Meeting Climate Targets for Major Carbon Emitters in the Middle East: The Role of Natural Gas and Renewable Technology Transitions

by

Norhan M. Bayomi

Bachelor of Science in Architecture,
Cairo University, 2008

Masters of Science in Architecture
Cairo University, 2012

Submitted to the Department of Architecture
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Building Technology
at the

Massachusetts Institute of Technology

June 2017

Signature of Author: Signature redacted
Department of Architecture
May 1st, 2017

Certified by: Signature redacted
John. E. Fernandez
Professor of Building Technology
Thesis Supervisor

Accepted by: Signature redacted
Sheila Kennedy
Professor of Architecture
Chair of the Department Committee on Graduate Students

Thesis Committee

John E. Fernandez
Thesis Supervisor
Professor of Building Technology
Department of Architecture
Massachusetts Institute of Technology

Christoph Reinhart
Thesis Reader
Professor of Building Technology
Department of Architecture
Massachusetts Institute of Technology

Mandira Roy
Thesis Reader
Research Associate
Institute for Data, Systems and Society
School of Engineering
Massachusetts Institute of Technology

Meeting Climate Targets for Major Carbon Emitters in the Middle East: The Role of Natural Gas and Renewable Technology Transitions

by

Norhan M. Bayomi

Submitted to the Department of Architecture
on May 1, 2017 in partial fulfillment of the requirements for the
Degree of Master of Science in Building Technology

Abstract

Energy is a key ingredient to facilitate economic development in the Middle East. Expectations for a rapidly growing economy in the next decade will likely cause an increase in the fraction of energy consumed domestically tumbling what is available for export. Rising living standards, energy-intensive urban expansion and mounting power demands compound the energy challenge in the Middle East. After Paris Climate Agreement in 2015, countries in the Middle East have committed to curb their GHG emissions and increase the deployment of renewable technologies. As a result, energy systems have been under significant transitions driven by environmental policies and economic development. The thesis explores the role of energy supply and power generation sector in the Middle East to meet climate goals. Emissions are examined under the 450- pathway for the Middle East, developed by the International Energy Agency (IEA) to contribute to the global goal of staying below 2^0C. The focus is given to four countries, namely Iran, Saudi Arabia, Kuwait and the UAE, which account for around 76% of the region's CO_2 emissions. Accordingly, the main objective is to first, examine possibilities from transitioning to natural gas usage in the total primary energy supply mix. Second, examine current power generation strategies to assess their contribution under 450-emission scenario. Finally, develop an optimal electricity generation mix that satisfies emission targets in 2020 and 2030 using Mean Variance Portfolio Theory (MVP). Data collected throughout the thesis and results of the analysis are compiled and presented in an interactive web tool (MENA-CC.com) that allows users to have open access to energy data sets, graphically conduct country-to-country comparison, examine different power scenarios and assess emissions trajectories relative to the 450-emission target.

Thesis supervisor: John E. Fernandez
Title: Associate Professor of Building Technology

In The Name Of Allah the Most Gracious the Most Merciful

Acknowledgements

My most sincere gratitude goes to my mentor and my advisor, Prof. John E. Fernandez. I am grateful and blessed for all his trust and enormous support to pursue my research. I thank him for his encouragement and patient guidance during the development of this work. He allowed me to explore many avenues of research while being encouraging and supportive. I express my extreme gratitude to my thesis committee members, Prof. Christoph Reinhart, his guidance and support throughout my time at MIT, always pushing me forward with his inspiring discussions. Prof. Mandira Roy, for her huge support and guidance to develop the optimization model presented in this work. Her insightful guidance has directly involved with many aspects of Chapter 6 and the overall development of the thesis. I also express my gratitude to Prof. Jessika Trancik for her incredible feedback and deep discussions that assisted in the development of this work.

I also would like to thank Prof. John Ochsendorf and Prof. Caitlin Mueller for expanding my knowledge and for their enormous feedback that contributed in shaping and improving my thesis. I am grateful for Prof. Les Norford and Prof. Leon Glicksman for their great technical support. Kathleen Ross for being a helpful and supportive administrative assistant. Also, Cynthia Stuart and Renee Caso for their generous assistance through my time at MIT. I have enjoyed working alongside my colleagues and friends at the Building Technology Program at MIT. I am grateful and blessed to have experienced such a deep intellectual camaraderie in the Building Technology lab. Specially, Alpha Yacob and Bradley Tran, you have amazed me with your kindness and you both made my time at MIT more enjoyable. Also, Arafa Aijazi, Carlos Cerezo, Irmak Turan and Liz Mccormick for being great companions.

I am personally grateful for my amazing friend, Tarek Rakha. You have always been there for me to give me guidance, support and filled my experience at MIT with your invaluable encouragement. I will forever indebted for being such a good friend, you have kept me centered in so many ways and I will always look up to you.

I would thank my Egyptian family here at MIT, especially Randa Azab and Islam Hussein for their support and being amazing friends. Also, special gratitude to Plus-Architecture family in Cairo and Riyadh. My partners Mohamed Maabed and Ali Belal, for their continuous encouragement and deep discussions. Special gratitude to Mohamed Maabed for being an amazing and supportive partner, pushing me forward with his enthusiasm and continuous encouragement. Also, I would like to thank Hani Jamal, Ahmed Salah and the brilliant duo Ebrahim and Mostafa El Sawy for their contribution in MENA-CC website.

Finally, I will forever be thankful to my family, my mother for always believing in me and for her unconditional love and support, my father for his motivation and genuine encouragement. No words can describe how grateful I am to the amazing two years I spent at MIT. I hope with this work to have a modest contribution to my home region.

This work is dedicated to my brother, my backbone, and best friend, Tamer
May your soul rest in peace
and
May Almighty Allah dwell you in Jannatul Firdaus

Table of Contents

Section 1: Background and Literature Review

Section 2: Pathways to the 450-Emission Goal

1. Introduction

Since the emergence of the industrial age, humanity has utilized different forms of energy that have drastically transformed the built environment and provided levels of mobility and comfort that were unprecedented in human history. As energy became the central premise of all human activities, economic prosperity and urban development were strongly tied to the growth of energy consumption. With the overwhelming reliance on fossil fuel, humanity is now confronted with major energy challenges. These challenges have two critical aspects. First, the increase of Greenhouse Gas emissions[1] (GHG) as part of the expenses of burning fossil fuels. Second, the reliance on finite fossil fuel resources for energy provision will not persist in the future. The overwhelming dependence on fossil fuels has altered both Earth's climate and vital human systems resulting into what is now identified as Climate Change[2] phenomenon. As it was affirmed by the Intergovernmental Panel on Climate Change[3] (IPCC) "warming of the climate system is unequivocal, as is now evident from observation of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007b). Since then, there has been a growing consensus among scientific community and policy makers of human activities' impacts on Earth's ecosystem. Altogether, with questions related to climate change effects on the development of energy systems. One effective evidence of human impacts on climate variability is the observed increase in global CO_2 emissions.

By the beginning of industrial revolution in the 1700s, the rate of Carbon Dioxide emissions (CO_2) have steadily accelerated and the levels are now almost 35% higher mainly due to human activities from burning fossil fuels and deforestation (IPCC, 2013). More recently at the global scale, growth rates of emissions have been rapidly increasing as well. Between 2000 and 2004, emissions from burning fossil fuels have grown from an annual average of 1% to almost 3% (Raupach et al., 2007). Notably, the strongest growth in emissions happened in developing economies that accounted for almost 73% of the global increase in emissions (Raupach et al., 2007). A recent study that analyzed population growth within the next 50 years, has indicated that most of the expected population growth will happen in developing and least developed countries (Bongaarts, 2016). With greater population and economic growth, larger environmental degradation will be expected. In addition, significant challenges will be expected in contexts that lack efficient energy systems similar to those in developing regions. Such challenges will entail profound transformations in the energy structure. Yet, in developing regions, the long-term concerns about environmental sustainability are mainly overshadowed by more immediate apprehensions related to securing future energy supply. In this sense, it is critical to understand how emerging economies could expand their energy supply while simultaneously contribute to the global transition towards low carbon future.

Recent climate agreements call for significant changes in the way energy will be produced and consumed in the next decades. Countries are now urged to reduce the reliance on fossil energy resources and cut GHG emissions. Still, challenges will be biggest for growing economies that are heavily dependent on fossil fuels in their energy supply and for economic development, like those in the Middle East. The uncertainty over energy supply under climate change threats, pushed countries in the Middle East to set strategies that meet

---

[1] *Greenhouse Gas*: Anthropogenic and natural gases that radiate specific wave lengths of infrared radiation emitted from the earth's atmosphere causing greenhouse gas effect (IPCC, 2007b).

[2] *Climate change*: Any significant change in normal weather patterns over an extended period of time, typically observed over a period of decades or longer (IPCC, 2007b).

[3] *Intergovernmental Panel on Climate Change (IPCC)*: Established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to provide scientific reviews and assessments of anthropogenic (human induced) climate change.

climate goals while contributing to future energy security. Most of these strategies are considered with energy diversification plans and power transition towards more renewable deployment. However, the effectiveness of these strategies under planned emission goals is largely overlooked. Most of the studies have either focused on technological based approaches to identify suitable technology options for different countries in the Middle East (Kazim, 2004; Lude et al., 2015a; Shafiqur Rehman, 2005; Sgouridis et al., 2016c) or economical based approach to develop low-cost power generation portfolios under specified demand and emission constraint. Still, quantifying CO_2 abatements from planned strategies and analyzing how adequate they are to reach emission goals is still missing.

The aim of this thesis is to examine emission saving potentials from fossil fuel transition in energy supply mix and renewable penetration in power generation sector under planned climate targets. Examining potentials of fossil fuel transition is relevant to understand the implications of shifting towards low-carbon resources like natural gas on emission reduction. Second, looking at power generation sector is relevant to understand if current power policies are sufficient enough to meet emission goals and underline the level of renewable penetration required to meet these goals. The focus is given to four countries in the Middle East that account for 76% of the total Middle East's CO_2 emissions and 78% of total energy consumption, namely Iran, Saudi Arabia, Kuwait and the UAE. Here the emission goal for the Middle East to contribute to the global goal of 2^0C is split up based on the percentage share of the four countries, and will be denoted as the "450-emission goal/pathway". Analysis will take into account emission goals set as part the Intended Nationally Determined Contributions (INDCs) of the four countries and announced renewable targets.

This introductory chapter draws out intersections between climate change challenges and global energy use. It is oriented towards the understanding of the relationship between energy systems and CO_2 emissions escalation under climate change goals. Section 1 of this introduction provides an overview of climate change science and associated risks. Section 2 highlights the global energy landscape from the perspective of climate change and underline main challenges linked to growing energy demand. Section 3 reviews main energy challenges in developing regions. Finally, section 4 presents thesis structure, main objectives, significance, questions, methodology and concludes with an outline of each chapter.

1.1 Climate Change in Perspective

About 150 years ago, John Tyndall demonstrated that gases in the atmosphere absorb heat at different levels and that CO_2 has the ability to trap heat (Tyndall, 1861). Thirty years later, Arrhenius highlighted the notion of how burning fossil fuels resulted in greenhouse gas (GHG) emissions that can potentially warm the earth climate (Arrhenius, 1896). Now, it is certain that human activities are responsible of the increase in greenhouse gas concentration during the past decades. This was largely driven by economic development that coincided with the onset of industrialization era along with the increase of living standards in many parts of the world. All was fueled by fossil fuels and energy dense resources that represented relatively cheap energy conversion options. As a result, environmental impacts from energy consumption have aggressively increased at faster rates than what was previously expected. The year 2015 was marked as one of the hottest years in modern records, where the average global temperature across the planet reached about 0.90°C above the 20th century's average (Brown et al. 2016). According to the IPCC fifth assessment report, since 1951, the global mean temperature has increased by an average of 0.12° C per decade and the increased warming in global climate is extremely linked to the increase of greenhouse gas (GHG) concentration (IPCC, 2014). Among greenhouse gases, CO_2 is the most critical, due to its long lifetime concentration in the atmosphere that could last up to 100 years. During the past ten years, growing amounts of CO_2 emissions have been emitted to the atmosphere (Figure 1.1), reaching almost more than 30 Gt of CO_2 in 2010 (Ottmar Edenhofer et al., 2014). Future projections indicate that even under the most optimistic emissions scenario, further increase in the global mean temperature will be expected over the course of the 21st century.

