Water and Carbon Footprints of Turkish Energy Development Plans until 2030

A thesis submitted to the
Graduate School of Natural and Applied Sciences

by

Mohammad Abdullah Shaikh

in partial fulfillment for the
degree of Master of Science

in

Industrial and Systems Engineering

İstanbul Şehir University

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Industrial and Systems Engineering.

APPROVED BY:

Assoc. Prof. Dr. Bahadir Tunaboylu ....
(Thesis Advisor)

Assist. Prof. Dr. Hatice Tekiner Mogulkoc ....

Assist. Prof. Dr. Gokhan Kirkil ....

This is to confirm that this thesis complies with all the standards set by the Graduate School of Natural and Applied Sciences of İstanbul Şehir University:

DATE OF APPROVAL: 16 October 2017

SEAL/SIGNATURE:

Declaration of Authorship

I, Mohammad Abdullah SHAIKH, declare that this thesis titled, 'Water and Carbon Footprints of Turkish Energy Development Plans until 2030' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date: October 16, 2017

"If you can't measure it, you can't improve it."

-Peter Drucker

Water and Carbon Footprints of Turkish Energy Development Plans until 2030

Mohammad Abdullah Shaikh

Abstract

Effects of renewable and non-renewable energy on Water resources are mostly overlooked even though substantial consideration about the impacts of energy sources are given on carbon footprint reduction and energy security aspects. In this thesis, a framework for water and carbon footprint analysis is developed as an attempt to estimate the current and future trends of water consumption and withdrawal along with carbon emissions by electricity production scenarios, considering the national energy development plans. Furthermore, this research work also produced a decision support tool to determine water consumption, water withdrawal and carbon emissions based on the three different scenarios, keeping in view the overall energy mix under each scenario. Scenarios developed are Business-As-Usual (BAU), Official Governmental Plan (OGP), and Renewable Energy-Focused Development Plan (REFDP) and Turkish electric power industry is selected as a case study in this thesis. Results show that large amount of water is used by sources of electricity such as hydro-electricity and biomass, which are considered more environmental friendly as well as renewable forms of energy. By year 2030, average water consumption under OGP scenario is likely to be around 8.1% and 9.6% less than that of BAU and REFDP scenario. Meanwhile, average water withdrawal by the energy mix in year 2030 of REFDP is estimated to be around 46.3% and 16.9% less than that of BAU and OGP scenario. Likewise, carbon emissions by year 2030 based on the BAU scenario are anticipated to be 24% higher than OGP and 39% higher than REFDP scenario. Through a correlation analysis, we found out that carbon emissions and water usage are strongly correlated in BAU in comparison with OGP and REFDP, therefore we can conclude that carbon friendly energy sources will result in less water consumptions and withdrawals â especially under REFDP scenario.

Keywords: Decision support tool; Electricity production; Energy policy; Scenario analysis; Water and carbon footprint;

2030 Yılına Kadar Olan Türkiye Enerji Kalkınma Planında Su ve Karbon Ayak-izi

Mohammad Abdullah SHAIKH

Öz

Enerji politikalarında yer alan yenilenebilir ve yenilenebilir olmayan kaynakların enerji güvenliği ve karbon salınımının azaltılması yönleri ön planda tutulurken, su kaynaklarına olan etkisine yeterli önem atfedilememektedir. Bu tezin amacı, su ve karbon ayak izi analizlerinin yapılacağı bir sistemin geliştirilmesi ile ulusal enerji kalkınma planlarında yer alan su tüketimi ve enerji üretimi sektörlerinin gelecek durumlarını tahmin edebilmektir. Bu motivasyonla, Türkiye elektrik endüstrisi vaka çalışması olarak seçilmiçstir ve su tüketimini belirlemek için bir karar destek aracı geliştirilmiştir. Bu karar destek aracı Geleneksel İşletme(Gİ), Resmi İdari Plan (RİP) ve Yenilenebilir Enerji Odaklı Kalkınma Planı (YEOKP) isimli 3 senaryoyu içermektedir. Elde edilen sonuçlara göre yenilenebilir enerji kaynaklarının en fazla tükettiği kaynak su olarak belirlemmiştir. RİP'e göre 2030 yılı için tahmin edilen enerji senaryosunda ortalama su tüketimi YEOKP'dan 8,1% ve Gİâden 9,6% kadar daha düşüktür. Diğer taraftan, sonuçlar YEOKP senaryosundan kaynaklanan su çekilmelerinin diğer senaryolar olan Gİ'den 46,3% ve RİP'den 16,9% az olacağını göstermektedir. Gİ'den kaynaklanan karbon salınımları RİP'ten 24% oranında ve YEOKP'den 39% oranında daha yüksek öngörülmüştür. Diğer senaryolara kıyasla Gİ senaryosunda karbon salınımları ve su tüketimleri güçlü biçimde doğru orantılıdır ve bu sebeple karbon dostu enerji kaynakları daha az su tüketilmesine ve suyun yeryüzünden daha az çekilmesine vesile olacaktır.

Anahtar Sözcükler: Su ve karbon ayak izi, Elektrik üretimi, Senaryo analizi, Enerji politikası, Karar destek aracı.

Dedicated to my parents and siblings.

Acknowledgments

I am grateful to Almighty Allah for all His blessings and easing my way through the successful completion of this research work. He showed me ways out of difficult times and provided me with courage and ability to dealt difficult times during the course.

My heartiest gratitude to my thesis advisor, Professor Dr. Bahadir Tunaboylu, for his moral and technical support. He backed me up in hard times and is always a moral boosting personality. Thank you very much Professor.

I would also like to thank Dr. Hatice Tekiner Mogulkoc for being my academic advisor during the course of my studies. I also had this opportunity to assist her for several courses. I have enjoyed working with her and have learned tremendously. Her mentorship has always been helpful and I am honoured to have her as one of my teachers.

Special thanks to my external supervisor, Professor Gokhan Kirkil for collaborating with us throughout this research. His valuable suggestions and feedbacks were indeed very helpful.

Thanks to Dr. Murat Kucukvar and Dr. Nuri Onat as well, for motivating me in this field of study. I am thankful to them for their wholehearted support and incredible guidance at every step of my research work and their honest critical analysis of my work. Their efforts are enormous behind all my research and this work would not even have existed without them.

I would like to acknowledge my friends, who have always stood by my side, particularly in difficult and stressful times. I specially want to thank Taha and Ali for always being my first support in Istanbul, Istanbul Sehir University and during the whole course of this research and my studies. Sajid, Rashad, Ndricim and Yassir: thanks for being amazing office mates. I am in debt because of your unconditional support and your sincere advises whenever I required. Nabeel, Toqeer, Arsalan, Sikandar, Rafay; thank you very much for being such great friends and for easing my way through my research. Presence of my friends around me was a great assistance.

Most importantly, I want to acknowledge my parents. I cannot thank them enough. Their encouragement and support have always kept me motivated to pursue my ambitions. I am extremely blessed to be parented by the best pair in this world. All I am today is because of them. My brother, Anas, deserves special thanks for covering for me in my absence back home despite his studies and other endeavors - Thank you very much to all of you.

Contents

List of Figures

List of Tables

Abbreviations

BAU	**B**usniess **A**s **U**sual
OGP	**O**fficial **G**overnmental **P**lan
REFDP	**R**enewable **E**nergy **F**ocused **D**evelopment **P**lan
UNDP	**U**nited **N**ations **D**evelopment **P**rogram
GHG	**G**reen **H**ouse **G**as
CO_2	**C**arbon **D**ioxide
IEA	**I**nternational **E**nergy **A**gency
ARIMA	**A**uto **R**egressive **I**ntegrated **M**oving **A**verage
kWh	**k**ilo **W**att **h**our
PV	**P**hoto **V**olatic
NREL	**N**ational **R**enewable **E**nergy **A**gency
EGS	**E**nhanced **G**eohtermal **S**ystems

Chapter 1

Introduction

1.1 Introduction

According to the United Nations Development Program (UNDP) Human Development Report [1] , every continent is expected to be hit by water scarcity. Around one-fifth of the world's population is directly affected by water shortage and 500 million people are at risk of it [2]. Electric power generation can cause substantial greenhouse gas (GHG) emissions as well as water consumption and withdrawals. Although GHG emissions due to electric power generation is extensively studied, its impacts on water resources have been overlooked. Majority of the power plants use fresh water, which is already a scare resource [3]. The energy sector is vulnerable to water resource availability as substantial water is required by both fossil and renewable energy sources [4]. This water requirement is in the form of water consumption and water withdrawal and must be considered when studying the environmental impacts of energy generation and in finding a pathway for controlling, and minimizing the environmental damages of development [5]. Measures to optimize the usage of global water resources are also in order when framing new policies and setting goals [6].

Water shortage and Greenhouse Gas (GHG) emissions are global concerns and serious threats to human security [7, 8]. More than 50% of the world's population is expected to live in water scarce areas in the next 50 years [9]. Due to an increase in energy demand/supply as well as a rise in the adoption of water-intensive energy sources such as bio-fuels, a rise of 85%, from the current water usage, is expected in water usage for energy production until 2025 [10]. On the other hand, water is expected to become scarcer in the future because of the increase in the demand for food, energy and water associated with the projected population increase. By 2050, overall increase in water use is expected to be between 62% to 76% [11]. Furthermore, Carbon Dioxide (CO_2) is the basic constituent of GHGs, accountable for more than 60% of greenhouse effect and resulting in unusual changes in global temperatures [12–15]. GHGs are the biggest contributor in global warming [16]. Power plants alone contribute to over 40% global anthropogenic CO_2 emissions [17]. Global mean temperature is on the rise with respect to pre-industrialization and if measured to curb the emission of GHGs are not taken, the average mean temperature of Earth is expected to go up to 5°C by the end of this century [18]. Based on our current practices of carbon emissions, average global temperatures are expected to increase to up to 1.3°C as compared to the temperatures before industrial revolution [19]. The adverse effects of extensive emissions of GHGs are already evident in terms of rising sea levels, unusual variations in temperatures and rain cycles [20]. Unless concrete steps are taken at regional and global levels to cope with water scarcity and environmental degradation, human development cannot continue at the expected rate [21, 22].

Turkey, which is situated at a strategic location of Asia and Europe, is going through a dynamic transformation resulting in excessive consumption of its water resources. Total energy consumption increased by 117% from 1990 to 2000 and by 92.2% from 2000 to 2013 in conjunction with the rapid growth of the industrial, transportation and service sectors in Turkey [23]. Following the restructuring of country's electricity sector that initiated in 1980s, both consumption and generation of electricity have experienced a dramatic change [24]. The changes in the electricity mix of Turkey between 1990 and 2013 are presented in Figure A.1 (in Appendix). Fossil sources such as coal and natural gas have the largest share of Turkish electricity supply mix. Natural gas accounts for more than half of all fossil fuel-fired generation. Hydropower production is dominant renewable energy source. Biomass, geothermal and solar PV were adopted by the Turkey's electricity sector in 2007 and have grown at a steady pace ever since. The Turkish government plans to increase the share of nuclear power, wind and solar energy in its energy supply portfolio in the future [25].

Turkey's electricity consumption was doubled between 2001 and 2014. Figure A.2 (in supporting information file) shows the annual trend of total energy consumption by the residential (households) and non-residential (industrial, commercial, service, transportation, agriculture, fishing, etc.) sectors. Turkey is perceived to be rich in fresh water resources when compared to the other countries in the region. The country is situated in a semi-arid region and has only one-fifth of the water available per capita of water rich regions like North America and Western Europe. Turkey has annual 1,500 cubic meters water per capita which is well below 10,000 cubic meters water per capita considered for water rich countries [26]. The per capita energy consumption in Turkey is just 16% of that of the European Union's average. Nevertheless, Turkey's energy consumption is increasing steeply because of the fast-paced industrialization and urbanization. Turkey is not an oil-rich or a massive natural gas producer, like some of its neighbors. Thus, it has tried to meet its major energy needs through the locally available coal resources and hydropower as well as imported natural gas. The government plans to meet its rising energy demand through sources that will require water for electricity production [26, 27]. Although, several sustainability assessments have focused on Turkey's electrical sector [28–31], a comprehensive study has yet to be performed on the water impacts of Turkey's electricity generation. Thus, this study is an initial effort to help optimize the use of water resources in Turkey's power generation sectors and to providing the Turkish policy makers with information on the water use of alternative energy mixes to meet the future energy demand.

Water and energy generation are strongly related with each other [32]. Therefore, to effectively control and curtail the water usage in electricity production, it is necessary to reliably account for water usage in the energy generation process [33]. Madani and Khatami [34] reviewed various indices that have been used in the literature to evaluate the impact of energy production on water resources. According to their review, water consumption refers to the amount of fresh water actually consumed in the process of producing electricity. This water gets out of the system and becomes unavailable for the other uses. Water consumption can occur in the form of evaporation of water from the reserviors, mixing the water with effluents, spilling it in sea, or through any other process which makes the water unusable at the end of the process [34]. Water withdrawal, however, is the amount of water withdrawn from water sources (e.g. reservoirs and rivers), which is mostly used for cooling purposes and is returned to the system at the end of the energy production process [35].

Power plants, particularly fossil fueled plants, contribute substantially to the carbon emissions. In China alone, 48% of the total carbon emissions stemmed from electricity generation through fossil fuel as of 2010 [36]. Coal fired power plants emit the maximum GHG emissions followed by liquid fuel oil and natural gas power plants, , respectively. Importantly, renewable energy sources like hydroelectric, biomass, solar and geothermal also leave carbon footprint as they are utilized for energy generation - hence, they are not completely green energy sources.

This thesis aims to present a framework assessing water and carbon footprints for national energy development plans, by presenting a spreadsheet model analyzing the water consumption and withdrawal as well as carbon emissions from all the energy sources. The developed model can serve as a decision support tool to aid policy makers take decisions about electricity generation sources with a good understanding of the implications of their decisions for a nation's water resources and environmental policies. As a case study, a scenario analysis is conducted to estimate the water consumption, withdrawal, and carbon emissions associated with Turkish Government's energy plans until 2030. Figure A.3 in supplementary file shows the forecasted rising energy consumption in Turkey until 2030. Turkey's electricity needs will almost double, nearly 95% increase, until 2030 compared to 2015 levels, which will put additional stress on water resources and can cause significantly more GHG emissions. So we have to find a best energy generation mix of energy sources to keep the country's water usage and carbon emissions under the critical levels.

In the following sections of this thesis, the methodology of this study is defined and the data collection methods are discussed. This is followed by a scenario analysis of Turkish energy mix. Finally, the results are incorporated into a decision support tool to provide a generalized view of water usages and GHG emissions of different energy mixes and help optimizing the country's water and carbon footprint. Policy implications are discussed and then thesis is concluded by presenting the key findings of this study.

Chapter 2

Methodology

2.1 Method

The electricity consumption data is obtained from the International Energy Agency (IEA) [37] and Turkish Statistical Institute [38]. Using autoregressive integrated moving average (ARIMA), the electricity consumption data is forecasted fort the analysis period. The method employed for doing scenario based energy water analysis involves four primary segments, as shown in Figure 2.1 [39]. The Electricity production in Turkey is studies with respect to individual energy sectors available in the country from 1990 to 2013. A large portion of this data is obtained from the database of International Energy Agency. Over this 23 years' span, it is revealed that Coal, Natural Gas and Hydropower are the most dominant sources of electricity in the country. Liquid fuels, on the other hand, have never been a major source of energy. Wind, solar and geothermal energy sectors grew after 2003 and are still in their developing stage. The Auto Regressive Integrated Moving Average (ARIMA) forecasting tool is used to forecast the energy production in Turkey, keeping in view the socio-economic factors, population growth, regional and climatic changes until 2030.

Water consumption and water withdrawal rates of all the energy sources are extensively studied in the next phase. For energy sector, water usage is highly dependent on the type of cooling system used. Therefore, this thesis considers the most commonly used cooling systems for each energy source and their water usage rates are shown in terms of the range of minimum, mean and maximum amount of water usage that is expected to happen over the coming years. Carbon emissions from power plants are quantified based on the capacity factors, life cycle assessments, productivity and cooling systems. For each energy source, corresponding equivalent carbon emissions per kilowatt-hour (kWh) are quantified based on thorough literature review discussed in the section 2.2.

