useful energy demand. Furthermore, BUEMS is based on the bottom-up modelling methodology which allows users to analyze implications at high resolution, i.e. sectorally and technologically detailed. By computing technology-specific and sector-specific CO2 emissions, the model features energy and environmental policy analysis. For this purpose, the following scenario groups are defined: (i) base scenario, (ii) five energy policy scenarios, (iii) six CO2 emission reduction (as a percentage of base emissions) scenarios, and (iv) four emission tax scenarios.

In all policy scenarios, the exogenous electric and non-electric energy energy demand of the sectors are kept at the same level. That means, none of the sectors will be affected in terms of supply security if energy investments get dominated by renewable energy and decrease usage of thermal energy sources such as hardcoal and lignite. In other words, alternative "green" energy sources give markets the ability to meet the required demand of the sectors while decreasing total CO2 emissions.

The policy scenario in which both wind and solar power investments are accelerated provides the best results in terms of diminishing CO2 emissions. This scenario has the lowest level of CO2 emissions among all policy scenarios as expected. In this scenario, total CO2 emission decrease by 15% in 2047 with respect to the base scenario. The scenario in which only wind power investments are made is the second best policy scenario in terms of decreasing total CO2 emission, and it results in CO2 emissions decrease by 11% in 2047. The scenario in which only solar power investments are made is the third best option for decreasing CO2 amounts among all policy scenarios, as in this scenario CO2 emissions decrease by 9% in 2047. The scenarios which limit the usage of coal use have similar results for CO2 emission reduction. In these scenarios, total amount of CO2 emissions diminishes by 1-3% per period of 2047. Furthermore, the scenario with 30% emission reduction overall across all sectors gives the best result for decreasing CO2 emission amount between all scenarios as expected, and it provides 32% decrease in CO2 emission by the period of 2047.

On the other hand, marginal abatement cost is the most important indicator to compare scenarios economically. The scenarios which remove the usage of imported coal in electricity generation and the scenario in which only wind power investments are made have the minimum two marginal abatement cost values, 27$/ton and 31 $/ton respectively, among all policy scenarios in 2047. This number is 51$/ton for the scenario in which both wind and solar power investments are made and 50$/ton for the scenario in which only solar power investments are made. On the other hand, 10% and 20% percent reduction scenarios indicate alternative economic ways for CO2 emission reduction. Taxation policy for CO2 emissions can be effective in reducing emissions also, however this policy is not an economic way for the market. For the scenario in which 50$ tax for per ton of CO2 emission is applied, the unit cost for decreasing CO2 emission is 167$/ton in year 2047. Percent reduction scenarios indicate more efficient ways for CO2 emission reduction. The unit cost for decreasing CO2 emission is 48$/ton in the scenario with 30% reduction and it gives better results than the 50$ tax scenario in terms of CO2 emission reduction (32% for year 2047).

Results of the percent reduction scenarios indicate a significant reduction of CO2 emissions in the electricity sector when compared to others. Similar to the renewable energy scenarios in which the diffusion of renewable energy technologies is accelerated, in direct percent reduction scenarios the share of renewables in electricity generation is considerably increased, especially wind power. On the other hand, the share of coal in electricity generation is decreased in the percent reduction scenarios as would be expected. It can be concluded from these results, if more investments are made in renewable energy technologies and utilization of coal sources is decreased, than the aim of decreasing CO2 emissions shall be more affordable and attainable.

It can be concluded that, making investments in renewable energy gives better results for the environment although they increase the total cost by 2-3% and in these scenarios demanding sectors can benefit from thermal energy sources directly by their energy technologies to prevent possible lack of energy for the operations. Thus, it can be concluded that, investing in renewable energy technologies is beneficial for the market and in this way usage of thermal sources decreases automatically. On the other hand, the reduction scenario with 30% reduction overall yields the best way to decrease total amount of CO2 emission and it gives the best results for a preferable environment, also it is an economic way for the market.

In a nutshell, it can be suggested from model results to keep up with the worlwide developments and make more investments in renewable energy technologies for creating a sustainable future for all living creatures. Even though, these investments increases the total energy cost in the short-run, they become cost-effective in the long run as there are no fuel costs, and they decelerate emission of greenhouse gases and create new job opportunities.

Further analysis can be conducted by changing values of different variables and technologies to analyze other alternative energy scenarios for Turkey energy market and these studies with various scenarios of renewable sources will be helpful to display the future of renewable energy and coal utilization in Turkey. By increasing the number of these studies and creating alternative"green" energy policies, a healtier and livable world for all living creatures will be possible in the future.

REFERENCES

1. "*İstatistiksel Tablolar ve Dinamik Sorgulama*", https://www.tuik.gov.tr/PreTablo.do?alt_id=1029, accessed: at February 2018.

2. "*Renewables Statistics*", https://www.iea.org/statistics/topics/renewables/, accessed: at June 2018.

3. "*Seragazı Emisyon İstatistikleri, 1990-2015*", http://www.tuik.gov.tr/PreHaberBultenleri.do?id=24588, accessed: at February 2018.

4. Kumbaroglu, G., "Environmental taxation and economic effects: a computable general equilibrium analysis for Turkey", *Journal of Policy Modeling*, Vol. 25, pp. 795–810, 2003.

5. "*Kömür*", http://www.enerji.gov.tr/tr-TR/Sayfalar/Komur, accessed: at February 2018.