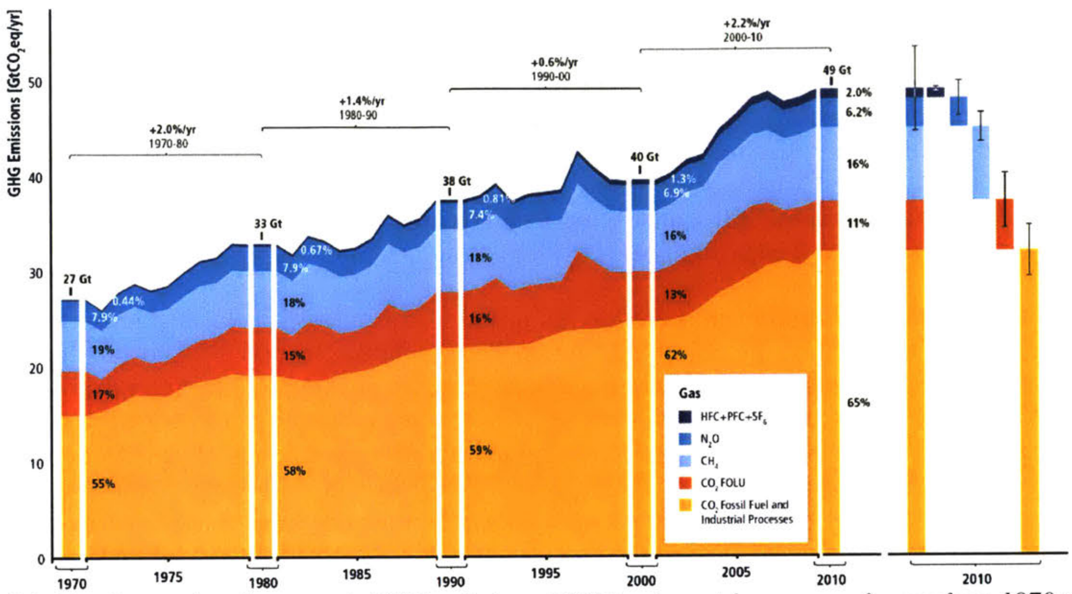


Figure 1.1: Total annual anthropogenic GHG emissions ($GtCO_2eq$/ year) by groups of gases from 1970 to 2010. CO_2 emissions from fossil fuel combustion and industrial processes increased by almost 62% during the past 10 years. Average growth rates of GHG emissions have almost doubled during 2000 to 2010 compared to the period of 1990-2000 (Ottmar Edenhofer et al., 2014).

The global understanding of climate change impacts has considerably progressed during the past decade. With the growing concerns discussed above, the international society has agreed upon the need to limit anthropogenic interference within the climate system. In 2009, the Copenhagen Accord acknowledged that the global mean temperature should not exceed 2°C above preindustrial levels (UNFCCC, 2009). This implies stringent bounds on long-lived greenhouse gases (GHG) concentration to below 450 ppm and reduction in anthropogenic forcing[4] (Allen et al., 2009).

There are major challenges to stay within the budget of 2°C. Meinshausen (2009) found that the maximum temperature increase that the earth will experience by 2100 is dependent on total CO_2 emissions in the year 2050 rather than the final CO_2 concentration. Accordingly, he estimated that total emissions from 2009 to 2050 should stay below 700 Gt of CO_2 in order to have a probability of 75% to stay below 2°C. However, over the period 2000 to 2012, about 330 Gt of CO_2 emissions were already emitted (Olivier et al., 2014). Thus, the trend the world is currently following is different from the one we need to mitigate climate change. In order to reach the goal of 2°c, emissions need to fall twice the rate they have grown in recent years, the longer we wait the less realistic climate goals become (Figure 1.2).

---

[4] Anthropogenic forcing: Changes in the concentration of radiatively active gases (CO_2, N_2O, and CH4) in the Earth's atmosphere. It has been found that human activities, such as burning fossil fuels and changes in land-use, are the main cause of Anthropogenic forcing (Myhre et al., 2013).

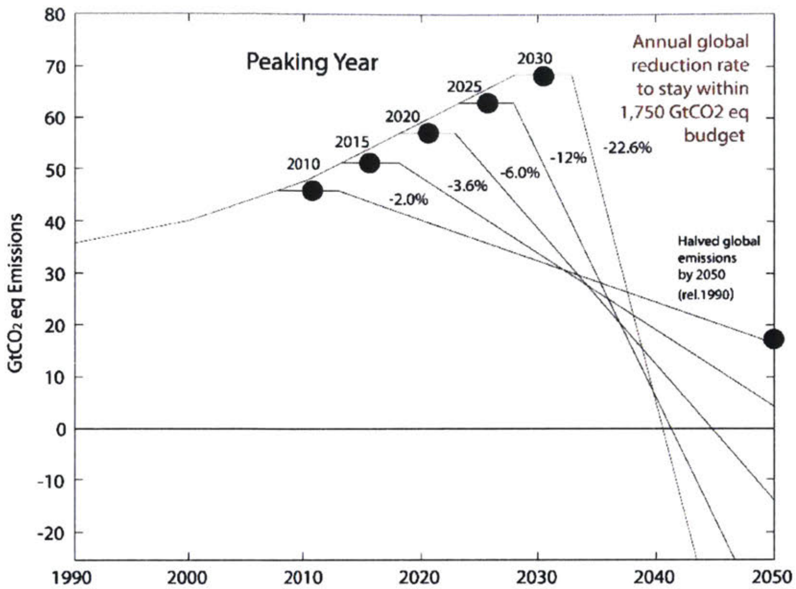


Figure 1.2: Estimates of global emissions peak required to reach 2°C based on Meinshausen (2009) and required reduction based on the starting year. It is clear that delayed actions mean more aggressive reduction required each year that could eventually lead to unrealistic goals.

Challenges discussed above cannot be addressed without examining the role of energy. The fundamental energy changes needed to achieve climate targets are undisputable, but they cannot be only reached through a single region or fragments of different regions, each country has its own unique energy characteristics that bring up different mitigation possibilities. The following section looks at the interrelationship between energy use, energy production and the increase of global anthropogenic concentration. It provides an overview of the global energy development and outlines associated challenges.

1.2 Energy and Climate Change

Energy security and climate change are two of the most pressing challenges facing the global society. Energy as an integral part of the economic development that is indispensable to sustain economic processes like power generation, industry and transportation (TWAS, 2008). At the same time, environmental and social risks from climate change call for a substantial transformation in the global energy system. Energy sector alone accounts for 74.6% of total GHG emissions out of which CO_2 emission account for nearly 80% (Ottmar Edenhofer et al., 2014). It has been widely acknowledged that impacts from energy use are expected to exceed any impacts from other sources such as industrial activities and land use changes. During the period of 1850 to 2005, global energy use and production grew by almost 50 folds, from 0.2 bn toe to reach 11 bn toe (IEA, 2007). Concurrently, energy related emissions have been rapidly increasing. Over the period 2000 to 2010, energy related GHG emissions accelerated from a yearly average of 1% (1990-2000) to around 3.1% despite the UNFCC and the Kyoto protocol agreements. In addition, emissions from energy sector alone reached over 18 Gt of CO_2 eq. in 2012, with 75% from electricity and head production as presented in figure 1.3 (Mulugetta et al., 2014).

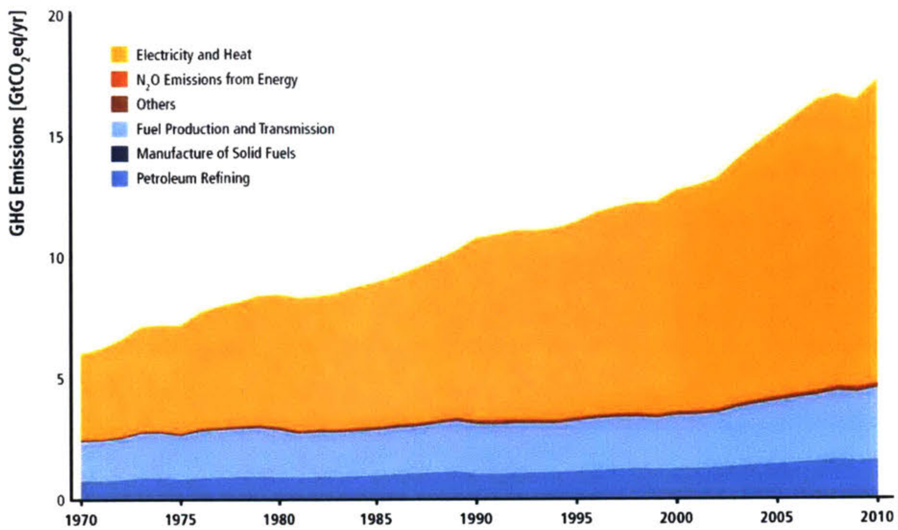


Figure 1.3: GHG Emissions from energy sector.
Fuel production and transmission accounted for 16% of total emissions increase during the past 10 years followed by petroleum refining sector. Although GHG is largely predominant by CO_2, methane represented 31% mainly from coal and gas production (Mulugetta et al., 2014).

Most of the historic growth in energy consumption was concentrated in developed societies. From per capita perspective, these societies consumed quantities of energy that were more than 100 times the quantities used by their ancestors back before they were introduced to energy exploitation (UNDP, 2007). Future energy projections suggest that current trends of energy use will probably continue in developed regions but at stronger rates in developing countries. In addition, global energy use will be expected to double or might even triple by 2050 (The European Commission Directorate General For Energy, 2013). According to the United States Energy Information Administration (EIA) recent projections, under Business As Usual scenario (BAU), global energy demand will increase by 48% between 2014 and 2040 as shown in figure 1.4 (Diefenderfer et al. 2016). What is more concerning is that these projections highlight a stronger increase in fossil fuel consumption that will grow nearly as strong as total consumption. As a result, fossil fuels (such as coal, liquid fuels and natural gas) will represent about 78% of the global energy consumption. Under these projections, energy related CO_2 emissions will increase from 3.23 Gt in 2013 to reach 4.3 Gt by 2040 (Diefenderfer et al. 2016).

From figure 1.4 below, it is clear that most of the projected energy demand will occur in developing nations (non-OECD), where most of the economic expansion and population growth are expected to happen. Energy use will grow by over 71% from 2012 to 2040 exceeding OECD'S by 89% in 2040. On the other hand, developed nations (OECD[5]) will continue to follow current trends with a relatively smaller increase by only 18%. In conjunction with these projections, energy-related emissions are also expected to follow similar trends (Figure 1.4), where emissions will level up more rapidly in developing nations than developed countries. By 2040, it is expected that energy-related emissions from developing countries will grow by over 51% compared to 2012 levels, reaching 2.94 Gt. While, developed countries' emissions will only rise by 8%. The large deviation between developing and developed nations points out to the huge challenges posed by these countries. Thus, if no adequate policies are pursued, climate goals will be challenging to achieve.

---

[5] OECD: Organization for Economic Co-operation and Development includes 35 of the world developed-economies where countries under OECD represent almost 63% of the global GDP. The aim of this organization is to address issues such as economic growth, energy policies and energy security for both members and non-members countries (Developing countries) (OECD, 2016).