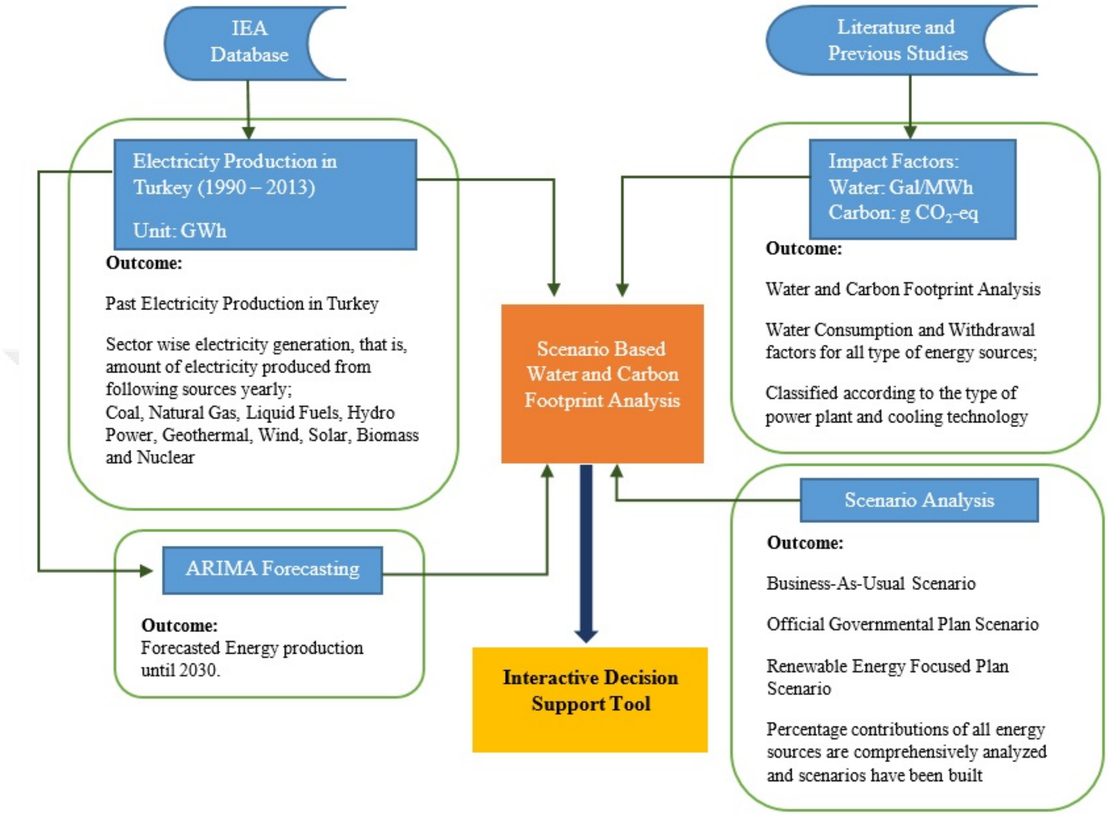

FIGURE 2.1: Methodology.

In scenario analysis, different policy options for Turkey are comprehensively considered. Three scenarios are formulated, namely: Business as Usual (BAU), Official Governmental Plan (OGP) and Renewable Energy Focused Development Plan (REFDP). For each scenario, relevant conditions are analyzed and the growth of each energy sector is studies over the time lapse of 5 years until 2030. Percentage contributions of every source combined with the total electricity forecast and water consumption and water withdrawal factors are all fused to analyze energy water nexus in Turkey. In order to make our study more interactive and useful for policy makers, a decision support tool is also developed with interactive capabilities. Further details on the interactive decision support tool are given in the following sections and its access link is given in the appendix.

There are three main assumptions in this study:

1. Electrical consumption is assumed to increase based on the ARIMA forecasting until 2030. The results of ARIMA have been compared with the available sources and are found to be comparative.

2. Electrical sectors share in overall energy production are based on past studies referred in earlier sections. In order to make it realistic, interactive system has been designed to make this model realistic.

3. Water factors, that is, unit water consumption and withdrawal values per electrical energy produced are taken in a range of minimum and maximum values because water consumption and withdrawal depends on several variables such as cooling system used in power plants, their efficiency, operating conditions and many more. Therefore, mean values of the ranges are used as a basis of our results.

4. GHG emission coefficients from different power generation sources quantified are considered to remain same over the period of analysis considered in this study.

2.2 Data Collection

To analyze water usage from energy sector in Turkey, following records were obtained from the available sources: total energy consumed in annual basis, a share of individual energy source in total energy consumption, proportions of electricity used by residential and non-residential sector in Turkey. Year 1990 was set as the base year for this study and 2014 is the most recent year for this study.

2.2.1 Energy Consumption

Total energy consumed and energy sector wise production on annual basis is summarized in Appendix table 2.1. Figure A.2 in appendix shows how the energy consumption (in Gigawatt- Hours) has varied over the years. Figure 2.2(a) shows the trend of percentage increase in the energy consumption with respect to the previous year. As it is apparent, there is a mix trend in the increase in energy consumption from year to year. However, comparing the increment from the base year, i.e. from 1990, energy consumption is increasing at a very rapid rate. The trend of energy consumption growth from 1990 is shown in Figure 2.2(b). Demand for electrical energy in Turkey doubled in 1999; with increasing population and rapid industrialization, energy consumption grew to about 206% in 2006. This sharp increase in trend continues as energy consumption increased about 338% in 2013 compared to 1990.

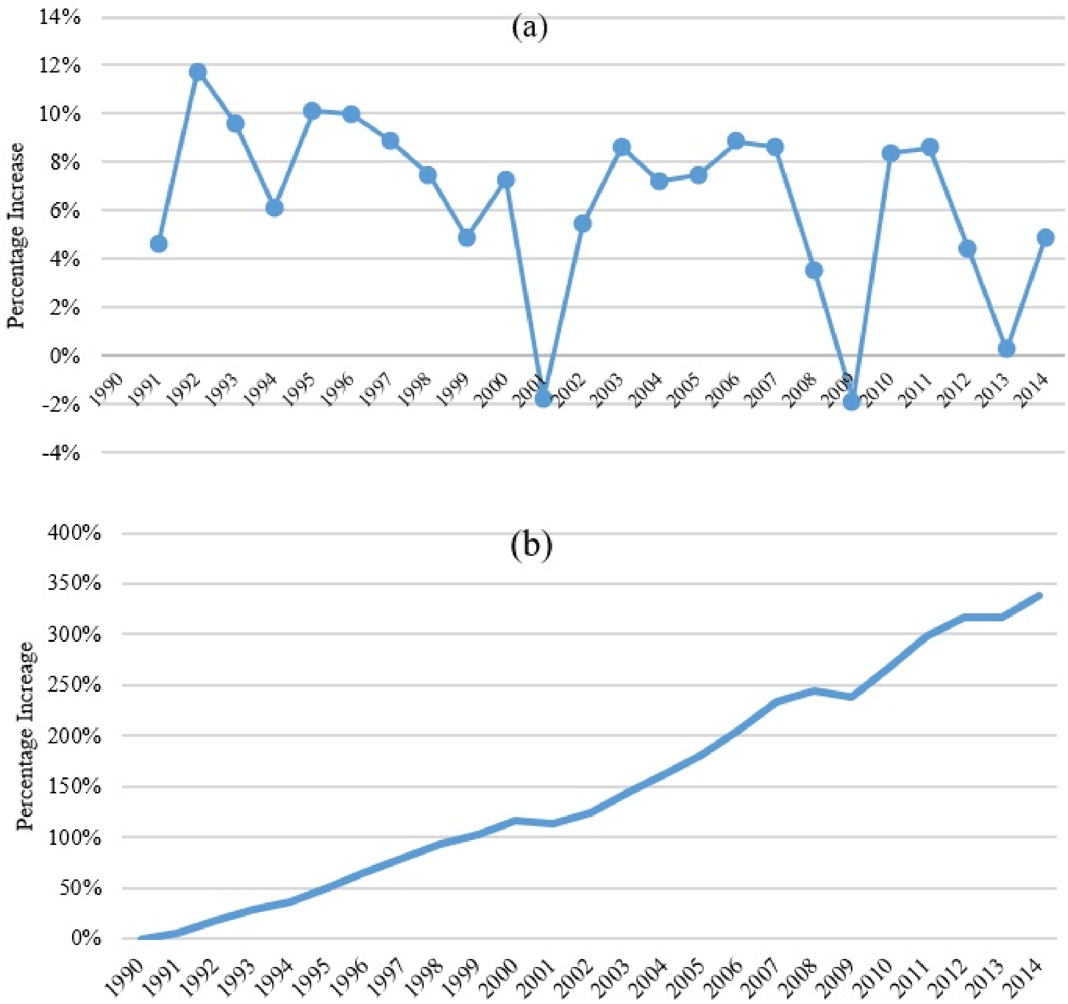

FIGURE 2.2: Electricity consumption trend (1990-2014) with respect to previous year.

To meet a steep rise in the energy requirements presented in Figure 2.2(b), energy sector has growth at a rapid pace as well - utilizing different energy sources to generate electricity. Coal, liquid fuels, natural gas and hydro power plants are the major contributors in the Turkish electricity generation. Other sources such as biomass and geothermal have been in existence since long, but their production volumes are not comparative. Wind energy and Solar PV have started to take roots in the country and are expected to grow with increasing environmental concerns.

Coal is a prime contributor in the generation of electricity. Shares of liquid fuels are relatively less, and declining trend is observed as the factual values move towards 2013.

Natural Gas fired power plants also dominate despite that the country depends largely on its import of Natural gas from other countries; which is an added burden on its economy as well [29]. Other renewable sources such as wind, solar photovoltaic (PV), geothermal and biomass are growing steadily at a normal pace. It is worth to mention that Turkey is among the few countries where geothermal technology is deployed to produce electricity [40].

Since our objective is to predict the water usage and carbon emissions over time in future, we have used ARIMA forecasting method to forecast energy consumption until 2030. Several other forecasting methods were tested, but ARIMA results were very comparative with the projections of Turkish Ministry of Development. Turkish ministry of Development presented energy demand projections of the coming two decades in their report "Turkish Energy Demand Projection Report" [41]. Their projections were very close to our ARIMA forecasting, hence, we relied on the results of our model to predict our results. Figure A.3 in appendix presents the energy requirements of Turkey until 2030. Variation in our forecasted results and the Ministry of Development predictions can also be noticed.

2.2.2 Water Consumption, Withdrawal and GHG Emission Factors

To access the amount of water withdrawn and consumed from different power sources, each source is studied for its own water consumption and withdrawal factors. Water and carbon factors of power plants do not vary substantially from country to country. Despite methodological differences among them, general trends are similar and broad conclusions about their footprints can be drawn.

Water usage levels for power plants depends on more than one elements: design of power plant, type of fuel used, cooling system technology [42]. Therefore, data ranges are used to propose the range of water consumed and withdrawn by power sectors where necessary. Water utilization in life cycle of almost all the energy sectors happen in their operational phase; except for non-thermal renewable source [43]. Thus, water used in operation of power sectors considers cooling systems, washing purposes and other auxiliary processes [42]. Regardless, the cooling system is the actual element determining the water utilization of a power sector [44]. Table2.1 shows the water consumption factors, in gallons per megawatt hours, by individual energy sectors based on the type of cooling

Table 2.1: Sector wise Water Consumption Factors (Gallons/MWh) [42]

Energy Sector	Cooling System	Technology	Min	Median	Max
Coal	Tower	Generic	480	687	1100
		Subcritical	394	471	664
		Supercritical	458	493	594
		IGCC	318	372	439
		Subcritical with CCS	942	942	942
		Supercritical with CCS	846	846	846
		IGCC with CCS	522	540	558
	Once-through	Generic	100	250	317
		Subcritical	71	113	138
		Supercritical	64	103	124
	Pond	Generic	300	545	700
		Subcritical	737	779	804
		Supercritical	4	42	64
Liquid Fuels	N/A	Combined	300	390	480
Natural Gas	Tower	Combined Cycle	130	198	300
		Steam	662	826	1170
		Combined Cycle with CSS	378	378	378
	Once-through	Combined Cycle	20	100	100
		Steam	95	240	291
	Pond	Combined Cycle	240	240	240
	Dry	Combined Cycle	0	2	4
	Inlet	Steam	80	340	600
Hydropower	N/A	Aggregated in-stream and reservoir	1425	4491	18000
Wind	N/A	Wind Turbine	0	0	1
Geothermal	Tower	Dry Steam	1796	1796	1796
		Flash (freshwater)	5	10	19
		Flash (geothermal fluid)	2067	2583	3100
		Binary	1700	3600	3963
		EGS	2885	4784	5147
	Dry	Flash	0	0	0
		Binary	0	135	270
		EGS	300	850	1778
	Hybrid	Binary	74	221	368
		EGS	813	1406	1999
Biomass	Tower	Steam	480	553	965
		Biogas	235	235	235
	Once-through	Steam	300	300	300
	Pond	Steam	300	390	480
	Dry	Biogas	35	35	35
Solar PV	N/A	Utility Scale PV	0	26	33
Nuclear	Tower	Generic	581	672	845
	Once-through	Generic	100	269	400
	Pond	Generic	560	610	720

system and technology used. Similarly, Table 2.2 shows the water withdrawal factors from individual energy sources according to the relevant cooling systems and technology. Graphical representation of water consumption and withdrawals are presented in Figure A.4 Figure A.5 shown in Appendix.

Table 2.2: Sector wise Water Withdrawal Factors (Gallons/MWh) [42]

Energy Sector	Cooling System	Technology	Min	Median	Max
Coal	Tower	Generic	500	1005	1200
		Subcritical	463	531	678
		Supercritical	582	609	669
		IGCC	358	390	605
		Subcritical with CCS	1224	1277	1329
		Supercritical with CCS	1098	1123	1148
		IGCC with CCS	479	586	678
	Once-through	Generic	20000	36350	50000
		Subcritical	27046	27088	27113
		Supercritical	22551	22590	22611
	Pond	Generic	300	12225	24000
		Subcritical	17859	17914	17927
		Supercritical	14996	15046	15057
Liquid Fuels		Combined Cycle	300	450	600
Natural Gas	Tower	Combined Cycle	150	253	283
		Steam	950	1203	1460
		Combined Cycle with CSS	487	496	506
	Once-through	Combined Cycle	7500	11380	20000
		Steam	10000	35000	60000
	Pond	Combined Cycle	5950	5950	5950
	Dry	Combined Cycle	0	2	4
	Inlet	Steam	100	425	750
Hydro			N/A	N/A	N/A
Wind			-	-	-
Geothermal		Upstream and downstream	0.5	3	10
		Binary: Hybrid cooling	220	460	700
		Binary: Dry cooling	270	290	630
		Flash	11	18	25
		EGS: Dry cooling	290	510	720
Biomass	Tower	Steam	500	878	1460
	Once-through	Steam	20000	35000	50000
	Pond	Steam	300	450	600
Solar PV		C-Si (crystalline silicon)	1	94	1600
		Other (primary thun film)	0.5	18	1400
		Flat panel	1	6	26
		Concentrated PV	24	30	78
Nuclear	Tower	Generic	800	1101	2600
	Once-through	Generic	25000	44350	60000
	Pond	Generic	500	7050	13000

Water consumption factors diversely vary from sector to sector [45]. Generic technology in tower cooled coal fired plants consume most water in Coal sector, followed by sub-critical and super-critical technologies; having maximum consumption factors of 1100 gallons per megawatt-hour, 942 gallons per megawatt-hour and 846 megawatt-hour, respectively. Water consumption factor in Liquid fuels and hydropower sectors vary from

300 gallons per megawatt-hour to 480 gallons per megawatt-hour and 1425 gallons per megawatt-hour to 18000 gallons per megawatt-hour, respectively. Natural gas power plants, as well as biomass power plants, which use steam to as a driver for turbine rotation, consume maximum water among other technologies. Enhanced Geothermal Systems (EGS) dominates geothermal technologies. Generic nuclear power plants having tower cooling system consume most water out of generic plants having once-through cooling system and pond cooling system. Hydropower sector, despite being a non-fossil based- renewable energy, happen to consume maximum volume of water among rest of the sources, largely because of the evaporation from exposed water surfaces of large reservoirs of dams and lakes [46].

Water withdrawal factors, on the other hand, lie on the higher side as compared to water consumption. This is due to the intensive water withdrawals for cooling purposes in coal, liquid fuels, natural gas, biomass and most importantly, nuclear energy sector. As in the case of water consumption, cooling technology has a substantial role to play.