6. "*Kurulu Güç*", https://www.teias.gov.tr/tr/i-kurulu-guc, accessed: at February 2018.

7. Atilgan, B. and A. Azapagic, "Energy challenges for Turkey: Identifying sustainable options for future electricity generation up to 2050", *Sustainable Production and Consumption*, Vol. 12, pp. 234–254, 2017.

8. Kilickaplan, A., D. Bogdanov, O. Peker, U. Caldera, A. Aghahosseini and C. Breyer, "An energy transition pathway for Turkey to achieve 100% renewable energy powered electricity, desalination and non-energetic industrial gas demand sectors by 2050", *Solar Energy*, Vol. 18, pp. 218–235, 2017.

9. Günkaya, Z., A. Özdemir, A. Özkan and M. Banar, "Environmental Performance of Electricity Generation Based on Resources: A Life Cycle Assessment Case Study

in Turkey", *Sustainability*, Vol. 8, 2016.

10. Ayvaz, B. and A. Kuşakçı, "Electricity consumption forecasting for Turkey with nonhomogeneous discrete grey model", *Energy Sources, Part B: Economics, Planning, and Policy*, Vol. 12, pp. 260–267, 2017.

11. Boran, F., "A new approach for evaluation of renewable energy resources: A case of Turkey", *Energy Sources, Part B: Economics, Planning, and Policy*, Vol. 13, pp. 196–204, 2018.

12. Tsai, S., Y. Xue, J. Zhang, Q. Chen, Y. Liu, J. Zhou and W. Dong, "Models for forecasting growth trends in renewable energy", *Renewable and Sustainable Energy Reviews*, Vol. 77, pp. 1169–1178, 2017.

13. Lee, C. and S. Huh, "Forecasting new and renewable energy supply through a bottom-up approach: The case of South Korea", *Renewable and Sustainable Energy Reviews*, Vol. 69, pp. 207–217, 2017.

14. Arrastía-Avila, M. and L. Glidden, "Cuba's Energy Revolution and 2030 Policy Goals: More Penetration of Renewable Energy in Electricity Generation", *International Journal of Cuban Studies*, Vol. 9, pp. 73–90, 2017.

15. Spiecker, S. and C. Weber, "The future of the European electricity system and the impact of fluctuating renewable energy – A scenario analysis", *Energy Policy*, Vol. 65, pp. 185–197, 2014.

16. Connolly, D., H. Lund and B. Mathiesen, "Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union", *Renewable and Sustainable Energy Reviews*, Vol. 60, pp. 1634–1653, 2016.

17. Yang, C., S. Yeh, S. Zakerinia, K. Ramea and D. McCollum, "Achieving California's 80% greenhouse gas reduction target in 2050: Technology, policy and sce-

nario analysis using CA-TIMES energy economic systems model", *Energy Policy*, Vol. 77, pp. 118–130, 2015.

18. Amorim, F., A. Pina, H. Gerbelova, P. Silva, J. Vasconcelos and V. Martins, "Electricity decarbonisation pathways for 2050 in Portugal: A TIMES (The Integrated MARKAL-EFOM System) based approach in closed versus open systems modelling", *Energy*, Vol. 69, pp. 104–112, 2014.

19. Chen, W., Z. Wu, J. He, P. Gao and S. Xu, "Carbon emission control strategies for China: A comparative study with partial and general equilibrium versions of the China MARKAL model", *Energy*, Vol. 32, pp. 59–72, 2007.

20. Comodi, G., L. Cioccolanti and M. Gargiulo, "Municipal scale scenario: Analysis of an Italian seaside town with MarkAL-TIMES", *Energy Policy*, Vol. 41, pp. 303–315, 2012.

21. Gunel, G., *Analysis of CO2 Emission Reduction, Energy and Economy Interactions in Turkey Using BUEMS-MACRO*, Master's Thesis, Boğaziçi University, 2018.

22. Isik, M., *Energy Economy and Environment Integrated Large Scale Modeling and Analysis of the Turkish Energy System*, Ph.D. Thesis, Boğaziçi University, 2016.

23. "*Türkiye Rüzgar Enerjisi Potansiyel Atlası*", `http://www.yegm.gov.tr/YEKrepa/REPA-duyuru_01.html`, accessed: at June 2018.

24. "*Türkiye Güneş Enerjisi Potansiyel Atlası*", `http://www.yegm.gov.tr/MyCalculator/Default.aspx`, accessed: at June 2018.

25. "*YEKDEM*", `http://www.yegm.gov.tr/yenilenebilir/YEKDEM.aspx`, accessed: at December 2018.

26. "*Denge Tablolari*", `http://www.eigm.gov.tr/tr-TR/Denge-Tablolari/Denge-Tablolari`, accessed: at February 2018.

27. "*Tarım ve Gıda*", http://tarim.kalkinma.gov.tr/tarim/, accessed: at February 2018.

28. "*YEKA İhaleleri Rüzgar*", http://www.hurriyet.com.tr/ekonomi/son-dakika-yeka-ihalesinin-kazanani-belli-oldu-40539083, accessed: at February 2018.

29. "*YEKA İhaleleri Güneş*", https://www.ntv.com.tr/ekonomi/dev-gunes-santrali-ihalesini-kazanan-belli-oldu,nr0quwslBkeEOFGpBSdDSg, accessed: at February 2018.