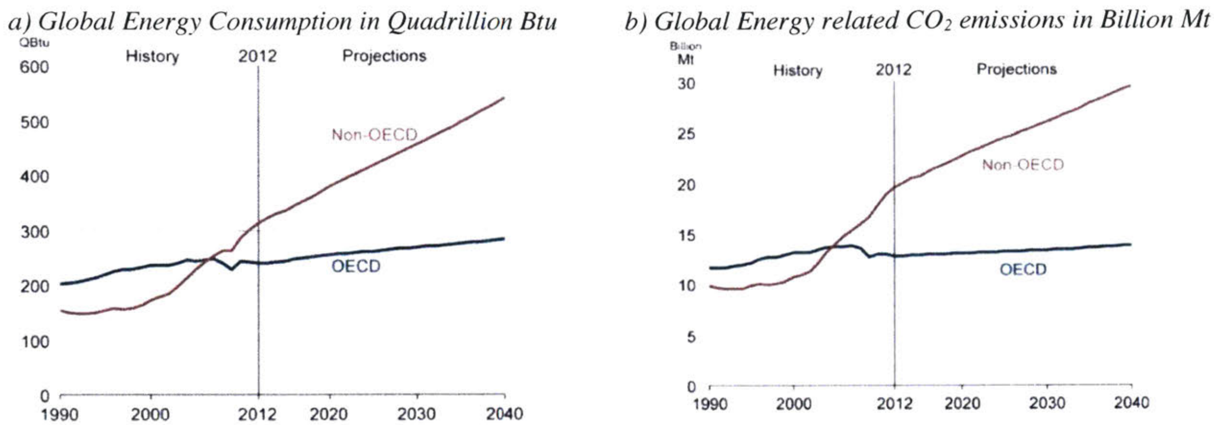


Figure 1.4: a. World energy consumption by region, from 1990 to 2040 (quadrillion Btu) b. OECD and non-OECD energy-related carbon dioxide emissions (billion metric tons). It can be noticed that energy consumption and associated emissions in OECD region will continue to follow current trends, on the other hand, non-OECD will witness a vast increase in both energy consumption and CO_2 emissions (Diefenderfer et al., 2016).

Projected increase in energy use will not only contribute to the global climate change, but it will also give rise to other risks. Increase in energy use implies further exploitation of finite fossil fuel resources posing challenges to economies that are significantly based on fossil fuels exports. In addition, energy increase involves high externalities related to environmental damages that have to be paid as an expense of energy consumption. Thus, for energy-related emissions to change significantly, underlying technologies used to generate energy have to be largely developed. The availability of alternative technologies is the main determinant of whether reaching planned climate targets is possible or not.

1.3 Challenges in Developing Regions

Historically speaking, economic development has always been strongly tied to emissions increase. In this sense, developing economies are now confronted with a two-fold challenge: supplying energy demands required for economic growth while concurrently contributing to the global climate goals of limiting their GHG emissions. Therefore, the conflict between fueling energy demands and meeting environmental development goals needs urgent attention. Although developing countries have contributed very little to climate change in the past, they are also the ones who will be most vulnerable based on their adaptive capacity to face climate risks (Jakob et al., 2014). There is a large debate on whether developing countries should take different path than developed economies to ensure adequate economic growth for generations to come. However, emission reductions from developed countries only will be insufficient to avoid prospective climate change risks (Jakob et al. 2014). In addition, global economic growth has been largely dependent on emission-intensive fossil fuel resources and even with the ongoing progress in low carbon technologies, fossil fuels still represent the cheapest option for developing economies to expand energy and power capacity (Schmidt et al. 2012). This underlines possible impacts of climate change on the economic development in developing regions. Especially in economies that are based on fossil fuels revenues like those in the Middle East.

The current dependence on fossil fuels resources in developing regions indicate that they are replicating past trends that today's rich countries have followed (Jakob et al. 2012). These societies are still undergoing through the process of industrialization, so provision of energy services to billions of people under a modest stress on global resources is challenging (TWAS, 2008). Furthermore, delayed emissions reduction in developing economies will bear risks of deferring the clean transition of their energy systems. In this sense, three key questions arise: how can regions like the Middle East contribute to global emission reduction, what emission savings can be obtained from transitioning to low-carbon energy resources?, and how can power systems contribute effectively to current climate targets?

1.4 Thesis Motivation and Structure

Growing energy demands in the Middle East are set to affect energy and power security within the next decades. Although the region holds nearly half of the global fossil fuel reserves (IEA, 2016), countries in the Middle East, including oil-rich ones, are facing problems in supplying their domestic energy demands. Rapidly growing energy consumption and water desalination requirements have driven countries in the Middle East to look for alternative energy resources to supply growing demands and maintain their economic position. With the ongoing climate discussion, several countries have set plans to diversify their energy mix and cut GHG emissions. As a result, the integration of low carbon and renewable energy resources have been recognized as a central mean to meet climate policies objectives and maintain their role in the global energy market. This goes hand-in-hand with energy efficiency from different economic sectors. The complexity of these challenges over the development of energy supply and power generation sector in the Middle East is the main motivation behind this thesis.

Thus, the aim is to examine how the Middle East can meet agreed upon climate targets. This will be achieved through estimating emission saving potentials from current diversification strategies in the power sector and transitioning to low-carbon resources in the primary energy supply mix. The scope is given to four countries, which constitute around 76% of the total Middle East CO_2 emissions. The contribution of this research stems from establishing, a first to our knowledge, an inclusive analysis and comparative assessment between these four countries and estimating their contribution under the region's emission goals. In addition, an interactive web-tool is developed as a complementary instrument for the Middle East energy analysis where users have an open access to energy datasets, conduct country-to-country comparison, examine different power scenarios and assess emissions trajectories relative to the 450-emission target. This tool (*MENA-CC.com*) will present a pilot contribution to the energy and power analysis of the Middle East through a single inclusive platform.

1.4.1 Research Goal

The main goal of the thesis is to examine emission saving potentials to meet climate goals from four key energy players in the Middle East, namely Iran, Saudi Arabia, Kuwait and the UAE, under planned climate targets. Emission saving potentials will be examined within two pathways. First, reduction achieved from transitioning to natural gas usage in the total primary energy supply mix. Second, estimating the adequate level of renewable deployment in power sector that is consistent with the 450-emission target set for the Middle East. Here the 450-emission pathway describes the contribution of the Middle East to the global 2°C pathway. The target implies substantial deviation in GHG emissions below 1990 levels but with no specific estimates (IPCC, 2007a). So, the International Energy Agency (IEA) estimates for the Middle East are used. According to these estimates, the region's total CO_2 emissions by 2030 should not exceed 1700 Mt (IEA, 2015d). Under this target, potentials of emission reduction are examined.

1.4.2 Research Significance

Understanding possible emission reductions that can be attained from low-carbon energy transition and renewable power generation will considerably assist in energy planning process. Highlighting environmental viability of current energy and power strategies is important to the success of climate policies. In addition, better knowledge on individual technologies' variability with respect to future emission goals can be of value to policy makers, developers, private investors and both political and academic societies. Finally, establishing an estimate of emission saving potentials within the bounds of climate targets can enable these countries to understand how to move forward and assist in the development of their energy systems.

1.4.3 Research Objectives

The main goal of this research is to estimate emission saving potentials from low-carbon energy transition and renewable generation within the bounds of 450-emission pathway. This will be achieved through a set of objectives listed as follows:

a. Examine energy demand and supply alongside trends of CO_2 emission.
b. Analyze the magnitude of emission saving potentials from low-carbon energy transition in countries with large fossil fuel reserves.
c. Examine current power generation technologies and underline renewable energy resources potential.
d. Examine power strategies under planned emission targets and evaluate their environmental viability.
e. Explore and develop different electricity generation mixes that meet emission goals in 2020 and 2030.
f. Underline key technologies in case of large renewable penetration and identify barriers to their deployment.

1.4.4 Research Questions

The role of low carbon fossil energy and power generation that is coupled with greater integration of renewable energy technologies could boost the complementary capacity of the Middle East to mitigate future increase in CO_2 emissions. However, the integration of these two aspects together in countries with large fossil fuel reserves needs further investigation. Thus, the two main questions that the research addresses are: What are the emission saving potentials from countries with large fossil fuel reserves, and how effectively could they contribute to the Middle East's climate goal? Under these two main questions, a set of secondary questions corresponding to the aforementioned objectives as:

a. What do current energy production and energy use trends mean for CO_2 emission escalation in the Middle East?
b. What is the role of countries with large fossil fuel base in the sustainable development of the region's energy sector?
c. How can countries with large fossil fuel reserves contribute to regional emission reduction goals?
d. Can shifting to natural gas act as a technology bridge to fill emission gap in resource-rich countries?
c. How does the current structure of power sector affect the expansion of renewable technologies?
d. What are the potentials of large renewable deployment from the perspective of resources availability?
e. What mix of renewable technologies are more effective to reach emission targets?
f. What obstacles and challenges can be expected under large renewable penetration?

1.4.5 Methodology

In this thesis, emission saving potential in four countries in the Middle East is examined under the 450-emission pathway. This will be estimated particularly in case of energy supply transition to natural gas usage and larger penetration of renewable technologies in power generation. Considering the 450-emission pathway as the main scope of investigation, an energy supply scenario with greater usage of natural gas is proposed and an optimal generation portfolio is developed for the four countries examined in the thesis. The four countries are Iran, Saudi Arabia, Kuwait and the UAE, and will be denoted as "major emitters". Although Iraq represents nearly 8% of total Middle East CO_2 emissions, it is not included in the analysis due to the significant uncertainty from current political tension. Kuwait is chosen over Qatar despite the proximity of their emission shares. This is mainly due to challenges associated with significant growth in peak power demand and threats from Kuwait's recent shift to natural gas imports to sustain energy supply.

For the development of the natural gas transition scenario, a regression model is implemented to project energy supply and demand of different fossil fuels in 2020 and 2030. These projections will be then used to estimate emissions saving potential from transitioning to natural gas usage in the total primary energy supply mix of the four countries under the 450-emissions pathway. Next, the Mean Variance portfolio theory (MVP) is implemented to develop an optimal generation mix that meets the 450-emission goal with the lowest cost. The proposed optimization framework will be carried out on two phases. The first phase focuses on the selection and characterization of feasible renewable technologies in accordance with national power strategies and examine their emissions relative to the 450-emission pathway. The second phase aims at minimizing cost and risk of the generation portfolio to meet demand and constrained emissions of the 450-emission pathway

In adopting this framework, four power strategies are examined. Reference Scenario to represent Business as Usual (BAU) mix, National Strategy Scenario that pertains current power strategies and planned renewable targets, 450-Scenario that portrays the optimal electricity generation mix which satisfies 450-emission goal, and Deep Decarbonization Scenario that denotes the theoretical assumption of full renewable deployment and complete phase out of conventional energy. The four scenarios will represent power generation mixes for target year 2020 and 2030. Within this framework, a set of analyses will be undertaken as follows:

[1] Developing a baseline power demand scenario: based on current trends and national forecasts;
[2] Examining renewable energy resources potentials and identify key technologies in case of large renewable deployment
[3] Identifying the share of renewable technologies based on current capacities and national power strategies;
[4] Examining national power strategies under the 450-emission goal;
[5] Estimating emission reduction required to meet the 450-emission goal.

1.4.6 Target Audience

The proposed analysis for a developing region like the Middle East could support the development of current energy agendas with more emphasis on the contribution of renewable technologies. Results from this research are not meant to outline the optimal energy supply mix or power strategy, but rather expected to be of use to policy makers, private investors, energy planners and decision makers to understand on what terms can these countries effectively contribute to the region's emission goals. Yet, the transition to low-carbon and clean energy alternatives would still require a robust framework with supporting policies to push the development of energy systems.

1.5 Thesis Outline

To understand the potentials of emission reduction under climate goals, the thesis is organized into two main sections. Each section provides a specific outcome. The first section of the thesis is intended to present an overview of the energy landscape in the Middle East with an inclusive analysis of energy and power structure in the four countries of interest. This section contains chapter 2 through chapter 4. Chapter 2 addresses energy landscape in the Middle East, emissions trends, renewable energy resources potentials and climate change policies. Chapter 3 and chapter 4 focus on the four major emitters from the perspective of energy and power supply. Chapter 3 provides an analysis of energy supply, energy consumption, energy subsidy framework, trends of CO_2 emissions and conclude with a comparative energy assessment between the four countries and the world average. Chapter 4 examines power generation sector including power generation technologies, power consumption in different economic sectors, renewable resources potentials and nuclear power plans.