Once-through cooled generic coal power plants withdraw most water out of all the cooling technologies and technologies of coal energy sector considered in this study. The highest water withdrawals factors for coal power production range from 20,000 gallons per megawatt-hour to 50,000 gallons per megawatt-hour. Natural gas designed on combined cycle power plants and steam withdraws most of the water, with steam plants dominating like they dominated in water consumption. Combined cycle plants withdraw minimum of 11,380 gallons per megawatt-hour to the maximum limit of 20,000 gallons per megawatt-hour while gas plants using steam withdraws 10,000 gallons per megawatt-hour to 60,000 gallons per megawatt-hour. Water withdrawal factors in geothermal power sector have minimum ranges between 220 gallons per megawatt-hour to 290 gallons per megawatt-hour and maximum range between 630 gallons per megawatt-hour to 720 gallons per megawatt-hour. Biomass and nuclear are thought to be environmental friendly power options, but they also withdraw considerable volumes of water. Biomass plants with steam technology and once-through cooling system withdraws 20,000 gallons per megawatt-hour to 50,000 gallons per megawatt-hour and generic nuclear plants with once-through cooling withdraws 25,000 gallons per megawatt-hour to 60,000 gallons per megawatt-hour. Solar photovoltaic (PV) energy sector withdraws as low as 0 gallons per megawatt-hour to 1600 gallons per megawatt-hour. However, mean water withdrawal in solar PV is also close to 0 gallons per megawatt-hour. Wind energy withdraws no water; therefore, it is the least water dependent source as far as water withdrawal is concerned. Hydropower water withdrawal factors of run-of-the river hydropower plants are not considered in this study due to the fact that these power plants are generally located in between the natural flow of the river and do not take away water from other purposes like agriculture, industrial and domestic purposes for a long period of time.

GHG emission factors or carbon coefficient of power generation sources are also considered to analyze environmental impacts resulting from power sources of various types. For every power generation source, detailed examination of the factors like capacity factor, technology type, life cycle assessment, cooling technologies and other related factors is done along with their corresponding effects on the eventual carbon emissions from former literature and reports. For example, National Renewable Energy Laboratory (NREL) report on the "life cycle assessments of coal-fired power production" and "Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System" quantified the contributions of GHGs by coal and natural gas combined power plants respectively [47, 48]. Hiroki Hondo [49] has done a comprehensive study of greenhouse gas emissions from coal, natural gas, hydroelectric, nuclear, wind, solar and geothermal power plants in relation to global warming. White and Kulcinski [50], Odeh and Cockerill [51], Meier [52] and various other researchers [53–55] have extensively studied the emissions from different power generation sources and their work is used in this study to predict the carbon emissions from the respective power sources in Turkey. Figure 2.3 shows the Pareto diagram of the average GHG emissions by all the power sources present in Turkey. Coal, liquid fuel and natural gas fueled power plants constitute to 90% among the overall carbon emission factors, in terms of grams per kilowatt-hour. Although solar energy and geothermal energy are assumed to be renewable having no carbon emissions, but we have found out that their average greenhouse gas emission factors are about 50 g CO_2-eq/kWh and 34 g CO_2-eq/kWh respectively [56, 57]. Extraction of energy from waste, as in the case of electricity generation from biomass, contributes to GHG emissions as well and happen to emit about 32 g CO_2-eq/kWh [58].

On the other hand, values of the water usage factors by energy sources are presented in terms of volume per unit electrical output (gallons per Megawatt-hours). They are further categorized as the minimum amount of water used, mean amount of water used and the maximum amount of water used by each type of cooling technology. The amount of water used by a power plant will lie between the minimum and maximum value,

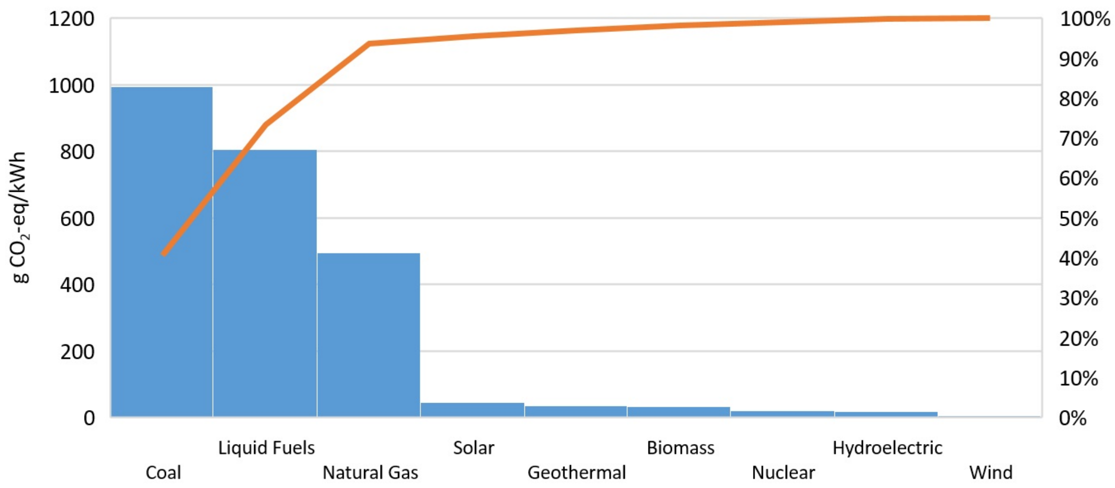

FIGURE 2.3: The average GHG emissions by energy sources.

depending on the source, cooling method and technology. This thesis considers the minimum amount of water, the range of mean amount of water that a power plant may use and the maximum level of water that any source can use while producing the required electricity. As there are many cooling technologies associated with energy sectors, mean factors are bifurcated as the lower mean and upper mean, suggesting the minimum and maximum value among the mean values of all the cooling technologies of a specific energy sector. The reason for making a range of mean in each energy source is to depict the average water usage by each sector irrespective of their cooling technology. In case where there is one cooling system, the range of mean is not applicable.

Above discussed GHG emission factors, water consumption and withdrawal factors will be used as a tool to calculate the equivalent grams of CO_2 emissions together with the volumes of water consumed and withdrawn in Turkey over the years and also, to predict the amount of water that will be consumed and withdrawn in the future years.

From carbon emission factors, water consumption and withdrawal factors, sector wise water utilization is calculated by:

$$WC_{xy} = WCf_x * EC_{xy} * 1000 \tag{2.1}$$

$$WW_{xy} = WWf_x * EC_{xy} * 1000 \tag{2.2}$$

$$CE_{xy} = Cf_x * EC_{xy} * 1000 \tag{2.3}$$

Where,

WC = Water Consumption;

WCf = Water Consumption Factor;

WW = Water Withdrawal;

WWf = Water Withdrawal Factor;

CE = Carbon Emissions;

EC = Energy Consumed;

x = Energy sector;

y = Year of study;

WC_{xy} = Water Consumption of x Energy sector in Year y;

WCf_x = Water Consumption Factor of x Energy sector;

WW_{xy} = Water Withdrawal of x Energy sector in Year y;

WWf_x = Water Withdrawal Factor of x Energy sector;

CE_{xy} = Carbon Emission of x Energy sector in Year y;

Cf_x = Carbon Emission Factor of x Energy sector;

EC_{xy} = Energy Consumed by x sector in Year y;

Units of water consumption and water withdrawal factors are gallons per megawatt hours (Gal/MWh) and unit of energy consumed is gigawatt hours (GWh). Hence, to homogenize the units, both eqn. 2.1 and eqn. 2.2 are multiplied by 1000. Similarly, units of carbon emission factors are grams of CO_2 and equivalent gasses per kilowatt-hour (g CO_2-eq/kWh) while units of energy consumed is GWh.

Total water consumption and withdrawal volumes for the year are calculated by using:

$$WC_y = \sum_{x=0}^{n} WC_{xy} \tag{2.4}$$

$$WW_y = \sum_{x=0}^{n} WW_{xy} \tag{2.5}$$

$$CE_y = \sum_{x=0}^{n} CE_{xy} \tag{2.6}$$

2.3 Energy-based Analysis

In this section, a general overview of Turkey's energy sources used for electricity generation is discussed. Their proportions in overall electricity production have been studies and analyzed from 1990 to 2013. Based on this analysis and external factors, their future developments have been predicted through scenario analysis discussed in coming sections.

Demand for electricity in Turkey is going through a rapid change [59] largely due to the surge in sectoral growth in the country. From 2004 to 2014, electricity demand has increased by 70% and in expected to grow at the same pace. Turkey's economy performance, technological advancements, amount of imports and exports, GDP growth and lifestyles of the people have considerably burdened the energy sector [60]. In order to meet these increasing needs, Turkish energy sector is largely dependent on fossil fueled power plants, particularly coal and natural gas. Therefore, Turkish government has not only to meet the ever-increasing power demand, but also to reduce its reliance on imports of energy and energy fuels.

Turkey's share of natural energy resources in terms of world reserves are very limited, therefore, more than 52% of Turkey's energy requirements are met through fuel imports [61], and sharp increase in electricity demands have increased the country's inclination to rely more on importing energy fuels and supplies [30]. Turkey's primary energy sources are coal, liquid fuels, hydropower, natural gas, geothermal energy, solar energy and biomass. The country produced about 44% of its electricity from gas, 24.8% electricity from coal, 25.2% from hydro, and rest from wind, geothermal, biomass and solar in 2014. The government is expecting the electricity demand to increase by 100% from 2014 to 2023.

29% of global energy demand come from coal, which result in 44% of global CO_2 emissions [62]. In turkey also, as it can be seen from Figure 2.4, coal and natural gas has been dominant in Turkish electrical sector. Hydropower also is one of the major contributors. Turkey imports most of its natural gas; even then, natural gas fired power production surged after 1998 and continues to vary in between 42% to 50% in the following years. Coal energy, on the other hand, slightly declined below 30% in 2001, but it is a major contributor in overall production. Contribution from liquid fuels is not very considerable since long and its rate is declining as other renewable technologies are taking their roots. Wind energy comes on surface in later 2007 and is growing steadily since then. In 2013, 3.1% of total energy requirements were supplied through wind energy.

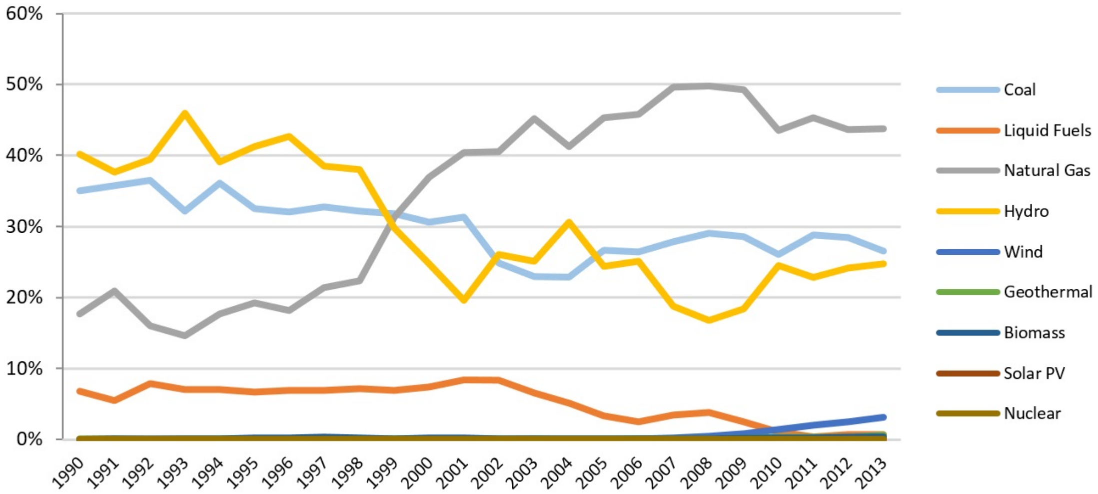

FIGURE 2.4: Turkey Electricity generation mix (1990 - 2013).

2.4 Scenario Analysis and Scenario Building

The primary motivation behind a scenario analysis is a target in mind or a goal that constitutes in the development of scenarios and to predict the results of future, based on the preset assumptions or goals. Since long, scenarios are used for discovering the forthcoming progress under a set of assumed conditions; especially in decision support in energy sectors [63]. This method of analysis gives the alternative options of how our subject of thesis will unfold.

In order to understand systems well, we need to evaluate their models through playing with the strings and constraints and then, by observing their behavior and responses, we tend to determine their likely future states. Unfortunately, this method is useful with non-sophisticated and certain systems. Real world systems, studying on energy sector in our case, is a very complex system whose sectors are so independently dependent of diverse factors that it is impossible to accurately predict their behavior. So judgmental tools are only used as experimental basis. Therefore, scenarios simplify this gap of our understanding about the working, behavior and evolution of complex systems. This is generally done by attaching quantitative narrative strings of the future with quantitative respective elements. This makes scenarios a useful tool for scientific assessments and for learning systems. Also, they enables the policy makers to analyze the system from multi dimensions before coming up to a decision [64]. Hence, they happen to be one of the main methods for solving the complexities and uncertainties associated in long term policy making by establishing the logical boundaries [65].

Scenario analysis for environmental and energy sectors have been done at different scales; ranging from worldwide long-term international scenarios to local mid-term scenarios [66, 67]. In this study, to analyze the water usages under different energy mixes of energy sectors, scenario analysis is therefore deployed as a productive tool to better understand and interpolate the volumes of water that will be used in Turkey in coming years. All the electricity producing sectors of Turkey are studied in detail keeping in view their contributions in the total electricity consumption of the country, their future perspectives in line with the governmental policies, their environmental impacts and socio-economic repercussions and their driving fuel availability.

Once the trends of energy mixes of different sectors are established, water consumption and withdrawal factors, presented in earlier sections, are used to calculate the amount of water consumed and withdrawn annually by each energy source in the country as explained in eqn. 2.1 and 2.2. A decision support tool is developed for policy makers to study the water consumption and withdrawals from each energy source, as well as collectively, of all the scenarios deployed. Also, developed tool can help them in observing the changes with any other electricity mix. The tool takes scenario input from user, which is the percentages of the distinct energy sectors in the overall energy sector of the country, and present detailed results of the water consumption and withdrawals made by individual scenarios and individual energy sources. The user can change the energy mixtures to compare the results of different scenarios.

Turkey, which corresponded to about 1.24% (around 459,102 Mega tons) of emissions equivalent of CO_2 in 2013, became the signatory of The Paris Agreement under United Nations Framework Convention on Climate Change [68]. Therefore, they have pledged to reduce the risks and impacts of climate change by curbing global average temperatures [69]. The government is working on building renewable energy resources, and establishing frameworks to improve technologies to prevent carbon emissions while securing the leakages of electricity in distribution system, which is in line with the COP 21 declarations. Furthermore, international economic institutions have predicted that Turkey's economic growth rates with remain on the higher side which will result in exponential increase in energy consumption as well [70].

To reduce the dependence on import of fuel for electricity, especially natural gas, Turkish government aims to exploit its coal resources for power generation under its plan of "Dash for Coal" [71]. Alongside this, the country is also aiming on long-term energy strategies to speed up its renewable energy consumption. Increasing the percentage mix of renewable energy production will also result in the reduction of shares of coal and natural gas [72]. Hydroelectric power potential has the capacity of meeting 33% to 46% of Turkey's electricity demand until 2020 and this share can easily increase to its maximum potential easily and economically until 2030 and further [73].

With increase in renewable energy projects around the world, costs of setting up renewable power energy technologies are decreasing gradually. Turkey, being abundant in renewable energy resources can clinch on this opportunity to cut down the use of imported coal and natural gas in power generation. The key renewable sectors for Turkish energy sector are hydropower, solar photovoltaic, wind, geothermal and nuclear energy [74]. By 2023, around 159,000 GWh of renewable electrical energy is projected to be installed in Turkey [70].

Keeping in view the governmental policies, worldwide technological trends and related factors that can influence electrical energy sector, along with the available studies about the future of Turkish energy sector, thorough analysis of energy sources in Turkey have been conducted and their potential mix have been simulated in three different scenarios until 2030. Percentage contribution of each power source is calculated and then, through scenario analysis, their mixes are predicted for 2020, 2025 and 2030. Three scenarios have been used: Business-As-Usual (BAU), Official Governmental Plan (OGP) of the government of Turkey based on the future energy projects and their expected deadlines, and the Renewable Energy Development plan (REFDP). After, water consumption and withdrawal are predicted by individual electricity generation source keeping in view their percentage contribution in the Turkish power sector. This resulted in foreseeing the volumes of water that will be required to cater Turkish electricity demands over the years until 2030. According to the Turkish Ministry of Energy and Natural Resources, 36 GW of hydropower electricity, 48 GW of wind energy and 2 GW of geothermal energy capacity is available in the country. While it is estimated that solar energy potential is as much as 380,000 GWh per year and biomass energy potential is about 1300 GWh per year.

2.4.1 Scenario 1 (BAU)

Scenario 1 is the first scenario developed to analyze the trends in growth of different power sectors and their water consumption and withdrawals until 2030. Scenarios have been developed in line with the current trends in the development of energy sectors in Turkey. BAU differs from official governmental plan as it does not consider ambitious projections. In this regard, present conditions of electricity sector and existing policies of Turkish government have been studied along with the projects that are in the process of completion in the coming times.

Figure 2.5 shows the variation of Turkish energy sector mix in BAU scenario from 2015 to 2030. Electricity consumption from coal energy in BAU scenario is expected to increase from 60,740 GWh in 2015 to 100,340 GWh until 2025, with a steady percentage of around 23% to 24% in the overall mix. By 2030, this proportion increased to 27%, taking energy production through coal to around 139,000 GWh. Energy production from natural gas resources is expected to decrease substantially as it is evident from the government's commitment of reducing dependency on import of gas and utilizing local coal resources. Natural gas accounts for approximately 44% of the overall energy mix in 2015 are projected to go down to around 23% until 2030 under BAU. This decrease in the percentage is not compatible with the increase in the overall demand; meaning that in 2015, about 116,500 GWh of electricity was produced from natural gas and in 2030, it is projected that 119,711 GWh of electricity will be produced. Amount of electricity produced in 2030 is still greater than its value in 2015. That is because of the overall exponential increase in the energy demand. Renewable energy under Business-as-usual scenario also depicts a very interesting trend. Hydropower energy is estimated to fluctuate from 25.8% in 2015 to 27.5% in 2020 to 26.6% in 2025 to 22.8%; while proportions of wind energy are expected to increase steadily, but still at a slow pace as compared to the rest of the world. It is estimated that wind energy proportions will increase from only 4.4% having just a share of 11,635 GWh to 13.2% making the share of about 68,000 GWh in 2030. Geothermal and biomass technologies under BAU are expected to stay under 1%, making their share very minimum. Solar photovoltaic (PV) technology in Turkey's BAU scenario is projected to take a heap until 2020. It is estimated that Turkey will be producing 3.6% (around 11,800 GWh) of its electrical energy from solar PV in 2020, 6.4% (26,500 GWh) in 2025 and 8.4% (43,250 GWh) in 2030. Nuclear energy power is expected to come on-line in 2023 and will be contributing 2.5% of the total energy share. The pace of development of nuclear plants in Turkey is expected to remain steady under BAU. Until 2030, 4.7% of the total energy is expected to come from nuclear technology.

2.4.2 Scenario 2 (Official Governmental Plan)

Scenario 2 is based on the targets and time-lines of Turkish government's projects to cater growing energy demand in the country. Existing policies to cope up the increasing power demands, capacity planning and current conditions of the electricity market and sector are all considered while formulating the energy mixes for this scenario. Government plans and deadlines along with projected time when future energy projects will come on-line are taken into account in this scenario.

Figure 2.6 shows the variation of Turkish energy sector mix in BAU scenario from 2015 to 2030. Official governmental plan suggests that the dependency on coal for energy will continue, however, it will not be a major player in the country's electricity mix as other renewable sources are expected to grow. Coal energy's contribution will range from 23% to 20.8% to 21.2% in 2015, 2025 and 2030 respectively. Natural gas, on the other hand, is expected to have a sharp decline due to the government's diversion towards exploiting local coal resources and building up renewable resources. A share of natural gas is expected to fall from 44% to 15% until 2030.

Wind, solar PV, and nuclear energy development is expected to grow substantially under this scenario. These targets are set in line with the global targets of reducing carbon emitting power dependencies and focusing on renewable energy sources. Wind energy is expected to have 23% share until 2030 in the country's overall electricity mix. Solar PV power production is assumed to grow from 1.6% in 2020 to 2.5% in 2023 to 4.5% in 2025 to 9.7% in 2030. As far as nuclear energy is concerned, the government plans

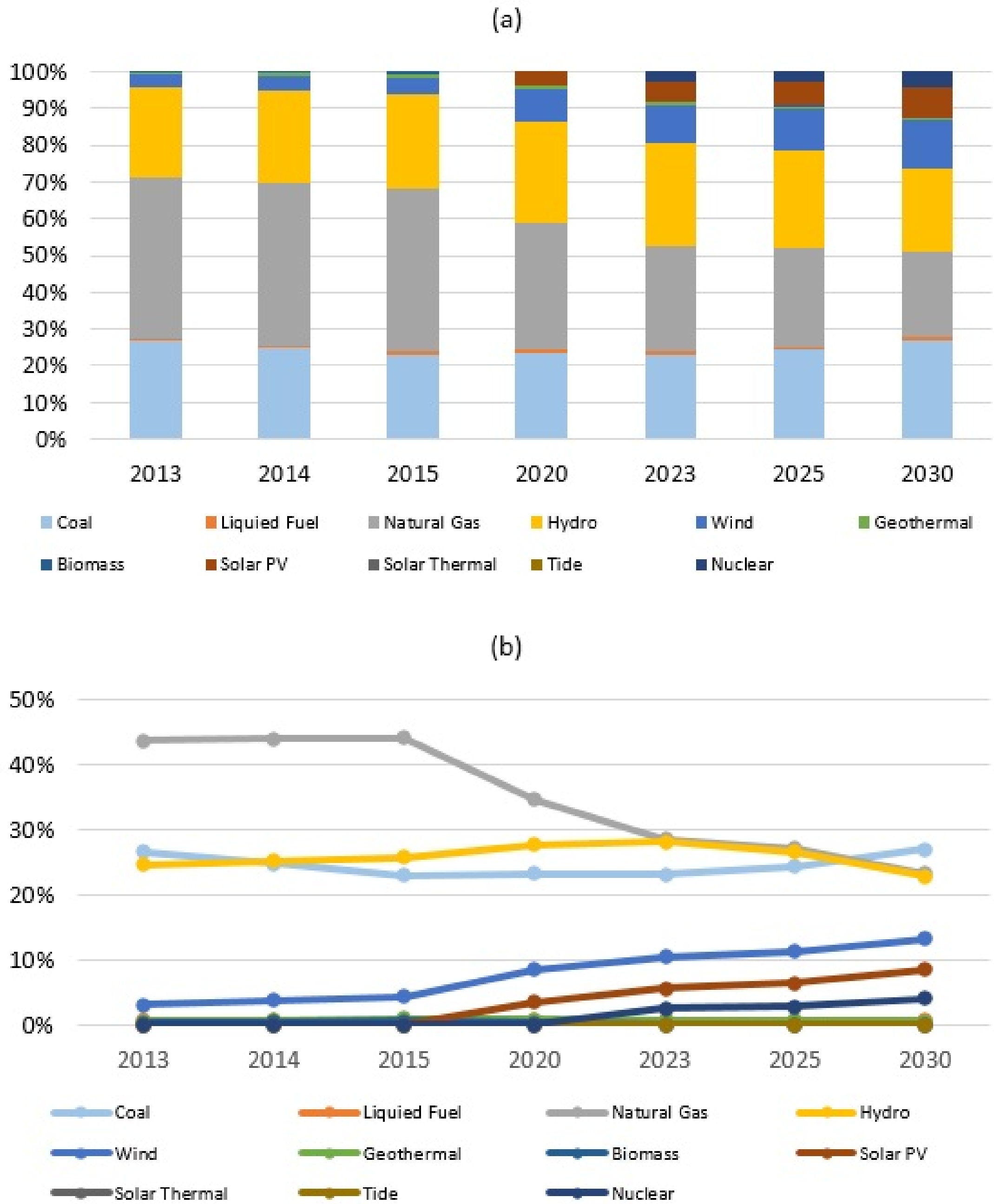

FIGURE 2.5: Scenario 1 (Business-As-Usual) Energy Mix Percentages (2013 - 2030) (a) cumulative stacked representation; (b) trend of percentage fluctuation Energy Mix percentages (2013 - 2030).

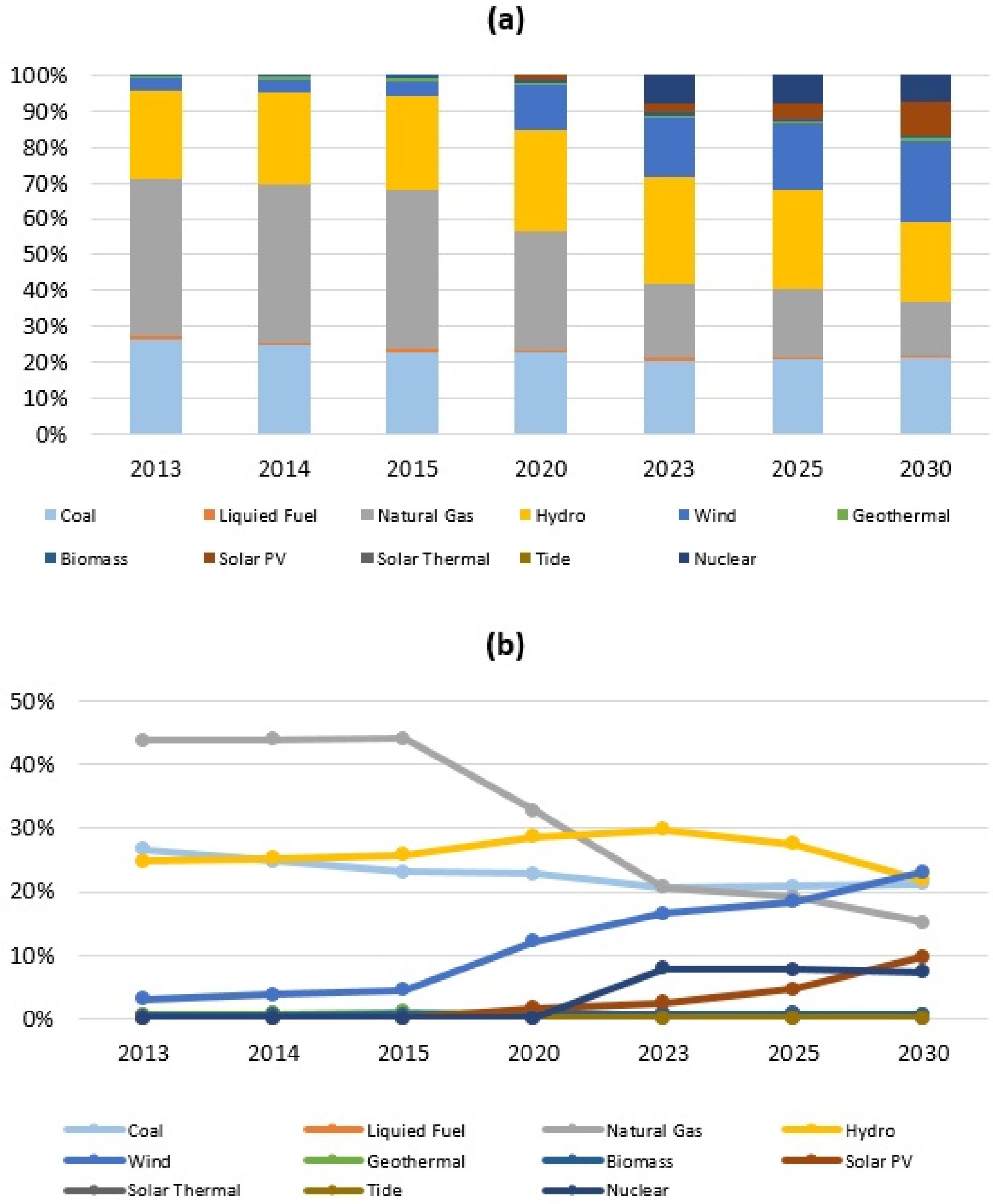

FIGURE 2.6: Scenario 2 (Official Government Plan) Energy Mix Percentages (2013 - 2030) (a) cumulative stacked representation; (b) trend of percentage fluctuation Energy Mix percentages (2013 - 2030).

to complete two under construction nuclear power plants by 2023, their projected power contribution to the system will be about 7.9% in 2023 and this proportion is expected to remain stable with the induction of Sinop and Lgenada nuclear projects until 2030 [25].

2.4.3 Scenario 3 (Renewable Energy Focused Development Plan)

Scenario 3 is the renewable energy focused development plan where the assumptions of Turkish government policies to prioritize renewable electrical options are taken into consideration for the coming decades. Development of coal and natural gas sector will be given less attention as compared to wind and solar photovoltaic (PV) energy, which have not been very dominant in Turkish electrical mix, despite their rapid growth worldwide [70].

2.7 shows the variation of Turkish energy sector mix in BAU scenario from 2015 to 2030. Energy production from fossil fuels is expected to fall substantially. Coal energy is expected to decrease from 23% in 2015 to 19.2% in 2020 to 14.8% in 2025 to 12.1% in 2030. Natural gas is also expected to decrease from 44% in 2015 to 20.6% in 2030. Development of renewable energy technologies are prioritized in this scenario, particularly wind energy and solar PV. In REFDP scenario, wind energy is expected to grow at a rate of about 5% to 6% every 5 years; i.e. from 4.4% in 2015, its proportion in overall electricity mix will climb up to 20% in 2030. Development of solar PV will also be also estimated to be on a higher node as compared to the other two scenarios. Solar PV has the potential to cater about 6% of Turkey's electric needs by 2020. This proportion is estimated to be doubled in 2025, as it will get to 12%. In 2030, solar PV contribution will reach to about 17.4%.

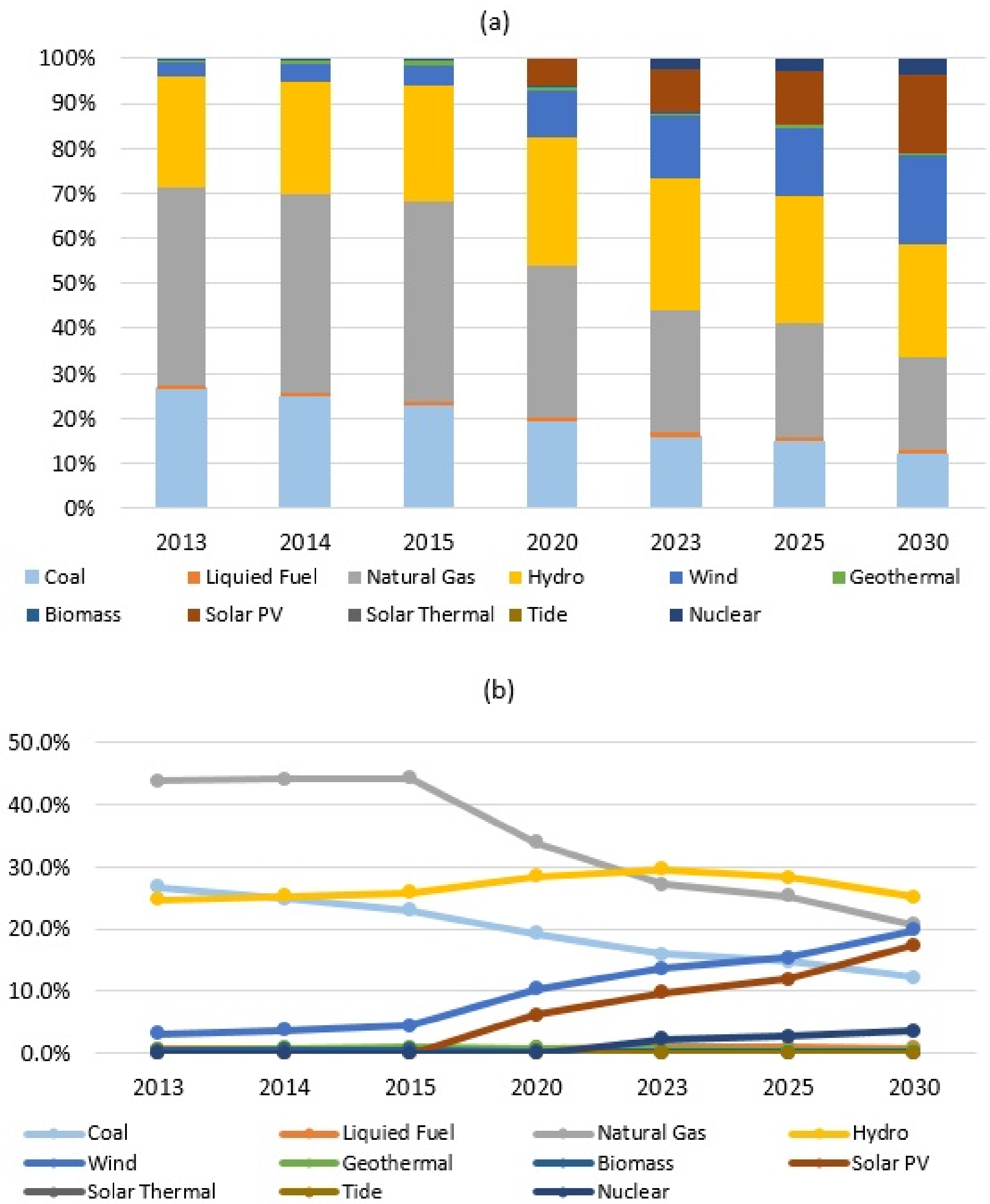

FIGURE 2.7: Scenario 3 (Renewable Energy Focused Development Plan) Energy Mix Percentages (2013 - 2030) (a) cumulative stacked representation; (b) trend of percentage fluctuation Energy Mix percentages (2013 - 2030).