The second section of the thesis is considered with emission saving estimation from energy supply and power generation sector under the 450-emission pathway using methodology describe in section 1.4.5. This section includes chapter 5 and chapter 6. Chapter 5 analyzes potentials of emission reduction through transitioning to natural gas usage from the perspective of energy supply and demand. Chapter 6 outlines the contribution of power generation sector from larger renewable penetration. This chapter presents main methodology, data used, assumptions, optimization model framework and main results. Chapter 7 concludes analysis outcomes, outlines conclusion, points out main findings across different chapters and proposes future work that could improve the contribution of power sector in climate change mitigation.

References

Al-Sahhaf, T. (2016). Sustainable Energy Research and Development. In *International Conference on New Trends for Sustainable Energy (ICNTSE)* (pp. 1–17). Alexandria, Egypt.

AlGarni, H., Kassem, A., Awasthi, A., Komljenovic, D., & Al-Haddad, K. (2016). A Multicriteria Decision Making Approach For Evaluating Renewable Power Generation Sources In Saudi Arabia. *Sustainable Energy Technologies and Assessments*, *16*, 137–150.

Allen, M. R., Frame, D. J., Huntingford, C., Jones, C. D., Lowe, J. A., Meinshausen, M., & Meinshausen, N. (2009). Warming Caused By Cumulative Carbon Emissions Towards The Trillionth Tonne. *Nature*, *458*(7242), 1163–1166. http://doi.org/10.1038/nature08019

Almansoori, A., & Betancourt-Torcat, A. (2015). Design Optimization Model For The Integration Of Renewable And Nuclear Energy In The United Arab Emirates' Power System. *Applied Energy*, *148*, 234–251. http://doi.org/10.1016/j.apenergy.2015.03.068

Arnesano, M., Carlucci, A. P., & Laforgia, D. (2012). Extension Of Portfolio Theory Application To Energy Planning Problem - The Italian case. *Energy*, *39*(1), 112–124.

Arrhenius, S. (1896). In The Air Upon The Temperature Of The Ground. *Philosophocal Magazine and Journal of Science*, *41*(page 270), 237–279.

Awerbuch, S. (2006). Portfolio-Based Electricity Generation Planning: Policy Implications For Renewables And Energy Security. *Mitigation and Adaptation Strategies for Global Change*, *11*(3), 693–710. http://doi.org/10.1007/s11027-006-4754-4

Awerbuch, S., & Berger, M. (2003). Applying Portfolio Theory To EU Electricity Planning And Policy Making. *IEA/EET Working Paper*, *3*(February), 69.

Bar-Lev, D., & Katz, S. (1976). Portfolio Approach To Fossil-Fuel Procurement in Electric Utility Industry. *Journal of Finance*, *31*(3), 933–947. http://doi.org/10.2307/2326437

Bazilian, M., & Roques, F. (2008). *Analytical Methods for Energy Diversity and Security*. Elsevier Science.

Bongaarts, J. (2016). Development: Slow Down Population Growth. *Nature*, *530*(7591), 409–412.

Brown, D., Cabbage, M., & McCarthy, L. (2016). NASA, NOAA Analyses Reveal Record-Shattering Global Warm Temperatures in 2015. *Nasa*. Retrieved from http://www.nasa.gov/press-release/nasa-noaa-analyses-reveal-record-shattering-global-warm-temperatures-in-2015

Damodaran, A. (2001). *Corporate Finance: Theory and Practice* (2nd ed.). John Wiley & Son.

Diefenderfer, J., Arora, V., & Singer, L. E. (2016). *International Energy Outlook: Liquid Fuels* (Vol. 484). United States.

Dodd, J. (2015). Analysis Iran Takes Action To Enable Renewables Growth.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Minx, J. C., Farahani, E., Susanne, K., ... Zwickel, T. (2014). *Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. http://doi.org/10.1017/CBO9781107415416

Escribano Francés, G., Marín-Quemada, J. M., & San Martín González, E. (2013). RES and risk: Renewable Energy's Contribution To Energy Security- A Portfolio-based Approach. *Renewable and Sustainable Energy Reviews*, *26*, 549–559. http://doi.org/10.1016/j.rser.2013.06.015

Fattouh, B., & Sen, A. (2016). *Saudi Arabia's Vision 2030: Oil Policy and the Evolution of the Energy Sector*.

Follet, A. (2016). Saudi Arabia To Start Building Nuclear Power Plants "Very Soon." Retrieved January 1, 2016, from http://dailycaller.com/2016/10/20/saudi-arabia-to-start-building-nuclear-power-plants-very-soon/

Groissböck, M., & Pickl, M. J. (2016). An Analysis Of The Power Market In Saudi Arabia: Retrospective Cost And Environmental Optimization. *Applied Energy*, *165*, 548–558. http://doi.org/10.1016/j.apenergy.2015.12.086

IEA. (2007). *Key World Energy Statistics. International Energy Agency (IEA)*.

IEA. (2015). *World Energy Outlook*. Paris, France. http://doi.org/10.1787/weo-2014-en

IEA. (2016). *World Energy Outlook 2016. International Energy Agency (IEA)*. Retrieved from http://www.worldenergyoutlook.org/publications/weo-2016/

IPCC. (2007a). *Climate Change: Contribution of working group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Mitigation*. Geneva, Switzerland.

IPCC. (2007b). *Climate Change Synthesis Report. Intergovernmental Panel on Climate Change*. Geneva, Switzerland.

IPCC. (2013). *Climate Change 2013: The Physical Sciences Basis*. Geneva, Switzerland.

IPCC. (2014). *Climate Change Synthesis Report: Summary Chapter for Policymakers. IPCC Synthesis Report*. Geneva, Switzerland.

Iran-German Cooperation. (2009). *Energy Scenarios for Iran*.

Iran's Ministry of Power. (2015). *Iran Electricity Statistics*. Tehran, Islamic Republic of Iran.

IRENA. (2015). *Renewable Energy Prospects: United Arab Emirates*. Abu Dhabi, United Arab Emirates.

Jakob, M., Haller, M., & Marschinski, R. (2012). Will History Repeat Itself? Economic Convergence And Convergence in Energy Use Patterns. *Energy Economics*, *34*(1), 95–104.

Jakob, M., & Steckel, J. C. (2014). How Climate Change Mitigation Could Harm Development In Poor Countries? *Wiley Interdisciplinary Reviews: Climate Change*, *5*(2), 161–168. http://doi.org/10.1002/wcc.260

Jakob, M., Steckel, J. C., Klasen, S., Lay, J., Grunewald, N., Martínez-Zarzoso, I., Edenhofer, O. (2014). Feasible Mitigation Actions In Developing Countries. *Nature Climate Change*, *4*(11), 961–968. http://doi.org/10.1038/nclimate2370

Kingdom of Saudi Arabia (KSA). (2016). *Saudi Vision 2030*. Riyadh, Saudi Arabia. Retrieved from http://vision2030.gov.sa/sites/default/files/report/Saudi_Vision2030_EN_0.pdf

Mahdi, W. (2016). Saudi Arabia Scales Back Renewable Energy Goal to Favor Gas. Retrieved from http://www.bloomberg.com/news/articles/2016-06-07/saudi-arabia-scales-back-renewable-energy-target-to-favor-gas

Markowitz, H. (1952). Portfolio Selection. *The Journal of Finance*, *7*(1), 77–91. http://doi.org/10.1111/j.1540-6261.1952.tb01525.x

Marreiro, G. A., Ramos-real, F. J., & Losekann, L. (2013). Efficient Power Generating Portfolio in Brazil: Conciliating Cost, Emissions and Risk. *Energy Policy*, *62*, 301–314. http://doi.org/http://dx.doi.org/10.1016/j.enpol.2013.07.049

McAuley, A. (2016). UAE eyes new clean energy generation target by 2030.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., … Allen, M. R. (2009). Greenhouse-Gas Emission Targets For Limiting Global Warming To 2 Degrees. *Nature*, *458*(7242), 1158–1162. http://doi.org/10.1038/nature08017

Mittal, S. (2015). UAE Reiterates Target Of 24% Clean Energy Share by 2021 CleanTechnica. Retrieved August 12, 2016, from https://cleantechnica.com/2015/10/30/uae-reiterates-target-24-clean-energy-share-2021/

Mondal, M. A. H., Kennedy, S., & Mezher, T. (2014). Long-Term Optimization Of United Arab Emirates Energy Future: Policy Implications. *Applied Energy*, *114*, 466–474. http://doi.org/10.1016/j.apenergy.2013.10.013

Mulugetta, Y., Hertwich, E., Riahi, K., Gibon, T., & Neuhoff, K. (2014). *Mitigation of Climate Change. IPCC Fifth Assessment Report*. Geneva, Switzerland.

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., … Zhang, H. (2013). Anthropogenic and Natural Radiative Forcing. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 659–740. http://doi.org/10.1017/ CBO9781107415324.018

OECD. (2016). What is the OECD. Retrieved March 3, 2016, from http://usoecd.usmission.gov/mission/overview.html

Olivier, J. G. J., Janssens-Maenhout, G., Muntean, M., & Peters, J. A. H. W. (2014). *Trends in Global CO2 Emissions*. Netherlands.

Oxford Business Group. (2016). Kuwait's Drive Toward Fuel Subsidy Rationalisation. Retrieved January 3, 2017, from http://www.oxfordbusinessgroup.com/news/kuwait's-drive-toward-fuel-subsidy-rationalisation

Patz, J. A., Holloway, T., Campbell-Lendrum, D., & Foley, J. A. (2005). Impact of Regional Climate Change On Human Health. *Nature*, *438*(7066), 310–317. http://doi.org/10.1038/nature04188

Raupach, M. R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J. G., Klepper, G., & Field, C. B. (2007). Global and Regional Drivers of Accelerating CO2 Emissions. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(24), 10288–10293. http://doi.org/10.1073/pnas.0700609104

Reuters. (2017). Saudi Arabia to Launch a $30-$50 Billion Renewable Energy Program. Retrieved October 2, 2017, from http://fortune.com/2017/01/16/saudi-arabia-renewable-energy-program/

Rezaian, J. (2010). Iran Remains Stable Despite Dramatic Price Increases. Retrieved January 3, 2017, from https://www.pri.org/stories/2010-12-20/iran-remains-stable-despite-dramatic-price-increases

Saurabh. (2016). Kuwait Commissions Its First Solar Power Project. Retrieved January 1, 2016, from http://cleantechies.com/2016/10/31/kuwait-commissions-its-first-solar-power-project/

Schmidt, T. S., Born, R., & Schneider, M. (2012). Assessing The Costs of Photovoltaic and Wind Power in Six Developing Countries. *Nature Climate Change*, *2*(5), 1–6. http://doi.org/10.1038/nclimate1490

Smith, A., Schellnhuber, H. J., & Mirza, M. M. Q. (2001). *Vulnerability to Climate Change and Reasons for Concern: A Synthesis. Climate Change 2001: Impacts: Adaptation and Vulnerability*.

Smith, J., Schneider, S., Oppenheimer, M., Yohe, G., Hare, W., Mastrandrea, M., … van Ypersele, J.-P. (2009). Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) "Reasons For Concern." *PNAS*, *106*(11), 4133–4137. http://doi.org/10.1073/pnas.0812355106

Soofi, A. S., & Goodarzi, M. (2017). *The Development of Science and Technology in Iran: Policies and Learning*. Palgrave Macmillan.

The Academy of sciences for the Developing world (TWAS). (2008). Sustainable Energy for Developing Countries. *Surveys and Perspectives Integrating Environment and Society*, *2.1*, 1–48. http://doi.org/10.2307/1926992

The European Commission Directorate General For Energy. (2013). *World Energy Scenarios*.

Tyndall, J. (1861). The Bakerian Lecture: On the Absorption and Radiation of Heat by Gases and Vapours, and on the Physical Connexion of Radiation, Absorption, and Conduction. *Philosophical Transactions of the Royal Society of London*, *151*(1861), 1–36. http://doi.org/10.1098/rstl.1861.0001

UNDP. (2007). *A Review of Energy in National MDG Reports*. New York, U.S.

UNFCCC. (2009). *Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009, Addendum, Part Two: Action taken by the Conference of the Parties at its fifteenth session. Unfccc*. New York, U.S.