Chapter 3

Results Discussion

3.1 Results Discussion

The results present water consumption and withdrawal factors, GHG emission factors, scenario analysis and forecasted electricity production. A time-series analysis results covering 2015, 2020, 2025 and 2030 are presented in this section and all the scenarios are showed and discussed alongside each other. Water usage in 2015 is same for all scenarios as 2015 is set as the base year and percentage contribution of all the energy sources is same in all the scenarios for this year. Eqn. 2.4, Eqn. 2.5 and Eqn. 2.6 developed in the methods sections are used to calculate the total water consumption and water withdrawal, as well as the total amount of CO_2 emissions for all the scenarios. Amount of water consumed and the amount of water withdrawn are compared separately along side the amount of carbon emissions for each scenario in the following sections.

Firstly, amount of gallons of water consumed and withdrawn as a result of the total electricity production in the country are presented and are categorized by individual power sector. The author has driven the percentages from these values and have represented them in separate figures. Then total water consumption, withdrawal and carbon emissions results are shown collectively to give a different illustration of the scenarios for every 5 years until 2030. It is important to mention that the results shown in this thesis are largely summarized. Please refer to our decision support tool (see Appendix for link) for detailed results and more insights of analysis.

3.2 Comparison of water footprint scenario results

Expected annual water consumption and withdrawal trends are shown in 3.1. The results indicate that overall water withdrawal is roughly 8-10 times greater than water consumption. In 3.1(a), where trend based on scenario 1 is shown, total water consumption levels are expected to increase from $3.92 * 10^{11}$ gallons in 2015 to $5.04 * 10^{11}$ gallons in 2020. This value is expected to rise to $6.06 * 10^{11}$ gallons in 2025 and by 2030, we expect the total water consumption to remain relatively steady and hit to the level of $6.67 * 10^{11}$ gallons. This is mainly due to the slow and steady growth of wind and solar energy sector in the country and decline of dependencies in natural gas and hydropower. Water withdrawals, on the other hand, are expected to show a considerable rising trend because Turkish power sector relays more on coal energy and nuclear energy projects in the long run under BAU scenario resulting total annual water withdrawals of $3.18 * 10^{12}$ gallons, $3.46 * 10^{12}$ gallons, $4.09 * 10^{12}$ gallons, $5.21 * 10^{12}$ gallons in 2015, 2020, 2025 and 2030 respectively.

3.1(b) represents the expected trends in water usage growth based on the scenario 2 of this study, which is, considering if the energy sector grows as per the official governmental plan. In this case, water consumption for 2020 and 2025 are comparative as compared to scenario 1, but in 2030, we expect water consumption to be 7.5% lesser than what is was in scenario 1; mainly because of less reliance water thirsty sources like coal and natural gas in the official governmental plan by 2030. Reduced dependence on coal and natural gas in scenario 2 will also result in less water withdrawals from Turkish water reserves in Scenario 2 as compared with Scenario 1. Our analysis suggests that under scenario 2, 3.5% less water will be withdrawn in 2020 while 8.3% less water will be withdrawn in 2025 and 20.15% less water will be withdrawn in 2030 as compared with BAU.

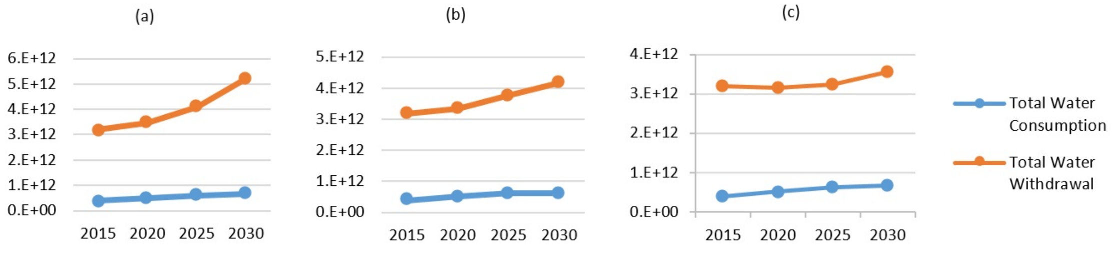

FIGURE 3.1: Water Usage Trend (a) S1, (b) S2, (c) S3 (all values are in gallons).

Table 3.1: Water consumption and withdrawal comparison.

	Total Water Consumption (Gallons)			Total Water Consumption (Gallons)		
Year	S1	S2	S3	S1	S2	S3
2015	3.92E+11	3.92E+11	3.92E+11	3.18E+12	3.18E+12	3.18E+12
2020	5.04E+11	5.15E+11	5.10E+11	3.46E+12	3.34E+12	3.16E+12
2025	6.06E+11	6.09E+11	6.14E+11	4.09E+12	3.75E+12	3.23E+12
2030	6.67E+11	6.17E+11	6.76E+11	5.21E+12	4.16E+12	3.56E+12

Predicted water consumption and withdrawal trends for scenario 3, renewable energy focused plan scenario, are shown in 3.1(c). When Turkish energy sector grows as expected in the renewable energy focused plan, we expect water consumption to be 1.2% and 1% lower than Scenario 1 and Scenario 2 respectively in 2020 and this ratio will not vary much until 2025. However, in 2030, energy mixes in scenario 3 will result in 1.3% and 9.6% more water consumption as compared to scenario 1 and scenario 2 respectively. Hence, it is revealed that energy mix having considerable contribution of renewable sources such as hydropower can result in high water consumption. Water withdrawals, however, are less in this scenario as compared to the previous two scenarios. This is because of reduced dependencies on coal, natural gas and nuclear energy. In 2020, scenario 3 withdraws 8.7% and 5.4% less water while in 2025, it withdraws 21% and 13.9% less water and in 2030, it withdraws 31.7% and 14.4% less water than scenario 1 and scenario 2, respectively.

Table 3.1 summarizes the expected water usages for all scenarios. We conclude that the amount of water consumed by the energy mixture of different energy sources based on BAU are moderate as compared to the official governmental plan and renewable energy focused scenario. This is because hydropower energy consumes a great amount of water in form of evaporation from the reservoirs.

Year-wise total water consumption and withdrawals by individual scenarios are represented in Figure 3.2. Figure 3.3 shows the expected gallons of water usage by different energy sector in the scenarios defined. This water usage is based on the percent of the contribution made by all the sources in Turkish energy sector. Figure 3.3 is the extension of Figure 3.4 and it shows the results in terms of overall percentage. So, from Figure 3.3(a) and Figure 3.4 (a (i), (ii), (iii)), it is evident that hydropower energy sector is predicted to consume the maximum amount of water out of all the other energy sources. We can see that coal and natural gas power sectors are also expected to consume around 10% to 20% of the overall water with their percentages varying over time based on their contribution in the total power generation mix. For water withdrawal comparison, Figure 3.3(b) and Figure 3.4 (b (i), (ii), (iii)) show how energy sectors are predicted to withdraw water. Coal and natural gas power generation withdraw the maximum amount of water from the reservoirs for their electricity generation. Water withdrawal by nuclear power plants is expected to plunge as the power plants will come on-line and when they will start to produce electricity in coming years.

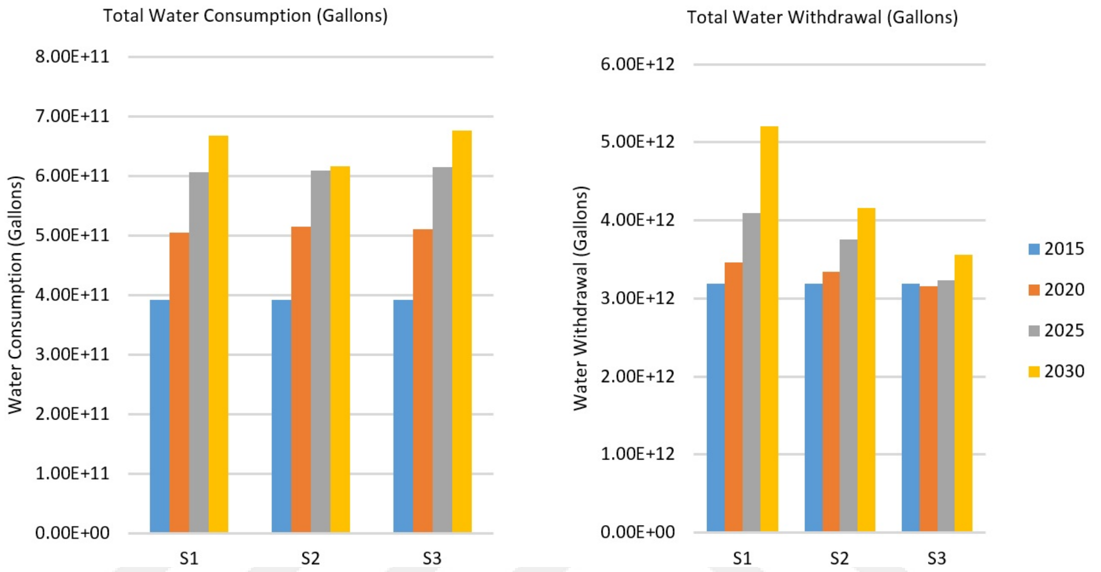

Figure 3.2: Water usage variation (a) S1, (b) S2, (c) S3.

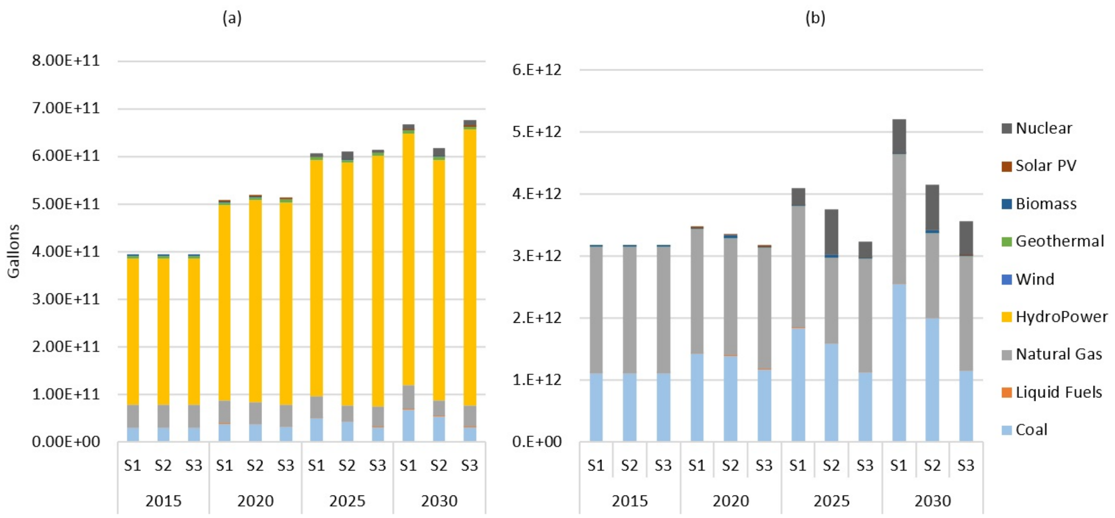

Figure 3.3: Water Usage comparisons (a) Water Consumption, (b) Water Withdrawal.

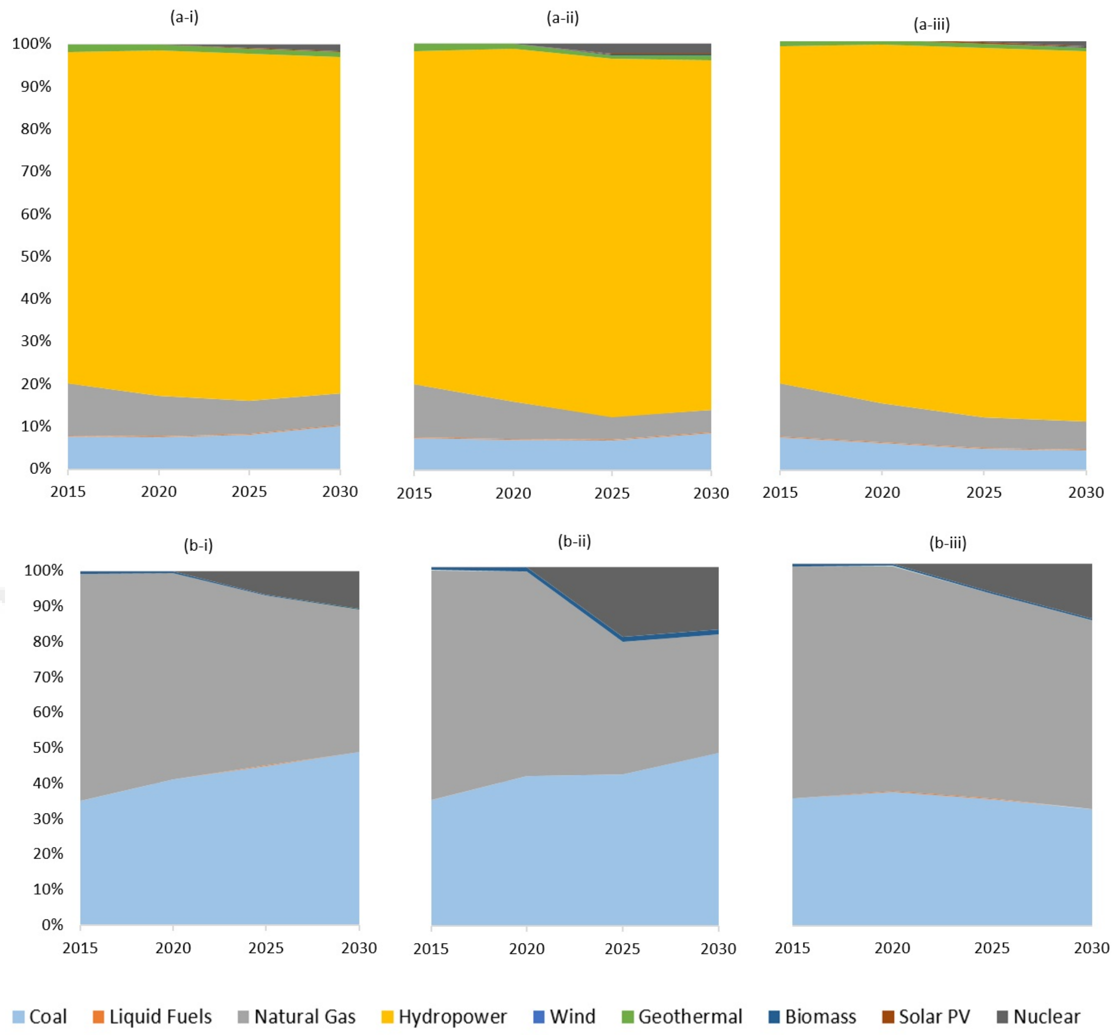

FIGURE 3.4: Water Usage Percentage comparison (a) Water Consumption, (b) Water Withdrawal; (i) Scenario1, (ii) Scenario 2, (iii) Scenario 3.

3.3 Comparison of carbon emission scenario results

Figure 3.5(a) shows the comparison between the total carbon emissions under different scenarios in Turkey and Figure 3.5(b) shows comparisons of carbon emissions based on the scenarios over time. If the development of Turkish energy sector continues to grow as per the Business-As-Usual (BAU) scenario, it will have highest carbon emissions as compared to Official Governmental Plan (OGP) scenario and Renewable Energy Focused Development Plan (REFDP). Under BAU scenario, carbon emissions are expected to increase at a constant pace from $1.21 * 10^8$ tons of CO_2 equivalent in 2015 to $1.62 * 10^8$ tons until 2025, marking an increase in carbon emissions of about 34% in just 10 years. This difference is expected to sharply increase in the following 5 years, and it is predicted that by 2025, Turkish carbon emissions under BAU scenario will go up to $2.05x10^8$ tons.

This enormous amount of carbon and equivalent gas emissions require about 4.8 billion tree seedling to be grown for continuously 10 years in order to curb the damages caused to the environment [75]. The primary reason in this increase in carbon emissions over time is the increased utilization of coal energy sources and steady growth of natural gas power plants.

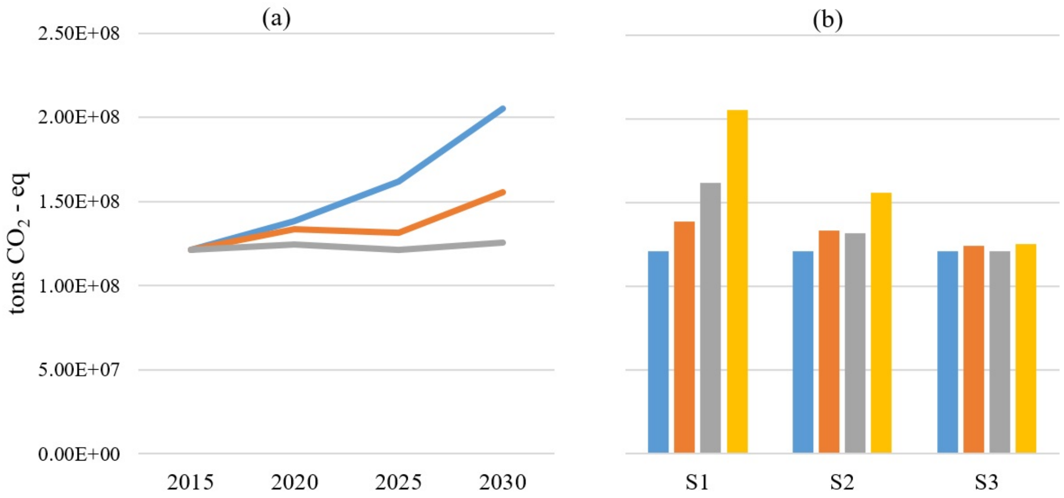

Figure 3.5: Carbon and equivalent gas emissions (a) Yearly comparison, (b) Head to head comparison of scenarios.

Conversely, OGP yields relatively less carbon emissions. From 2015 to 2020, we predict an increase of about 10.7% while it will almost remain at the same level until 2025. However, we expect a sharp increase of 28% until the year 2030. To absorb the amount of carbon emitted under scenario 2, 1.12 million acers of forestland is required to be preserved from conversion to cropland in one year [76]. As far as REFDP is concerned, it will result in the lowest amount of carbon emissions over the period of 25 years. Carbon emissions in this scenario are expected to remain steady as of the levels of 2015.

Figure 3.6 shows the contributions from all the power sources in polluting the environment and their expected trends based on different scenarios until year 2030. Coal and natural gas fired power generation sources dominate in all the scenarios while emissions from hydroelectric and solar PV power plants are to become prominent, as their contributions in overall energy sector mix will increase under REFDP scenario [77].

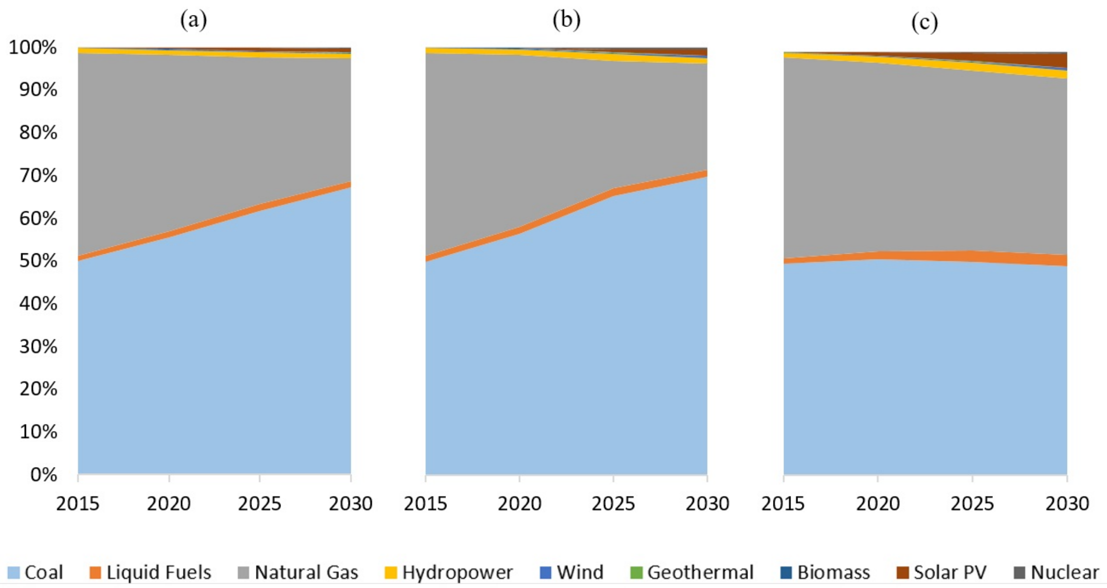

FIGURE 3.6: Carbon Emission percentage comparison (a) Scenario 1, (b) Scenario 2, (c) Scenario 3.

3.4 Water versus Carbon Footprints of Electricity Production Scenarios

The scenarios and results discussed in the earlier sections shows the expected growth of Turkish energy sector and predicted average water usage in terms of water consumption and withdrawal until 2030. Predictions about overall emissions of GHGs have also been made for the same time horizon. In order to study the linkage between carbon footprint and water footprint, correlation analysis between carbon emissions versus water consumption and carbon emissions versus water withdrawal is carried out as a tool to gauge the effects of variation in carbon and water footprints.

The results presented in Figure 3.7 show that under BAU scenario, total GHG emissions and total water withdrawal amounts are closely correlated - with 1:1 ratio, even more than GHG emissions and water consumption levels - with 1:0.94 ratio. Likewise, under OGP scenario, overall carbon emissions and water withdrawals have a ratio of 1:0.90, while carbon emissions and water consumption have a correlation of 1:0.76. However, REFDP scenario yields correlation values between carbon emissions versus water withdrawal and carbon emissions versus water consumption to be 1:0.63 and 1:0.53, respectively. These results give us the significance of restiveness between carbon and water footprints and their sensitiveness to the GHG emissions. For example, a correlation of 1:0.63 between GHG emissions and water withdrawal in REFDP illustrates that an increase in one factor of carbon emission will result in increase in water withdrawal, but with a factor of 0.63. Hence, based on the correlation results, REFDP is highly preferable under the threats of increased water scarcity and increasing carbon emissions.

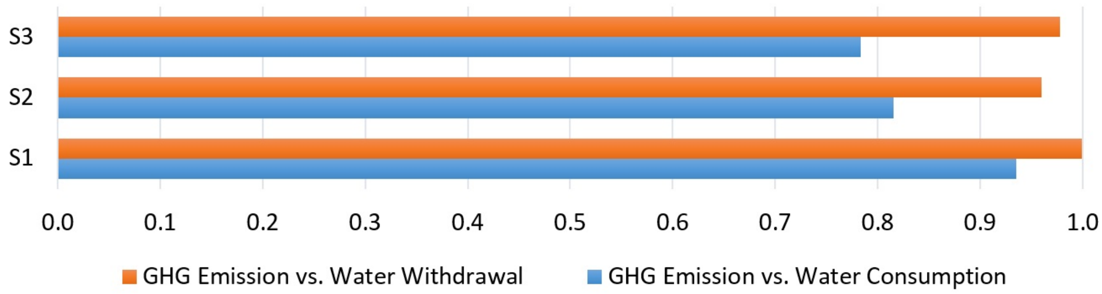

Figure 3.7: Correlation analysis of GHG Emissions Vs Water Consumption and Withdrawal.

Through this, policy makers and environmentalists will be able to see the trade-off between carbon emissions and water usage while devising the development of energy sector in Turkey. The decision support tool developed as part of this thesis (see appendix) is designed to enable the policy makers study the changes in water usages and carbon emissions as percentages of energy mixes are changed. Therefore, the percentages can be changed and their effect on the water consumption and withdrawals levels along with carbon emissions in the country. From our results, it is revealed that carbon and water footprints are positively correlated with each other; therefore, developing policies to reduce carbon emissions with also decrease water consumption and withdrawal. Furthermore, we found that coal, natural gas, hydropower and nuclear energy consumed the great amount of water while producing electricity. Additionally coal, natural gas and nuclear withdraws much of the water as well. Similarly, coal and natural gas fired power plants contribute most to the pollution in the country. Thus, we synthesis that hydropower sources, which are taken as renewable sources of energy, are a burden on the water resources. Likewise, this study can help the policy makers in deciding the policies when planning for power plants in the country.

Chapter 4

Conclusions and Future Work

The decision support tool developed in this study will serve in the critical decision-making about the future energy policies at national scale. Energy demand is growing at a rapid pace and various energy projects are under the phase of conceptualization and planning. Water is also becoming a scare resource and policy makers consider the implications of water parallel to the other environmental aspects while making plans of catering electricity demands. This study can be considered as a stepping-stone in developing a framework for considering the impacts of electricity production sources on national water resources in terms of water consumption and withdrawals. The decision support tool will enable the decision makers change their desired energy mixes and observe the corresponding results on water sources. We carried out a detailed study on the Turkish energy sector and its growth until 2030 under BAU, OGP and REFDP scenarios. Some of the general remarks and important results are summarized as follows:

- Hydropower consumes the maximum amount of water out of all the energy sources. Coal and natural gas power plants dominate in water withdrawals and carbon emissions. The findings also show that nuclear energy will also use a considerable amount of water resource, as their power plants will start to produce electricity with time.

- The Business-As-Usual (Scenario 1) consumes less water than the Official Governmental Plan (Scenario 2) and the Renewable Energy Focused Development Plan (Scenario 3) in 2020 and 2025. However, S1's water consumption will be greater than S2 and comparative to S3 by 2030. Hence, S2 is the most water efficient scenario as far as water consumption is concerned.

- Considering water withdrawals, S1 is found to withdraw the maximum water out of all the scenarios. Water withdrawal levels by individual scenarios are decreasing from S1 to S2 to S3. Therefore, S3 turn out to be the most efficient scenario in this case.
- S3 is the suggested scenario for future energy policy development because it is found to use the least water and emit the least carbon emissions among other scenarios.
- Water usage and GHG emissions are strongly correlated in S1. In S2, correlation weakens to about 12% and to 25% in S3 as compared with S1. Hence, re-establishing the eco-friendliness of REFDP scenarios in comparison with others.

The energy-water nexus is a trade-off between water consumption and water withdrawals by the individual energy sources [78]. Water usage is varied significantly from one power plant to another and it is dependent on many factors one of which is the cooling technology used. In this study, the average multipliers are used. However, maximum and minimum ranges of the results can be seen in the supporting information file mentioned in the appendix. Our aim for the future study is to categorize the power plants in Turkey through building a database and linking the decision support tool with it. In addition, we would like to extend this study to the other countries such as UK, European Union and United States.

Appendix A

Supporting Information File

Online link of Decision Support Tool

https://drive.google.com/open?id=0B93h7kps4ARzbzBMQklWSU1ES3M

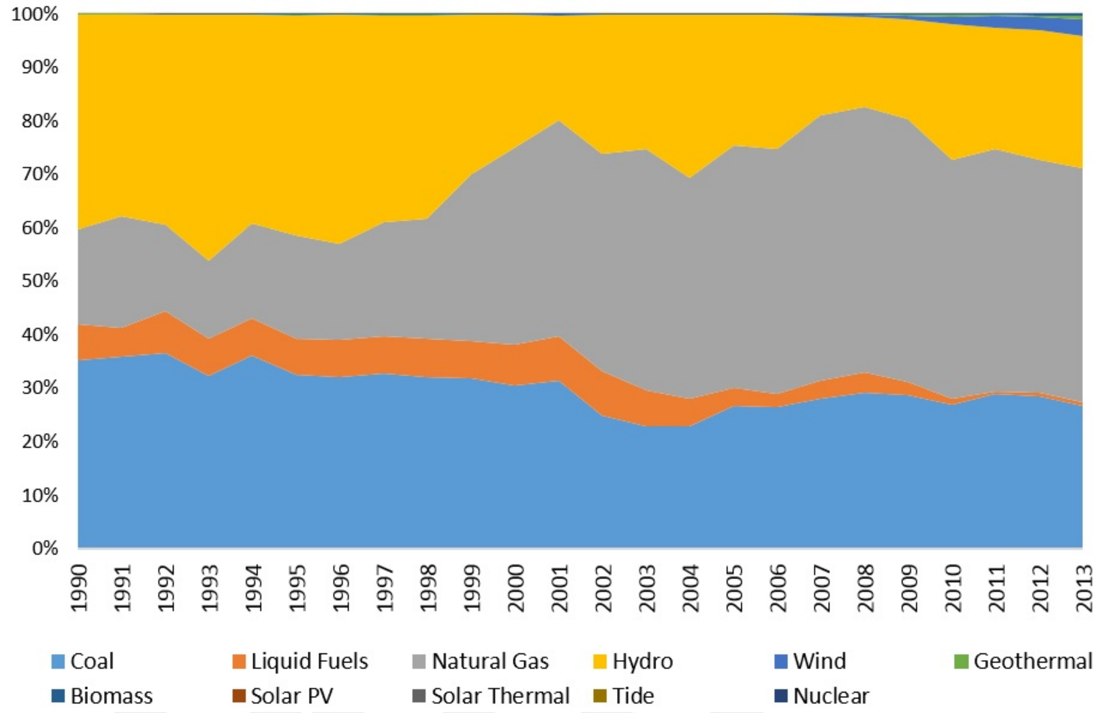

FIGURE A.1: Turkey sector wise electricity mix ("Electricity and Heat Statistics", 2016).

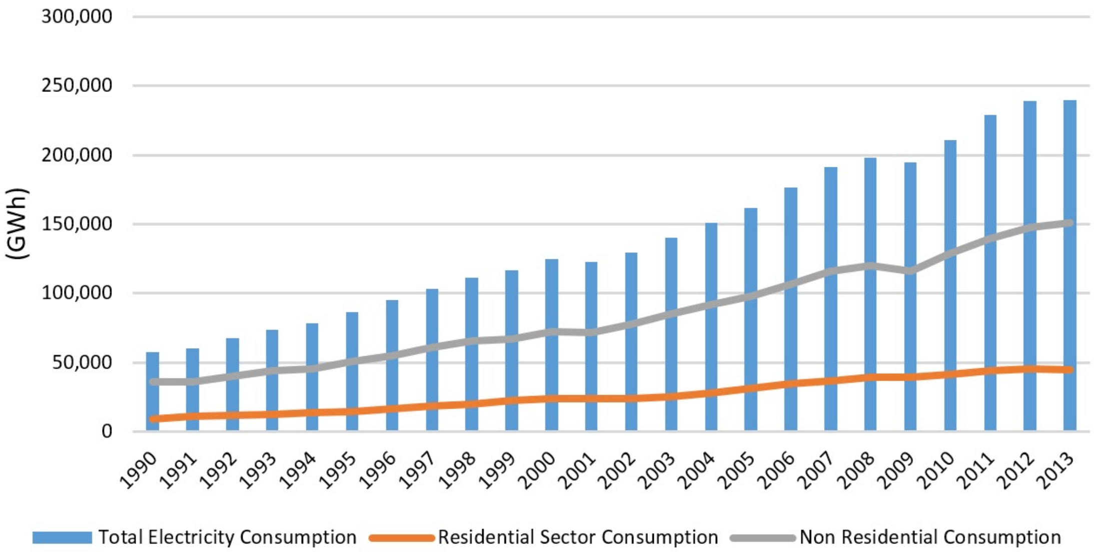

FIGURE A.2: Turkey Energy Consumption (1990 - 2013) ("Electricity and Heat Statistics", 2016).