Watson Farley & Williams. (2016). Renewable Energy in Iran. http://doi.org/58231623v1© Watson Farley & Williams 2016 All

World Nuclear Association. (2015). Nuclear Power in Saudi Arabia. Retrieved January 1, 2017, from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Saudi-Arabia/

World Nuclear Association. (2017). Nuclear Power United Arab Emirates. *Www.World-Nuclear.Org*. Retrieved from http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Arab-Emirates/

Zhu, L., & Fan, Y. (2010). Optimization Of China's Generating Portfolio And Policy Implications Based On Portfolio Theory. *Energy*, *35*(3), 1391–1402. http://doi.org/10.1016/j.energy.2009.11.024

2. Background

Climate Change and energy transition are two of the key challenges that humanity will face in the next decades. Such challenges are fundamentally linked to growing energy consumption and CO_2 emissions. This chapter provides an overview on the problem of energy consumption and related environmental impacts. The chapter presents at first a brief outlook of the current global energy trends, and then the focus is given to the Middle East region to understand its energy structure and principal trends that are shaping future energy development.

2.1 Global Energy Trends

Climate change and related climate policies are expected to affect the future development of energy sector and global emissions. Over the past decade, the global energy sector has changed significantly. This is mainly related to conflicting drivers represented in growing energy demand from developing economies, fluctuating fuel prices, geopolitical tensions, rapid increase in fossil fuel production and the dropping costs of renewable energy technologies. In addition, renewable technologies (particularly solar and wind) have experienced large technological learning effects on a global level. As a result, they have become cost competitive against other conventional technologies in some markets globally. On the other hand, the share of nuclear power in the global energy has been steadily decreasing. This can be observed in markets like Europe, where the share of nuclear technology in the global power generation has dropped from 33% in 1997 to 27% in 2011 (International Energy Agency, 2016).

Understanding trends of the global energy system is directly interconnected with the share of different energy resources. As previously discussed in chapter one, conventional energy resources play the key role in fueling the global energy demand and it is predicted that this trend will continue in supplying future needs. In 2014, fossil fuels contributed 81% of total primary energy supply (International Energy Agency, 2016), while nuclear was at almost 5% and renewables provided 14% as presented in table.2.1. Although there have been huge advances in renewable energy technologies, it can be seen that their contribution is still relatively modest.

Table 2.1: World Total Primary Energy Supply 2014. Based on data from (International Energy Agency, 2016).

Energy Resource	Primary Energy Supply (EJ)	Relative share (%)
Coal	164	28.6%
Oil	179	31.3%
Natural Gas	121	21.2%
Nuclear	27	4.8%
Hydro	14	2.4%
Biofuels	59	10.3%
Heat and other renewables (solar, wind, etc.)	8	1.4%
Total	**573**	**100%**

On the level of global energy consumption, oil represented the largest share due to demands from transportation sector for oil products, while natural gas and coal accounted for 26.5%. On the other hand, electricity represented about 20% of the global final energy consumption in 2014 as shown in table 2.2 below.

Table 2.2: World Total Final Energy Consumption 2014. Based on data from (International Energy Agency, 2016).

Energy Resource	Final Energy Consumption (EJ)	Relative share (%)
Coal	45	11.4%
Oil	158	39.9%
Natural Gas	60	15.1%
Biofuels and waste	48	12.2%
Heat and other renewables (solar, wind, etc.)	13	3.3%
Electricity	71	18.1%
Total	**395**	**100%**

As previously discussed, the contribution of non-hydrocarbon resources is relatively insignificant. Electricity generation sector is largely reliant on fossil fuels, as they accounted for 66.4% of total electricity generation in 2014 (International Energy Agency, 2016). Thus, shifting to low carbon energy resources will influence the reduction of fossil fuels in the total primary energy supply. Although this sounds as a promising pathway towards emissions reduction from the power sector, it should be taken into consideration the expected increase in the global power demands over the next decades (Schaeffer, 2015). Projections from the Exxon Outlook for Energy, global energy demand is expected to reach about 25% by 2040, and could surge significantly closer to a 100% (Exxon Mobile, 2015). The growth will be led by an increase in electrification of global economy. Where around 55% of the global energy growth over the next twenty years will be linked to power generation (figure 2.1-a). Accordingly, electricity mix will diversify and there will be a large uptick in demand for several types of energy, particularly less carbon-intensive sources such as natural gas, nuclear, solar and wind (figure2.1-b).

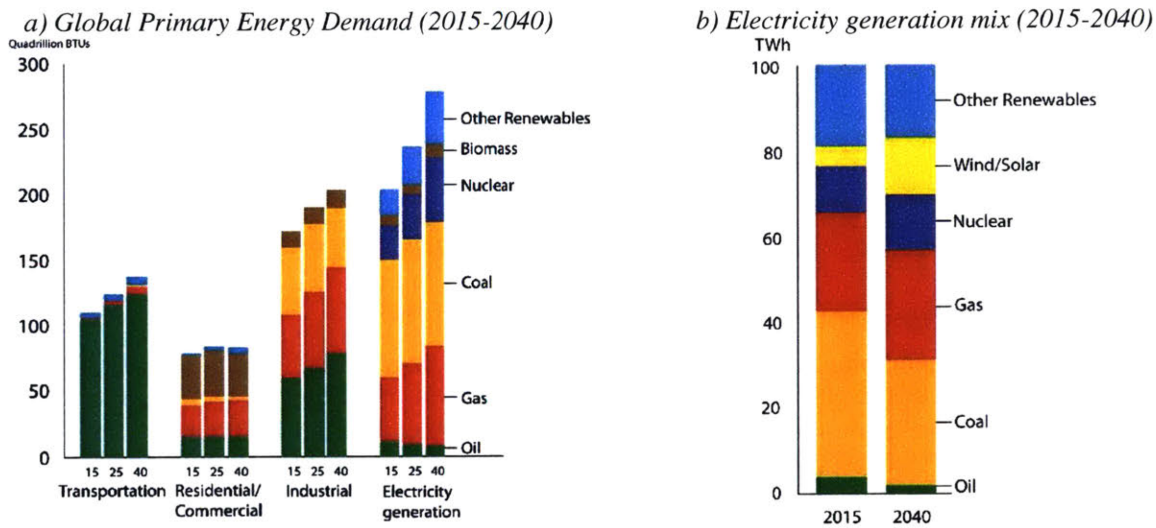


Figure 2.1: a) Global primary energy demand by sector and fuel up to 2040, b) Electricity generation mix projection in 2040 (Exxon Mobil, 2016).

2.2 Energy Trends in the Middle East

The Middle East is a region that encompasses hydrocarbon-rich economies that are largely dependent on fossil fuel for their energy supply and domestic consumption. The region has a large fossil fuel reserve that represents over half the world's proven, recoverable, crude oil, and a third of its natural gas reserves (British Petroleum, 2015). The region compromises of twelve countries, namely, Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the UAE and Yemen. Out of the twelve countries, Saudi Arabia, Iran, Iraq, Kuwait, The UAE and Qatar are the largest oil exporters in the region.

2.2.1 Energy Supply

The Middle East region plays a major role in the global oil and gas trade. The region contributes a large fraction of global fossil fuel production, representing 28% of total oil production and about 10% of global gas needs (International Energy Agency (IEA), 2004). Oil and natural gas resources are the main source of income to the majority of countries in Middle East. On the other hand, the region is heavily dependent on oil and natural gas that provided 98% of the total primary energy supply in 2013. According to the Middle East's energy balance, the total primary energy supply (TPES) has increased by an average rate of 10% annually since 1990 (figure 2.2-b), reaching 690 Million tons of oil equivalent (Mtoe) in 2013 (IEA, 2015a). Most of the primary energy supply is coming from oil (24% of production and imports), and natural gas (74% of production and imports). However, the share of oil and natural gas changed significantly between 1990 and 2013 (figure 2.2-b). In 2010, natural gas started to take over the Middle East TPES, as it accounted for 50% of the region's TPES in 2013. Such large upsurge led to an increase in gas imports in 2014 with 5% increase compared to 2013 (International Energy Agency, 2016).

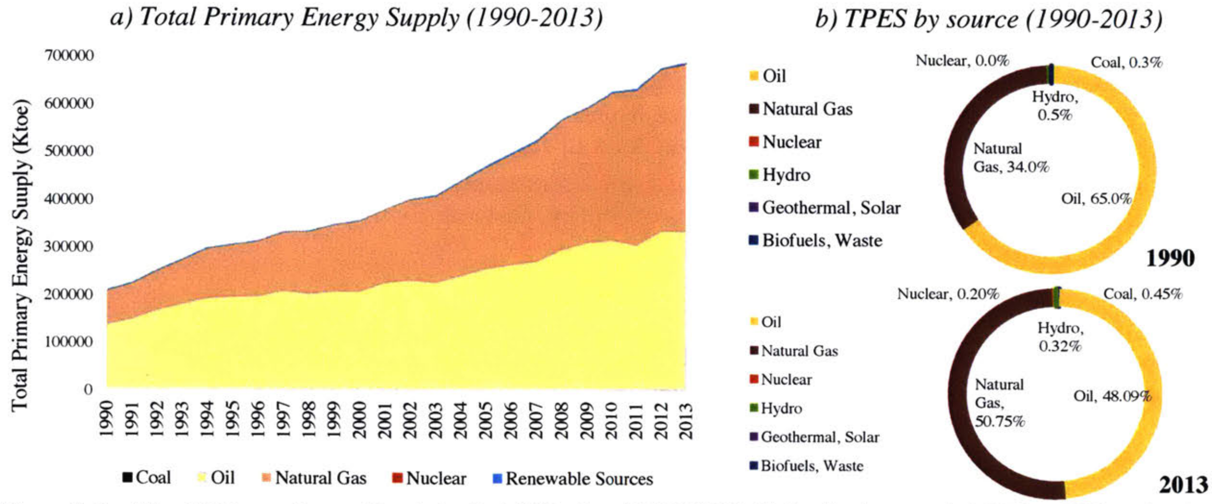


Figure 2.2: a) Total Primary Energy Supply in the Middle East (1990-2013), b) Fuel's share in the TPES in 1990 and in 2013. Based on data from (International Energy Agency, 2016).

2.2.2 Energy Consumption

Since 1970's, energy consumption trends in the Middle East have changed significantly. In 2014, the region accounted for around 5% of the global energy demand (IEA, 2015a). The rapid growth in gross domestic product and population explosion increased this share by almost fourfold from 1970's levels. In addition, the share of domestic energy consumption in the total production has grew from 4% in 1971 to 24% in 2010 as presented in table 2.3 (Farzaneh et al., 2016). Natural gas and oil have always fueled almost all of the region's needs (Table 2.3). Since the 1970, primary energy demand has been increasing at annual average rate of 6% (International Energy Agency (IEA), 2004). As energy demand in the Middle East is projected to continue its rapid growth in the future, expanding the production to maintain the export capacity becomes a crucial issue to secure energy supply.

Table.2.3: Primary Energy Demand in the Middle East (1970-2014).

	1970	2014	AAGR (1970-2014)
Total primary energy demand (Mtoe)	51	720	6%
Total primary energy demand per capita (toe)	0.4	3.2	5%
Oil primary energy demand (Mtoe)	38	343.7	5%
Share of Oil in total primary energy demand	**74.5**	**47.7**	-
Gas primary energy demand (Mtoe)	11	369.5	9%
Share of gas in total primary energy demand	**21.5**	**51.3**	-

Most of the growing demand is mainly coming from four countries, Iran, Kuwait, Saudi Arabia and UAE. Although these four countries have large fossil fuel reserves, especially Saudi Arabia and Iran, their energy consumption has been increasing significantly through the past thirty years. Figure 2.3 shows energy consumption across the four countries. In Iran and Saudi Arabia, energy consumption increased much faster and their share in the region's primary energy demand reached 62.5% in 2014 (IEA, 2015a). The large growth in energy consumption is directly linked to population growth, and high living standards associated with economic development. If these trends continue in the future, a reduction in their fossil fuel exports will be expected.

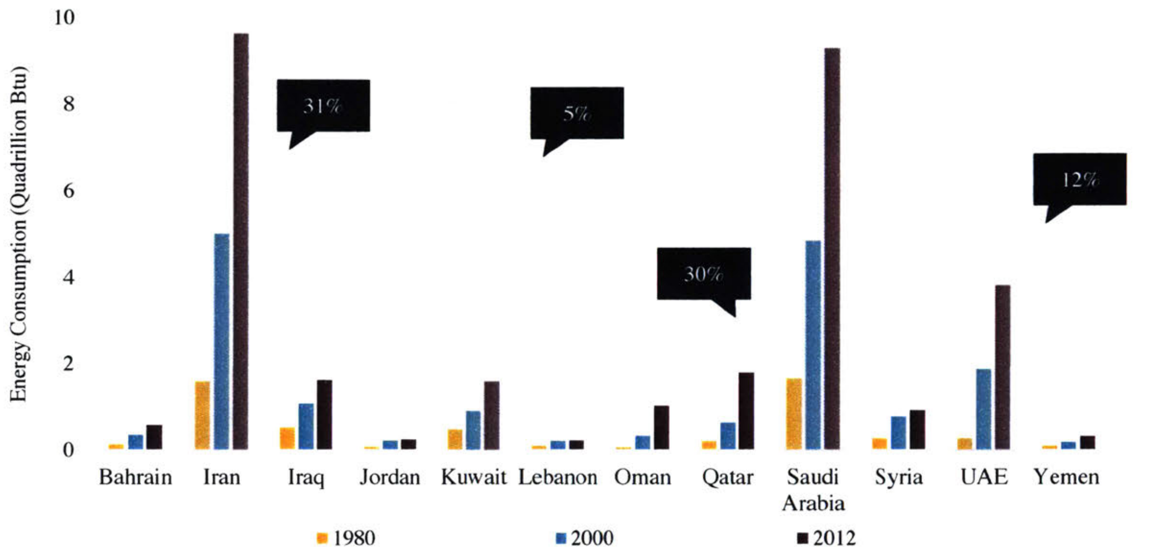


Figure 2.3: Total Energy Consumption in the Middle East (1980, 2000 and 2012), Callout bubble indicate the percentage share of the largest four countries in energy consumption. Based on data from (EIA, 2016).

For fossil fuels consumption, both natural gas and oil have grown faster than income since 1971 as presented in table 2.4 below. However, future projections predict that in the next two decades, natural gas consumption will grow half as fast as income. In addition, there will be a slower growth in oil consumption than income. Heavy fuel oil accounted for the largest share in the region's oil consumption since the early 1970's, primary used for electricity generation; however, it did not increase much since then. On the contrary, transport oil (such as diesel and jet fuel) and other oil products have grown faster than income throughout the past forty years (International Energy Agency (IEA), 2012).

Table 2.4: Levels and growth rates of income and consumption of oil and gas in 1971–2010, with projections to 2030. Based on data from (British Petroleum, 2011; International Energy Agency (IEA), 2012).

	1971-2010						Projections to 2030		
			Average Annual % Growth				**IEA**	**EIA/DOE**	**BP**
	1971 Level	**2010 Level**	*1971-2010*	*1971-1975*	*1975-1986*	*1986-2010*	*New Policies Scenario*	*Ref. case Scenario*	
Total Oil (mbd)	**1.1**	7.7	**5.10%**	5.3%	7.20%	4.00%	1.40%	1.70%	1.80%
Transportation Oil (mbd)	0.3	3.7	**6.60%**	13.2%	10.00%	3.80%			
Other Oil (mbd)	0.2	2.9	**6.40%**	10.7%	6.20%	5.80%			
Residual Oil (mbd)	0.6	1.8	**2.8%**	-2.1%	4.50%	2.90%			
Natural Gas (mbdoe)	**0.3**	6.6	**8.10%**	10.1%	10.00%	7.00%	2.50%	2.70%	3.90%
Real Income (2005$ PPP)	703	22600	**3.40%**	8.0%	-0.04%	4.40%	3.90%	3.80%	3.90%

2.2.3 End-use Sectors and Power Generation

Over the period of 1990-2014, energy consumption from economic end-use sectors, i.e., industry, transport, agriculture, buildings and non-energy use, has grown by almost 5.1% annually (IEA, 2015a). The highest growth in energy consumption since 2010 occurred in industry, transportation, and residential sector (IEA, 2015a). These three sectors accounted for 80% of the region's total energy consumption in 2014 (figure 2.4-a). Industry is considered the major energy-consuming sector, accounting for about 32% of the region's total energy consumption (Tolba & Saab, 2009). Transportation sector is the second largest, accounting for about 29%. In 2014, 65% of industry's energy consumption came from natural gas, while oil represented 22%, electricity 11%, and only 1% came from coal. For transportation, oil accounted for 95% and natural gas for 5%. Conversely, most residential energy consumption came from natural gas, accounting for 47%, followed by electricity accounting for 36% of the total consumption, while oil represented only 17% (Figure.2.4-b).

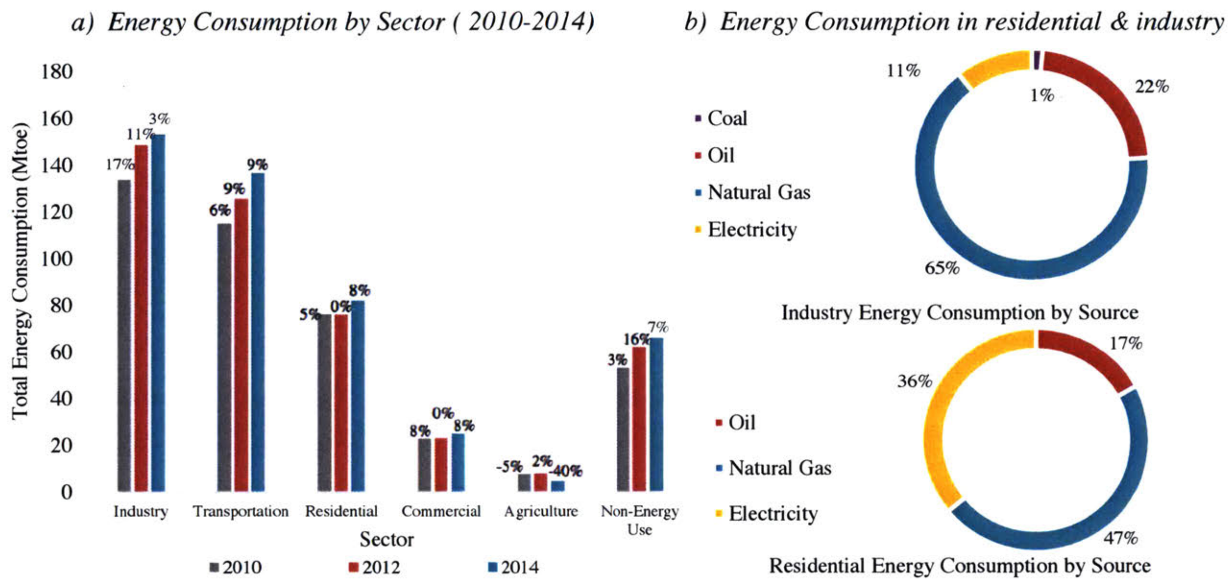


Figure.2.4: a) Energy consumption by sectors in 2010, 2012, 2014, b) Industry and Residential sector energy consumption by source in 2014. Based on data from (International Energy Agency, 2016; International Energy Agency (IEA), 2012).

As presented in figure 2.5, Iran, Saudi Arabia and the UAE are the largest contributors to energy consumption on a sectoral level as well. In Iran, for instance, residential sector represented 27% of the total energy consumption, while in Saudi Arabia, industry accounted for 34.4% of total final consumption, followed by transportation (31%). In the UAE, industry dominates total energy consumption, accounting for about 56% in 2014.

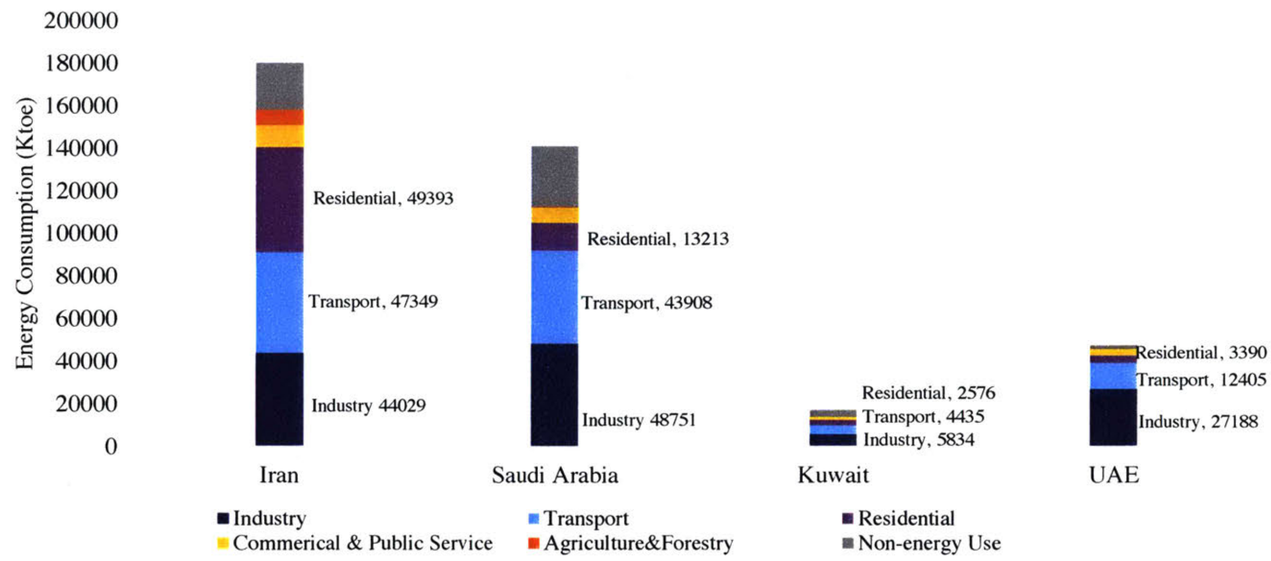


Figure.2.5: Total final energy consumption by sector across the Middle East countries. Based on data from (International Energy Agency, 2016; International Energy Agency (IEA), 2012).

The electricity generation sector represents the bulk of the region's total energy demand. Since 2004, electricity generation has increased rapidly, growing by almost 80% in 2013 (figure 2.6-a). Trends in electricity generation changed significantly between 1990 and 2013. Oil and natural gas accounted for about 95% of the total mix with a small share from coal and renewable power presented in hydroelectricity. In 2013, natural gas started to dominate the electricity mix, increasing to 63.5% of total mix while oil's share went down to 33.14% (figure 2.6-b). Recently, the use of nuclear and renewable energies has been rising, along with their production capacity. In 2014, hydro accounted for 2.0% of total generation with an increase of 21% compared to 2004. Although there is a projected increase in the share of renewables in electricity generation mix, fossil fuels will still contribute the largest share.