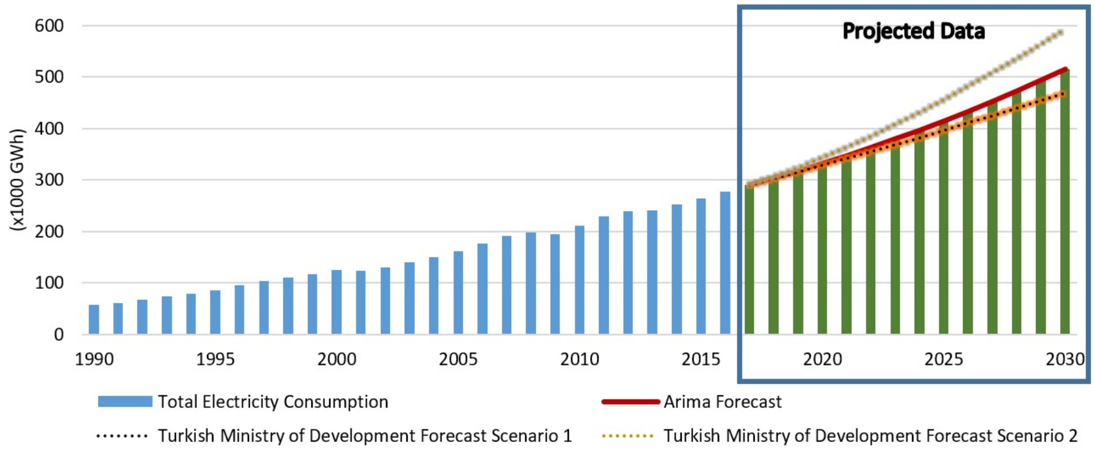

FIGURE A.3: Turkey's energy consumption over time.

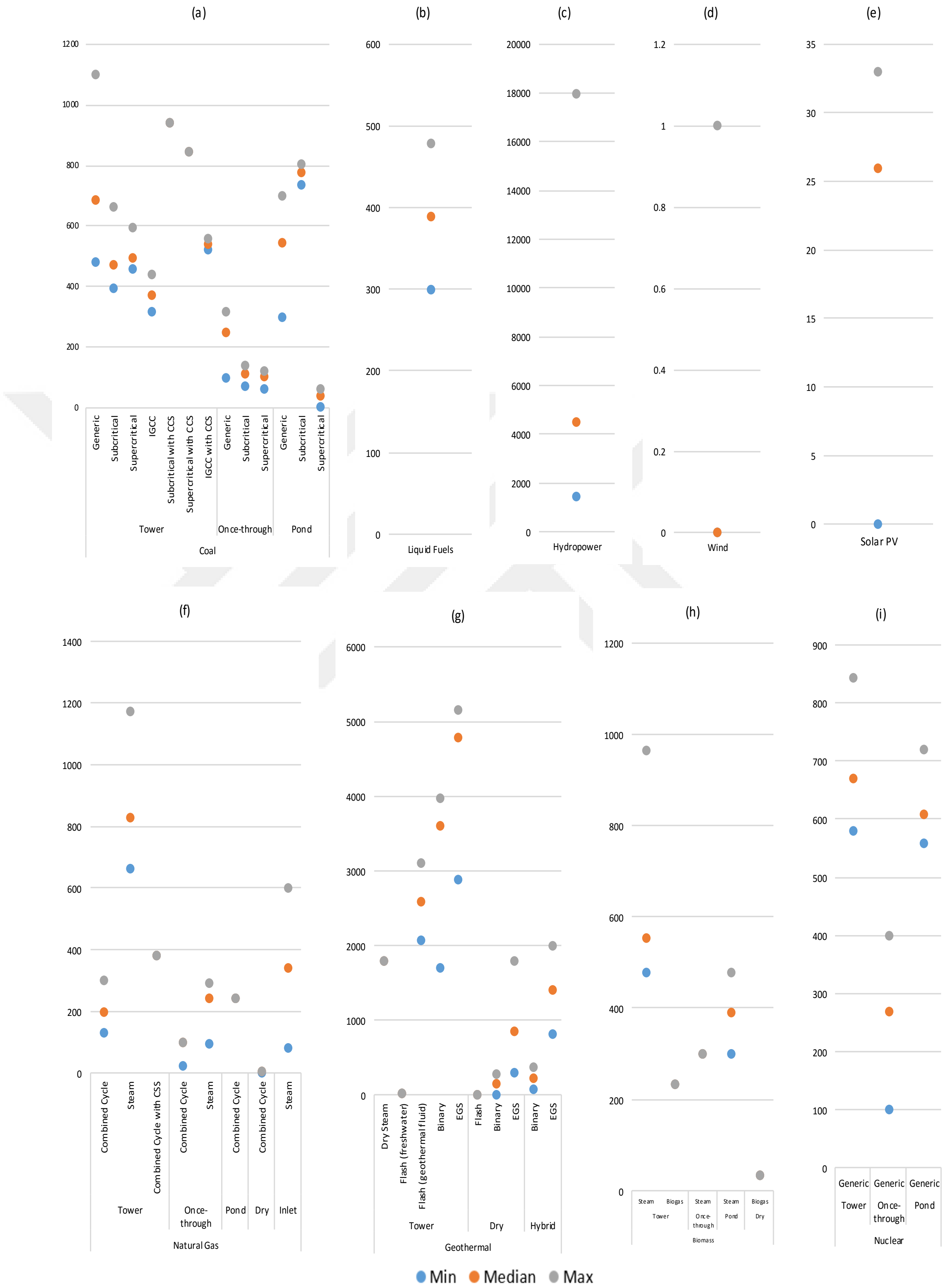

FIGURE A.4: Water Consumption Factors (Gal/MWh) (a) Coal, (b) Liquid Fuels, (c) Hydropower, (d) Wind, (e) Solar PV, (f) Natural Gas, (g) Geothermal, (h) Biomass, (i) Nuclear.

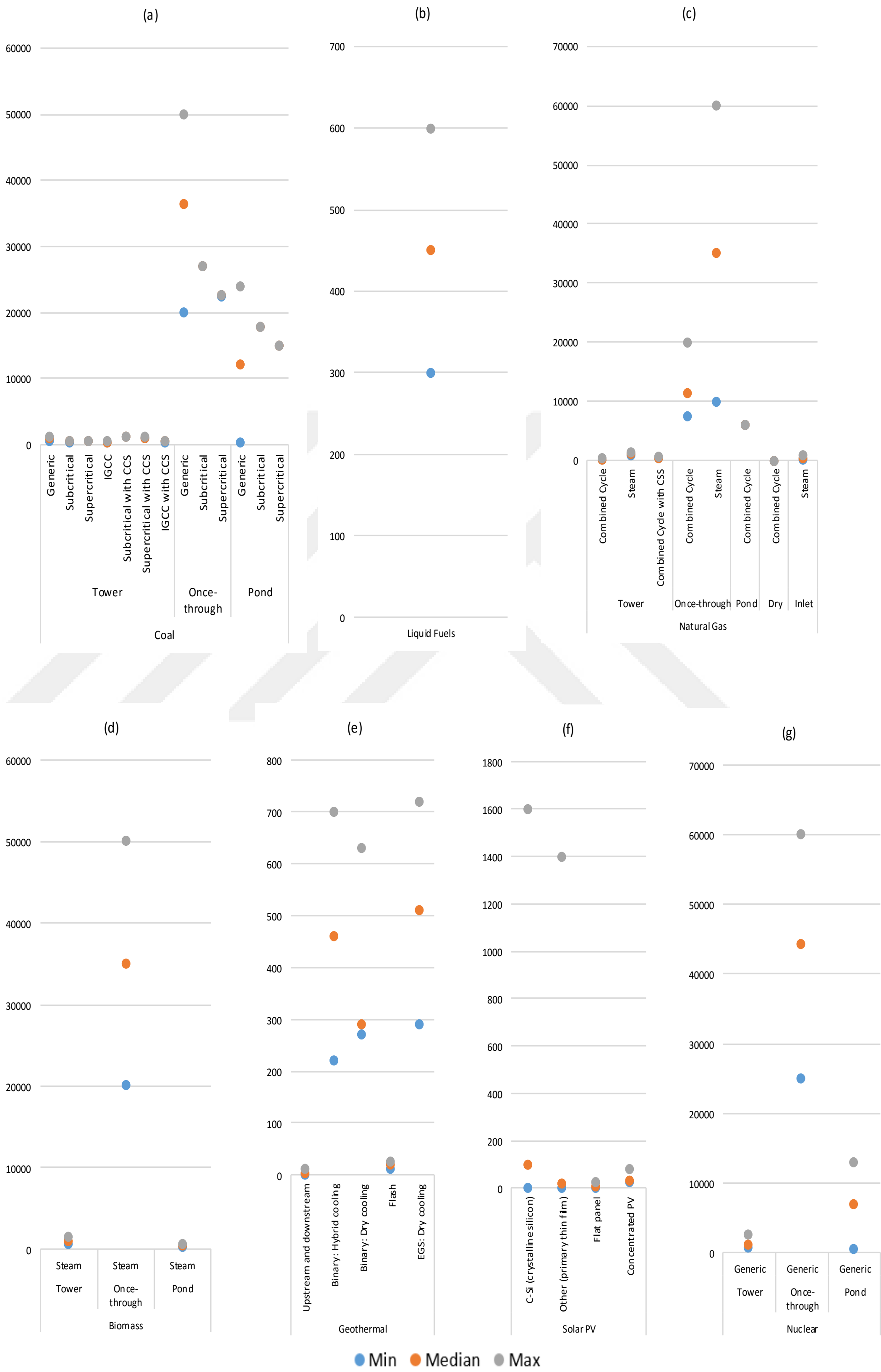

Figure A.5: Water Withdrawal Factors (Gal/MWh) (a) Coal, (b) Liquid Fuels, (c) Natural Gas, (d) Biomass, (e) Geothermal, (f) Solar PV, (g) Nuclear.

Bibliography

[1] U. Nations and C. Singer. *Human Development Report 2006 - Beyond scarcity: Power, poverty and the global water crisis*, volume 28. 2006. ISBN 0230500587. doi: 10.1016/S1352-0237(02)00387-8. URL `http://hdr.undp.org/en/media/HDR06-complete.pdf`.

[2] O. D. L. N. Unidas. Coping with water scarcity: Challenge of the twenty-first century. *Un Water*, 24(1):28–29, 2005. ISSN 0262-8104. doi: 10.3362/0262-8104.2005.038. URL `http://developmentbookshelf.com/openurl.asp?genre=article{&}id=doi:10.3362/0262-8104.2005.038`.

[3] C. W. King, A. S. Holman, and M. E. Webber. Thirst for energy. *Nature Geosci*, 1(5):283–286, may 2008. ISSN 1752-0894. URL `http://dx.doi.org/10.1038/ngeo195`.

[4] X. Zhang and V. V. Vesselinov. Energy-water nexus: Balancing the tradeoffs between two-level decision makers. *Applied Energy*, 183:77–87, 2016. ISSN 0306-2619. doi: 10.1016/j.apenergy.2016.08.156. URL `http://dx.doi.org/10.1016/j.apenergy.2016.08.156`.

[5] T O Wiedmann, H Schandl, M Lenzen, D Moran, S Suh, J West, and K Kanemoto. The material footprint of nations. *Proc Natl Acad Sci U S A*, 112(20):6271–6276, 2015. ISSN 0027-8424. doi: 10.1073/pnas.1220362110. URL `http://www.ncbi.nlm.nih.gov/pubmed/24003158`.

[6] S. Hadian and K. Madani. The Water Demand of Energy: Implications for Sustainable Energy Policy Development. *Sustainability*, 5(11):4674–4687, 2013. ISSN 2071-1050. doi: 10.3390/su5114674. URL `http://www.mdpi.com/2071-1050/5/11/4674/`.

[7] M. Halstead, T. Kober, and B. C. C. Zwaan. Understanding the energy-water nexus. *Policy Studies*, 2013(September):2012, 2014.

[8] A. Y. Hoekstra and T. O. Wiedmann. Humanity's unsustainable environmental footprint. *Science*, 344(6188):1114–1117, 2014. ISSN 1095-9203. doi: 10.1126/science.1248365.

[9] T. H. E. Central, Role Of, Wastewater Management, and I. N. Sustainable. *Sick Water - the Central Role of Wastewater Management in Sustainable Development.* 2010. ISBN 9788277010755. doi: 10.1007/s10230-011-0140-x. URL `www.grida.no`.

[10] *World Energy.* 2012. ISBN 9789264180840. URL `http://www.bp.com/extendedsectiongenericarticle.do?categoryId=9041233{&}contentId=7075263`.

[11] P. Taylor, J. Alcamo, M. Flörke, and M. Märker. Future long-term changes in global water resources driven by socio-economic and climatic changes Future long-term changes in global water resources driven by socio-economic and climatic changes. *October*, 6667(January 2012):37–41, 2007. ISSN 0262-6667. doi: 10.1623/hysj.52.2.247.

[12] K. Kaygusuz. Energy and environmental issues relating to greenhouse gas emissions for sustainable development in Turkey. *Renewable and Sustainable Energy Reviews*, 13(1):253–270, 2009. ISSN 13640321. doi: 10.1016/j.rser.2007.07.009.

[13] I. Ozturk and A. Acaravci. CO2 emissions, energy consumption and economic growth in Turkey. *Renewable and Sustainable Energy Reviews*, 14(9):3220–3225, 2010. ISSN 13640321. doi: 10.1016/j.rser.2010.07.005. URL `http://dx.doi.org/10.1016/j.rser.2010.07.005`.

[14] H. D. Matthews. A growing commitment to future CO2 emissions. *Environmental Research Letters*, 9(11):111001, 2014. ISSN 1748-9326. doi: 10.1088/1748-9326/9/11/111001. URL `http://stacks.iop.org/1748-9326/9/i=11/a=111001`.

[15] D. Satterthwaite. Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions. *Environment and Urbanization*, 20(2):539–549, 2008. ISSN 0956-2478. doi: 10.1177/0956247808096127. URL `http://journals.sagepub.com/doi/10.1177/0956247808096127`.

[16] S. H. Pishgar-Komleh, M. Omid, and M. D. Heidari. On the study of energy use and GHG (greenhouse gas) emissions in greenhouse cucumber production in Yazd province. *Energy*, 59:63–71, 2013. ISSN 03605442. doi: 10.1016/j.energy.2013.07.037. URL `http://dx.doi.org/10.1016/j.energy.2013.07.037`.

[17] S. Yu, Y. M. Wei, H. Guo, and L. Ding. Carbon emission coefficient measurement of the coal-to-power energy chain in China. *Applied Energy*, 114:290–300, 2014. ISSN 03062619. doi: 10.1016/j.apenergy.2013.09.062. URL `http://dx.doi.org/10.1016/j.apenergy.2013.09.062`.

[18] J. Rogelj, M. Schaeffer, M. Meinshausen, D. T. Shindell, W. Hare, Z. Klimont, G. J. M. Velders, M. Amann, and H. J. Schellnhuber. Disentangling the effects of CO ₂ and short-lived climate forcer mitigation. *Proceedings of the National Academy of Sciences*, 111(46):16325–16330, 2014. ISSN 0027-8424. doi: 10.1073/pnas.1415631111. URL `http://www.pnas.org/lookup/doi/10.1073/pnas.1415631111`.

[19] Y. J. Zhang and Y. B. Da. The decomposition of energy-related carbon emission and its decoupling with economic growth in China. *Renewable and Sustainable Energy Reviews*, 41:1255–1266, 2015. ISSN 13640321. doi: 10.1016/j.rser.2014.09.021. URL `http://dx.doi.org/10.1016/j.rser.2014.09.021`.

[20] V. Andreoni and S. Galmarini. Decoupling economic growth from carbon dioxide emissions: A decomposition analysis of Italian energy consumption. *Energy*, 44 (1):682–691, 2012. ISSN 03605442. doi: 10.1016/j.energy.2012.05.024. URL `http://dx.doi.org/10.1016/j.energy.2012.05.024`.