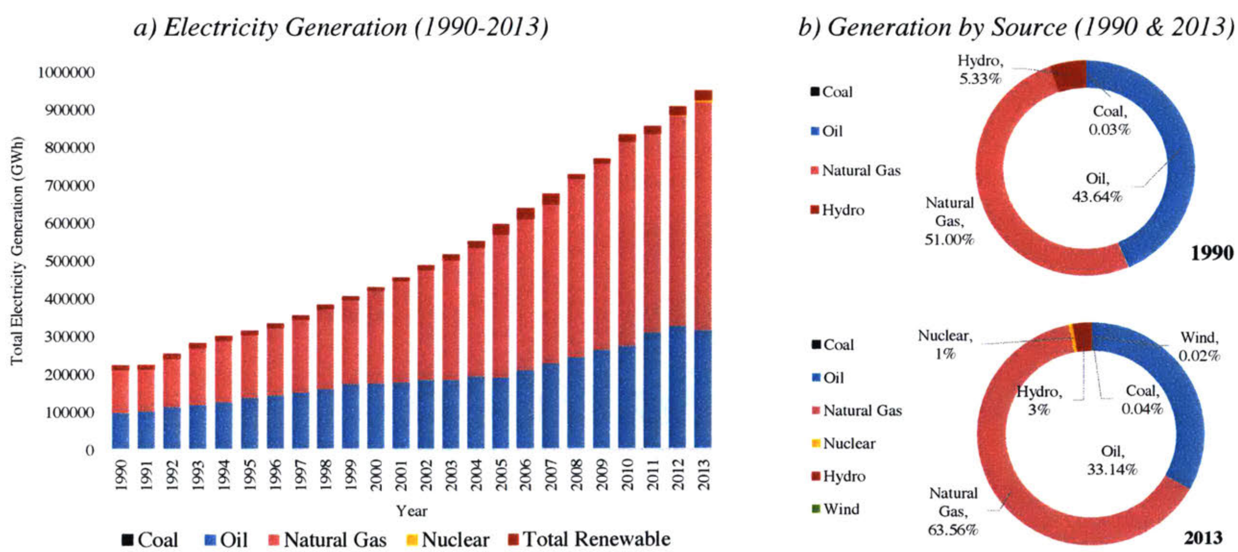


Figure 2.6: a) Electricity Generation mix by source (1990-2013), b) Changes in percentage share change between 1990 and 2013. Based on data from (International Energy Agency, 2016)

Current energy trends place the Middle East's economies among the least efficient in the world. Between 2004 and 2014, total energy consumption in the Middle East grew by almost 65%, and total CO_2 emissions grew by over 62% (IEA, 2016). In addition, total energy use is considered relatively high compared to other countries with same levels of GDP per capita, such as the UK and Japan. From Figure.2.7 below, it is clear that energy resources are deployed very inefficiently across the region. Although countries in the Middle East vary significantly in their GDP per capita, yet their per capita energy consumption are remarkably similar. This is mainly a result of the relatively low domestic energy-pricing environment in most of the countries in the Middle East, where fuel and electricity are sold at low rates (El-katiri, 2012).

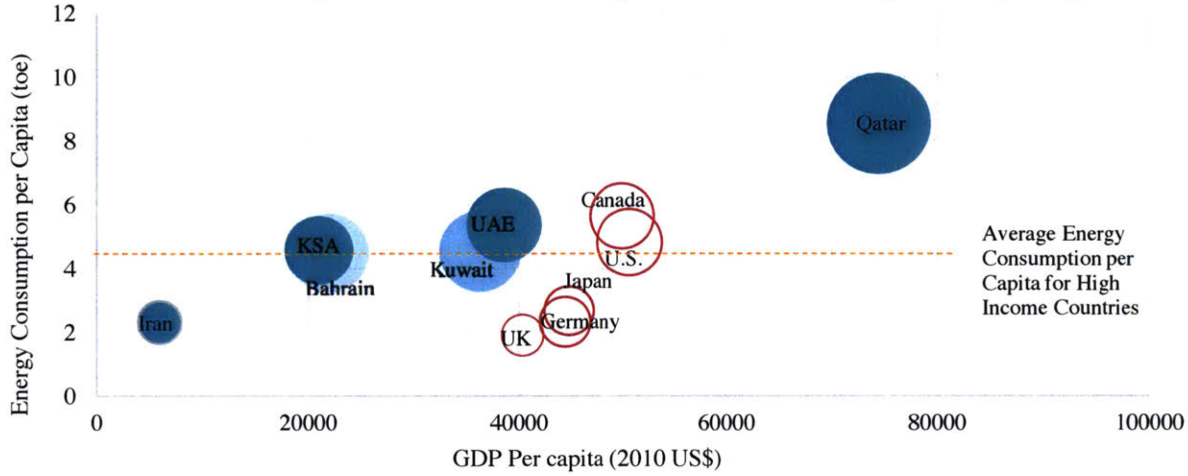


Figure.2.7: Energy intensity relative to GDP per capita in Middle East's countries and other developed countries with bubble size representing CO_2 emissions per capita. Based on data from (International Energy Agency, 2016).

2.3 Emissions Trends in the Middle East

Total GHG emissions in the Middle East have been increasing rapidly during the past decade. Between 1990 and 2010, GHG emissions have increased by an average annual rate of 5% (World Bank, 2016) . Most of the GHG emissions are coming from electricity and heat production sector that accounted for 38% of the total GHG emissions in 2010. Transportation and industry sectors accounted for 34% in the same year as shown in figure 2.8. CO_2 gas emissions have the largest share among other greenhouse gases in the Middle East. In 2010, CO_2 emissions accounted for 70% of total GHG emissions, mainly coming from power generation sector with a share of 52%. Industry sector accounted for 23% of total CO_2 emissions followed by transportation sector with a share of 21% (International Energy Agency, 2016).

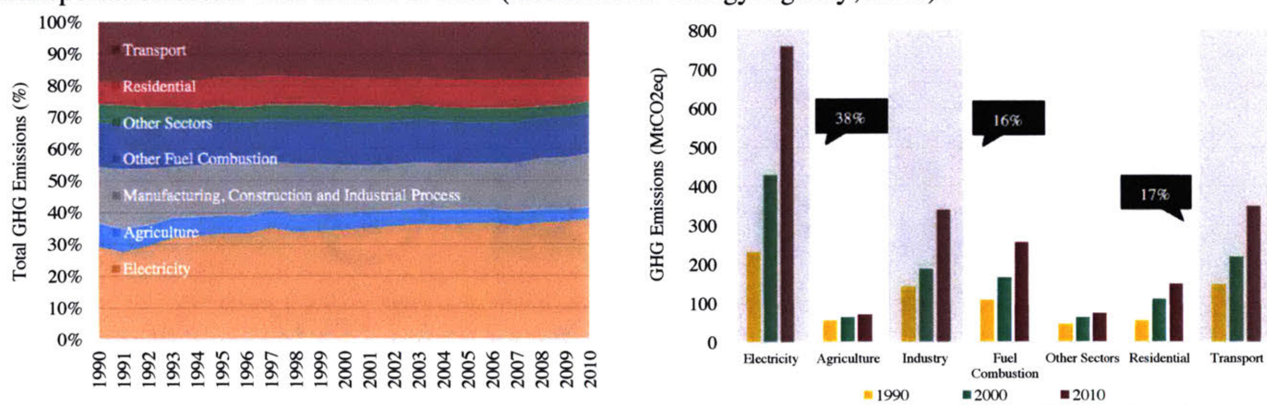


Figure 2.8: Left- Total GHG Emissions by sector, Right- Changes in GHG emissions in 1990, 2000, and 2010.
Emissions from building sector (commercial and residential) refer to emissions from onsite power generation and burning fuels for heat. Emissions from electricity use are excluded from building sector and covered in electricity and heat production. Other fuel combustion refers to combustion activities other than industrial and manufacturing processes. Other sectors refer to emissions from energy sector that are not associated with electricity and heat production. Based on data from (World Bank, 2016).

Between 1971 to 2012, the Middle East had the highest growth rates of CO_2 emissions globally, where its total CO_2 emission increased almost 16.5 fold (International Energy Agency (IEA), 2014). The rapid increase in emissions was largely driven by increasing energy demand from population growth and rising GDP especially between 2011 and 2012 as presented in figure 2.9 below (International Energy Agency (IEA), 2014).

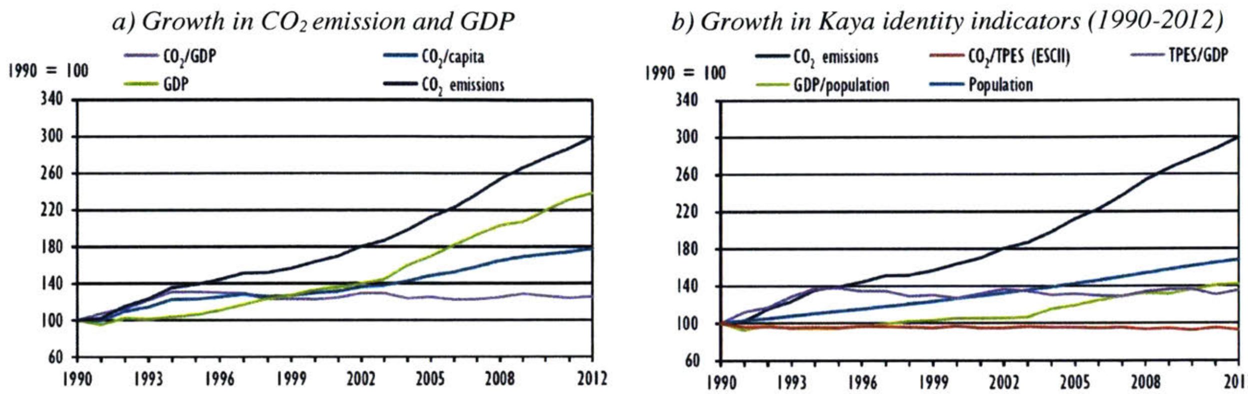


Figure 2.9: a) Changes in CO_2 and GDP indicators since 1990, b) Drivers of CO_2 emissions based on Kaya decomposition since 1990 (International Energy Agency (IEA), 2014).

Although the Middle East contribute a small fraction of the global CO_2 emissions, nearly 5%, emissions from energy consumption alone account for almost 6.4% of the global energy-related emissions (Boden et al., 2011). Among the twelve Middle East countries, four countries play the major role in emission increase, namely, Iran, Saudi Arabia, the UAE and Kuwait. In 2013, these four countries alone emitted about 76% of total Middle East CO_2 emissions with Iran and Saudi Arabia accounting for around 60% as illustrated in figure 2.10. For per capita emissions, the United Arab Emirates (UAE) and Qatar, are classified among the world's worst performing economies in terms of emissions per capita, where Qatar produces about 55.4 tons of carbon per person (Arouri et al., 2012).

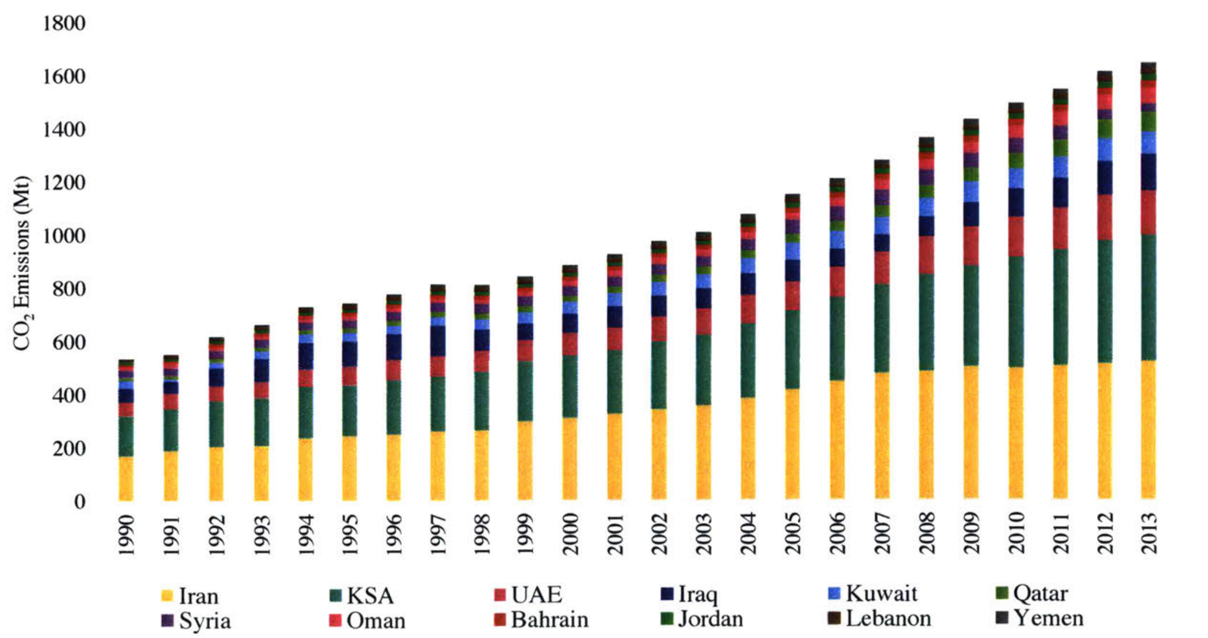


Figure 2.10: CO_2 Emissions by country (1990-2013). Based on data from (International Energy Agency, 2016)

2.4 Trends of Renewable Energy in the Middle East

The expected gradual depletion of fossil fuel reserves along with an increase in energy prices are all driving global energy supply towards more renewable resources over the next decade. Although the Middle East holds the largest potentials for renewable energy, not least solar energy, renewable energy still underdeveloped, contributing only about 5 % of the total Middle East primary energy supply mix (International Energy Agency, 2016). During the past decade, several Middle East's countries initiated pro-active policies and programs to increase renewable deployment in power sector. For instance, Saudi Arabia and the UAE have taken concrete steps towards producing clean energy on a large-scale and fostering sustainable development. This section provides a brief overview on the current renewable energy resources in the Middle East and highlights main gaps in renewable deployment.