[21] M. R. Raupach, S. J. Davis, G. P. Peters, R. M. Andrew, J. G. Canadell, P. Ciais, P. Friedlingstein, F. Jotzo, Detlef P. van V., and C. Le Quéré. Sharing a quota on cumulative carbon emissions. *Nature Climate Change*, 4(10):873–879, 2014. ISSN 1758-678X. doi: 10.1038/nclimate2384. URL `http://www.nature.com/doifinder/10.1038/nclimate2384`.

[22] S. R. Allen and G. P. Hammond. Thermodynamic and carbon analyses of micro-generators for UK households. *Energy*, 35(5):2223–2234, 2010. ISSN 03605442. doi: 10.1016/j.energy.2010.02.008. URL `http://dx.doi.org/10.1016/j.energy.2010.02.008`.

[23] R. TuÇ§rul OÇ§ulata. Energy sector and wind energy potential in Turkey. *Renewable and Sustainable Energy Reviews*, 7(6):469–484, 2003. ISSN 13640321. doi: 10.1016/S1364-0321(03)00090-X.

[24] I. H. S. Edin. Sector organization. 2015:1–10, 2015.

[25] W. N. Association. URL `http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/turkey.aspx`.

[26] Turkey's Policy on Water Issues, 2016. URL `http://www.mfa.gov.tr/turkey{_}s-policy-on-water-issues.en.mfa`.

[27] S. Abu-Ghosh, D. Fixler, Z. Dubinsky, and D. Iluz. Energy-input analysis of the life-cycle of microalgal cultivation systems and best scenario for oil-rich biomass production. *Applied Energy*, 154:1082–1088, 2014. ISSN 18729118. doi: 10.1016/j.apenergy.2015.02.086. URL `http://dx.doi.org/10.1016/j.apenergy.2015.02.086`.

[28] B. Atilgan and A. Azapagic. An integrated life cycle sustainability assessment of electricity generation in Turkey. *Energy Policy*, 93:168–186, 2016. ISSN 03014215. doi: 10.1016/j.enpol.2016.02.055. URL `http://dx.doi.org/10.1016/j.enpol.2016.02.055`.

[29] A. Ç. Köne and T. Büke. An Analytical Network Process (ANP) evaluation of alternative fuels for electricity generation in Turkey. *Energy Policy*, 35(10):5220–5228, 2007. ISSN 03014215. doi: 10.1016/j.enpol.2007.05.014.

[30] A. Demirba. Turkey's energy overview beginning in the twenty-first century. *Energy Conversion and Management*, 43(14):1877–1887, 2002. ISSN 01968904. doi: 10.1016/S0196-8904(01)00124-8.

[31] J. Yang and B. Chen. Energy-water nexus of wind power generation systems. *Applied Energy*, 169:1–13, 2016. ISSN 03062619. doi: 10.1016/j.apenergy.2016.02.010. URL `http://dx.doi.org/10.1016/j.apenergy.2016.02.010`.

[32] S. Chen and B. Chen. Urban energy???water nexus: A network perspective. *Applied Energy*, 184:905–914, 2016. ISSN 03062619. doi: 10.1016/j.apenergy.2016.03.042. URL `http://dx.doi.org/10.1016/j.apenergy.2016.03.042`.

[33] W. Huang, D. Ma, and W. Chen. Connecting water and energy: Assessing the impacts of carbon and water constraints on China's power sector. *Applied Energy*, 185:1497–1505, 2015. ISSN 03062619. doi: 10.1016/j.apenergy.2015.12.048. URL http://dx.doi.org/10.1016/j.apenergy.2015.12.048.

[34] K. Madani and S. Khatami. Water for Energy: Inconsistent Assessment Standards and Inability to Judge Properly. *Current Sustainable/Renewable Energy Reports*, 2(1):10–16, 2015. ISSN 2196-3010. doi: 10.1007/s40518-014-0022-5. URL http://link.springer.com/article/10.1007/s40518-014-0022-5{%}5Cnfiles/1713/Madani{_}Khatami{_}2015{_}WaterforEnergy.pdf{%}5Cnfiles/1712/s40518-014-0022-5.html.

[35] K. Feng, A. Chapagain, S. Suh, S. Pfister, and K. Hubacek. Comparison of Bottom-Up and Top-Down Approaches To Calculating the Water Footprints of Nations. *Economic Systems Research*, 23(4):371–385, 2011. ISSN 0953-5314. doi: 10.1080/09535314.2011.638276. URL http://www.tandfonline.com/doi/abs/10.1080/09535314.2011.638276.

[36] N. Zhang and Y. Choi. Total-factor carbon emission performance of fossil fuel power plants in China: A metafrontier non-radial Malmquist index analysis. *Energy Economics*, 40:549–559, 2013. ISSN 01409883. doi: 10.1016/j.eneco.2013.08.012. URL http://dx.doi.org/10.1016/j.eneco.2013.08.012.

[37] Electricity and Heat Statistics, 2016. URL http://www.iea.org/statistics/statisticssearch/report/?country=TURKEY={&}product=electricityandheat{&}year=Select.

[38] T. S. Institute, 2016. URL http://www.turkstat.gov.tr/.

[39] Z. Wang, R. Wennersten, and Q. Sun. Outline of principles for building scenarios - Transition toward more sustainable energy systems. *Applied Energy*, 2015. ISSN 03062619. doi: 10.1016/j.apenergy.2015.12.062. URL http://dx.doi.org/10.1016/j.apenergy.2015.12.062.

[40] R. Bertani. Geothermal power generation in the world 2005-2010 update report. *Geothermics*, 41(2012):1–29, 2012. ISSN 03756505. doi: 10.1016/j.geothermics.2011.10.001. URL http://dx.doi.org/10.1016/j.geothermics.2011.10.001.

[41] P. Kanunu, T. Elektrik, E. R. P. Talep, Y. S. A ları, R. M. T. Aylı k, and M. Carlo. ölçen bir uzaklık matrisi tanımlanmı, her bir senaryo için oluturulan uzaklık matrisleri birbiriyle en uyumlu olduu modellerin seçilmesi stratejisi izlenmitir . Seçilen modellere ilikin ekil 1 . Elektrik Enerjisi Talep Projeksiyonu Sonuçları- Yıll. pages 3–4.

[42] J. Macknick, R. Newmark, G. Heath, and K. C. Hallett. Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. *Environmental Research Letters*, 7(4):045802, 2012. ISSN 1748-9326. doi: 10.1088/1748-9326/7/4/045802. URL `http://iopscience.iop.org.lib-ezproxy.tamu.edu:2048/1748-9326/7/4/045802/article/`.

[43] V. Fthenakis and H. C. Kim. Life-cycle uses of water in U.S. electricity generation. *Renewable and Sustainable Energy Reviews*, 14(7):2039–2048, 2010. ISSN 13640321. doi: 10.1016/j.rser.2010.03.008. URL `http://dx.doi.org/10.1016/j.rser.2010.03.008`.

[44] J. Macknick, J. Meldrum, S. Nettles-Anderson, G. Heath, and A. Miara. Life cycle water use for photovoltaic electricity generation: A review and harmonization of literature estimates. *2014 IEEE 40th Photovoltaic Specialist Conference, PVSC 2014*, 015031:1458–1460, 2014. ISSN 1748-9326. doi: 10.1109/PVSC.2014.6925190.

[45] Y. Shang, P. Hei, S. Lu, L. Shang, X. Li, Y. Wei, D. Jia, D. Jiang, Y. Ye, J. Gong, X. Lei, M. Hao, Y. Qiu, J. Liu, and H. Wang. China's energy-water nexus: Assessing water conservation synergies of the total coal consumption cap strategy until 2050. *Applied Energy*, 2016. ISSN 03062619. doi: 10.1016/j.apenergy.2016.11.008. URL `http://linkinghub.elsevier.com/retrieve/pii/S030626191631594X`.

[46] M. M. Mekonnen and A. Y. Hoekstra. The blue water footprint of electricity from hydropower. *Hydrology and Earth System Sciences*, 16(1):179–187, 2012. ISSN 10275606. doi: 10.5194/hess-16-179-2012.

[47] P. L. Spath, M. K. Mann, and D. R. Kerr. Life Cycle Assessment of Coal-fired Power Production. *Other Information: Supercedes report DE00012100; PBD: 1 Sep 1999; PBD: 1 Sep 1999*, page 172, 1999. doi: 10.2172/12100. URL `/servlets/purl/12100-SypAiE/webviewable/`.

[48] P.L. Spath and M.K. Mann. Life Cycle Assessment of a Natural Gas Combined Cycle Power Generation System. pages 1–56, 2000. doi: 10.2172/776930. URL `http://www.osti.gov/servlets/purl/776930-cjKyRK/native/`.

[49] H. Hondo. Life cycle GHG emission analysis of power generation systems: Japanese case. *Energy*, 30(11-12 SPEC. ISS.):2042–2056, 2005. ISSN 03605442. doi: 10.1016/j.energy.2004.07.020.

[50] S. W. White and G. L. Kulcinski. Birth to death analysis of the energy payback ratio and CO2 gas emission rates from coal, fission, wind, and DT-fusion electrical power plants. *Fusion Engineering and Design*, 48(3-4):473–481, 2000. ISSN 09203796. doi: 10.1016/S0920-3796(00)00158-7. URL `http://www.sciencedirect.com/science/article/pii/S0920379600001587`.

[51] N. A. Odeh and T. T. Cockerill. Life cycle GHG assessment of fossil fuel power plants with carbon capture and storage. *Energy Policy*, 36(1):367–380, 2008. ISSN 03014215. doi: 10.1016/j.enpol.2007.09.026.

[52] P. J. Meier. Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis. *PhD Thesis*, (August):147, 2002. doi: UWFDM-1181.

[53] R. M. Neilson K. K. Bloomfield, J. N. Moore. Geothermal energy reduces greenhouse gases. *Bulletin. Geothermal Resources Council*, 32(2):77–79, 2003.

[54] S. Frick, M. Kaltschmitt, and G. Schröder. Life cycle assessment of geothermal binary power plants using enhanced low-temperature reservoirs. *Energy*, 35(5):2281–2294, 2010. ISSN 03605442. doi: 10.1016/j.energy.2010.02.016.

[55] Spitzley, D. V. and G. A. Keoleian. No TitleLife cycle environmental and economic assessment of willow biomass electricity: A comparison with other renewable and non-renewable sources. Technical report, University of Michigan, Center for Sustainable Systems, 2005.

[56] D. Nugent and B. K. Sovacool. Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey. *Energy Policy*, 65:229–244, 2014. ISSN 03014215. doi: 10.1016/j.enpol.2013.10.048. URL `http://dx.doi.org/10.1016/j.enpol.2013.10.048`.

[57] G. A. Thopil and A. Pouris. Aggregation and internalisation of electricity externalities in South Africa. *Energy*, 82:501–511, 2015. ISSN 03605442. doi: 10.1016/j.energy.2015.01.059. URL `http://dx.doi.org/10.1016/j.energy.2015.01.059`.

[58] B. Mainali, S. Been Emran, and S. Silveira. Greenhouse gas mitigation using poultry litter management techniques in Bangladesh. *Energy*, 127:155–166, 2017. ISSN 03605442. doi: 10.1016/j.energy.2017.03.103. URL `http://dx.doi.org/10.1016/j.energy.2017.03.103`.

[59] M. Duran Toksari. Ant colony optimization approach to estimate energy demand of Turkey. *Energy Policy*, 35(8):3984–3990, 2007. ISSN 03014215. doi: 10.1016/j.enpol.2007.01.028.

[60] A. Ünler. Improvement of energy demand forecasts using swarm intelligence: The case of Turkey with projections to 2025. *Energy Policy*, 36(6):1937–1944, 2008. ISSN 03014215. doi: 10.1016/j.enpol.2008.02.018.

[61] A. Sözen, E. Arcaklio lu, and M. Özkaymak. Turkey's net energy consumption. *Applied Energy*, 81(2):209–221, 2005. ISSN 03062619. doi: 10.1016/j.apenergy.2004.07.001.

[62] IPCC. Summary for Policymakers. *Climate Change 2014: Impacts, Adaptation and Vulnerability - Contributions of the Working Group II to the Fifth Assessment Report*, pages 1–32, 2014. ISSN 09601481. doi: 10.1016/j.renene.2009.11.012.

[63] R. Ghanadan and J. G. Koomey. Using energy scenarios to explore alternative energy pathways in California. *Energy Policy*, 33(9):1117–1142, 2005. ISSN 03014215. doi: 10.1016/j.enpol.2003.11.011.

[64] M. Jefferson. *Beyond Positive Economics?* Palgrave Macmillan UK, 1983. ISBN 978-1-349-16992-4.

[65] I. Wilson. From scenario thinking to strategic action. *Technological Forecasting and Social Change*, 65(1):23–29, 2000. ISSN 00401625. doi: 10.1016/S0040-1625(99)00122-5.

[66] E. Georgopoulou, D. Lalas, and L. Papagiannakis. A multicriteria decision aid approach for energy planning problems: The case of renewable energy option. *European Journal of Operational Research*, 103(1):38–54, 1997. ISSN 03772217. doi:

10.1016/S0377-2217(96)00263-9. URL http://www.sciencedirect.com/science/article/pii/S0377221796002639.

[67] K. Kowalski, S. Stagl, R. Madlener, and I. Omann. Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. *European Journal of Operational Research*, 197(3):1063–1074, 2009. ISSN 03772217. doi: 10.1016/j.ejor.2007.12.049. URL http://dx.doi.org/10.1016/j.ejor.2007.12.049.

[68] UNFCCC. Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. *Unfccc*, 01192(January), 2015.

[69] UNFCCC. Conference of the Parties (COP). Adoption of the Paris Agreement. Proposal by the President. *Paris Climate Change Conference - November 2015, COP 21*, 21932(December):32, 2015. ISSN 1098-6596. doi: FCCC/CP/2015/L.9/Rev.1. URL http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

[70] Enerji ve Tabii Kaynaklar Bakanlı. National Renewable Energy Action Plan. (December):1–229, 2009.

[71] Executive Summary, Coal Expansion, Public Support, Coal Subsidies, Producer Subsidies, Producer Subsidies, Power Production, Consumer Subsidies, Negative Externalities, Public Health, Climate Change, International Public Finance, Bilateral Public Finance, Policy Lending, Financial Intermediaries, Ending Public Support, Appendix A Turkish, Coal Subsidies, Public Assistance, Appendix B World, Bank Energy, Sector Policy, and Technical Assistance. Turkey ' s Coal Subsidies and Public Finance. 2014.

[72] N. For. Energy Action Document 2015. (Ipa Ii):2014–2020, 2015.

[73] O. Yuksek, M. I. Komurcu, I. Yuksel, and K. Kaygusuz. The role of hydropower in meeting Turkey's electric energy demand. *Energy Policy*, 34(17):3093–3103, 2006. ISSN 03014215. doi: 10.1016/j.enpol.2005.06.005.

[74] F. E. Boran, K. Boran, and T. Menlik. The Evaluation of Renewable Energy Technologies for Electricity Generation in Turkey Using Intuitionistic Fuzzy TOPSIS. *Energy Sources, Part B: Economics, Planning, and Policy*, 7(1):81–90, 2012. ISSN 1556-7249. doi: 10.1080/15567240903047483.

[75] M. S. Kiran, E. Özceylan, M. Gündüz, and T. Paksoy. Swarm intelligence approaches to estimate electricity energy demand in Turkey. *Knowledge-Based Systems*, 36:93–103, 2012. ISSN 09507051. doi: 10.1016/j.knosys.2012.06.009.

[76] Forestry Agriculture, Use, and Other Land. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, 2006. URL http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

[77] B. Greening and A. Azapagic. Environmental impacts of micro-wind turbines and their potential tocontribute to UK climate change targets. *Energy*, 59:454–466, 2013. ISSN 03605442. doi: 10.1016/j.energy.2013.06.037. URL http://dx.doi.org/10.1016/j.energy.2013.06.037.

[78] N. C. Onat, M. Kucukvar, and O. Tatari. Conventional, hybrid, plug-in hybrid or electric vehicles? State-based comparative carbon and energy footprint analysis in the United States. *Applied Energy*, 150:36–49, 2015. ISSN 03062619. doi: 10.1016/j.apenergy.2015.04.001. URL http://dx.doi.org/10.1016/j.apenergy.2015.04.001.