2.4.1 Current Use of Renewable Technologies

Forecasts of the International Energy Agency (IEA, 2015) indicate that energy demand in the Middle East is expected to increase above the world average between 2010 and 2030, growing at an average rate of 3% annually. In addition, electricity demand is also projected to increase at an annual average 6% over the same period (OECD & IEA, 2011). The significant growth in demand accompanied with large economic growth will entail an increase in power generation capacity. Currently, the share of RETs is relatively modest. Approximately within two-thirds of the Middle East countries, the share of renewables in the energy mix is 1% or less and about one-third of the countries are not using any renewable resources (Jalilvand, 2012). Furthermore, between 1990 and 2013, the share of renewable energy technologies went down from 1% to 0.5% as presented in figure 2.11.

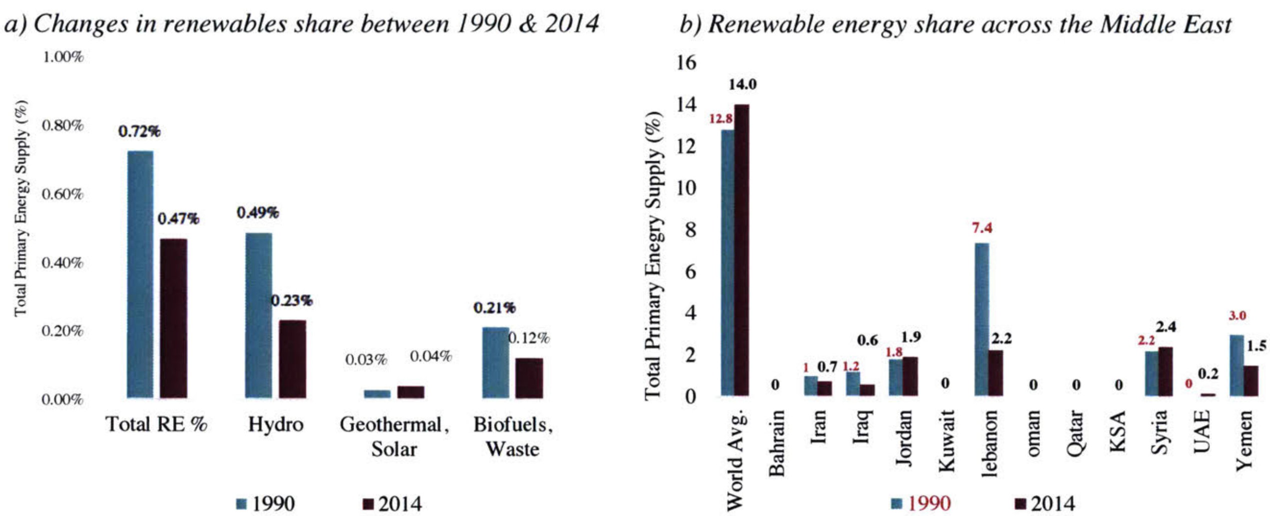


Figure 2.11: a) Share of renewable energy resources in total primary energy mix (changes between 1990 & 2014). b) Share of renewable energy resources across the twelve countries compared to world average (changes between 1990 & 2014). Based on data from (International Energy Agency, 2016; International Energy Agency (IEA), 2012).

In general, the region significantly lags behind the world average in terms of renewable deployment. Across the twelve Middle Eastern countries, the share of renewable energy has decreased drastically from 1990 to 2014. As presented in figure 2.11, only four countries met more than 1% of their total primary energy with renewable resources, namely, Jordan, Lebanon, Syria and Yemen in 1990. In addition, none of the four big countries does the share exceed 3%. On The other hand, renewables are least used or almost non-present across oil rich and gulf countries such as Oman, Qatar, Kuwait and Saudi Arabia.

2.4.2 Renewable Energy Resources Potential

Although many countries in the Middle East have access to large fossil fuel reserves, others lack domestic fuel production and are largely dependent on energy imports. With the projected increase in energy needs, a greater fiscal burden on energy imports will follow. Under these circumstances, untapped renewable resources represent a huge potential for fueling a large portion of growing energy demands. Furthermore, the region has a significant potential for renewable energy development given its geographic and environmental characteristics, particularly for solar and wind energy. Several studies have investigated renewable energy potential in the Middle East (Alnaser & Alnaser, 2015; Munawwar & Ghedira, 2015; Nematollahi et al., 2016). It was indicated that, the majority of Middle East's countries are geographically located as part of the SunBelt[6], where levels of solar insolation are among the highest in the world (Kearney et al., 2010). This section presents a discussion on the potential of renewable energy resources and planned deployment. The discussion will focus on both solar energy and wind energy, as these two represent the largest potential in the region.

2.4.2.1 Solar Energy

As previously mentioned, the Middle East has one of the highest solar potentials in the world. The region's Direct Normal Irradiance (DNI), for concentrated solar power technologies (CSP), is around 4.5 KWh/m^2/day, and the Global Horizontal Irradiance (GHI), for Photovoltaic (PV), is around 6.5 kWh/m^2/day (Kearney et al., 2010). Figure 2.12 presents the distribution of solar radiation across the Middle East. While most of the region's peak demand is during the daytime of summer months from June through August, studies have shown there is a large potential for meeting peak demand with only solar technologies. A recent study (Nematollahi et al., 2016) found that southwestern parts of the region, have higher values of solar radiation than in other parts of the region, especially in Eastern Iran, Oman, the UAE and Yemen and even higher levels in the South East countries, like in Iraq, Jordan and Saudi Arabia. Thus, systems like photovoltaics and solar heating represent an economical option for these countries. In addition, about 90% of the regions area is desert land that offers a huge potential for large-scale solar deployment. With such potentials for solar technologies, significant opportunities for resourcing energy supply as well as seawater desalination requirements can be achieved.

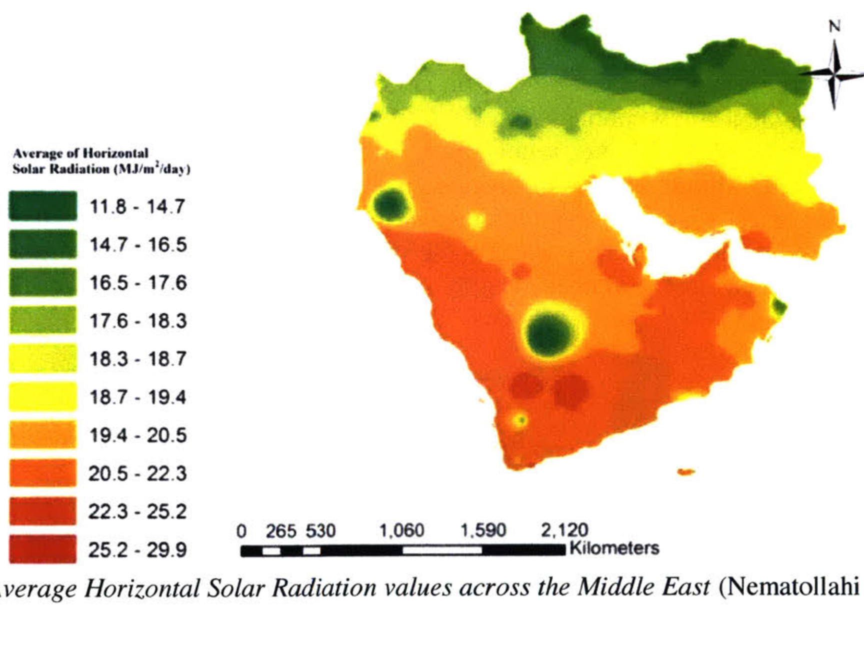


Figure 2.12: Average Horizontal Solar Radiation values across the Middle East (Nematollahi et al., 2016).

---

[6] SunBelt: A geographical region that is characterized by high availability of solar irradiation and it includes countries that are geographically located between 35°N and 35°S (Kearney et al., 2010)

2.4.2.2 Wind Energy

Potential for wind energy in the Middle East is considered high as well, however it is relatively modest compared to solar energy. The coastal line over the Red Sea and Gulf represent two of the most suitable locations for wind deployment, where wind availability reaches about 1400h/year (Alnaser & Alnaser, 2015). A recent study on wind potential across the Middle East (Nematollahi et al., 2016) found that countries like Saudi Arabia, Oman and Iran have one of the highest wind speed recorded at height of 50m, reaching an average between 5.39 m/s and 7.35 m as shown in figure 2.13. In addition, the maximum wind power density at 50m height is found in Oman, central Iran and some areas in Yemen. In addition, the coastal line of Saudi Arabia and islands in the Arabian Gulf are economically suitable for offshore wind deployment (Ferroukhi et al., 2013). Furthermore, countries like Iraq, Kuwait, Jordan, Lebanon and Kuwait have lower power density at 50m height.

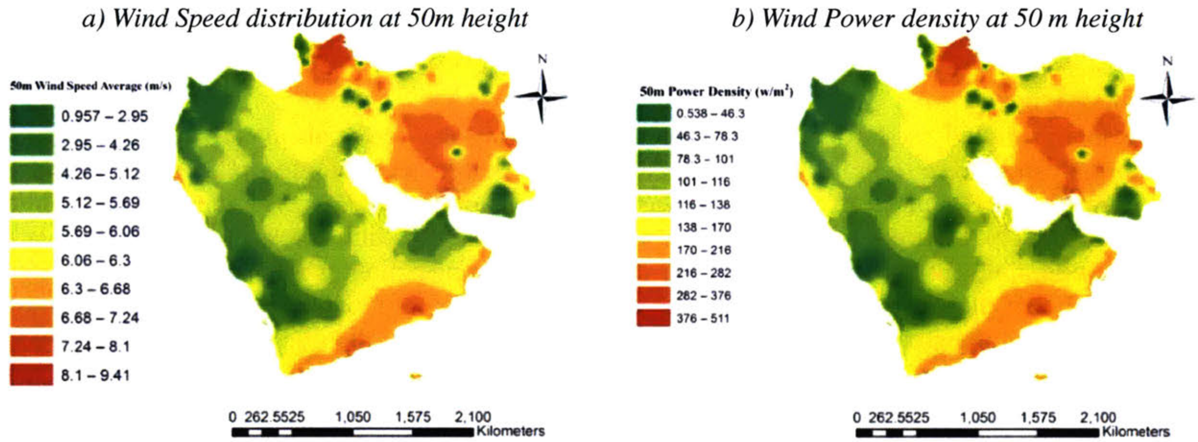


Figure 2.13: a) Average wind speed at 50m height across the Middle East, b) Wind power density at 50m height (Nematollahi et al., 2016).

2.4.2.3 Other Renewable Resources

The geographical characteristics of the Middle East region underline the huge potential for increasing the use of renewable energy, especially that the region holds about 45% of the global potential for renewable energy (Jalilvand, 2012). A study conducted in 2015 (Abdmouleh et al., 2015), examined the potentials of solar and wind energy along with other renewables, found that geothermal and biofuel present possible energy alternatives in the Middle East. As illustrated in figure 2.14 below, the availability of solar energy in the UAE has the highest share due to its strategical location for solar energy availability. On the other hand, in Saudi Arabia, potentials for solar and geothermal are the biggest. In Oman, solar and biofuel have the highest potentials in terms of resources availability.

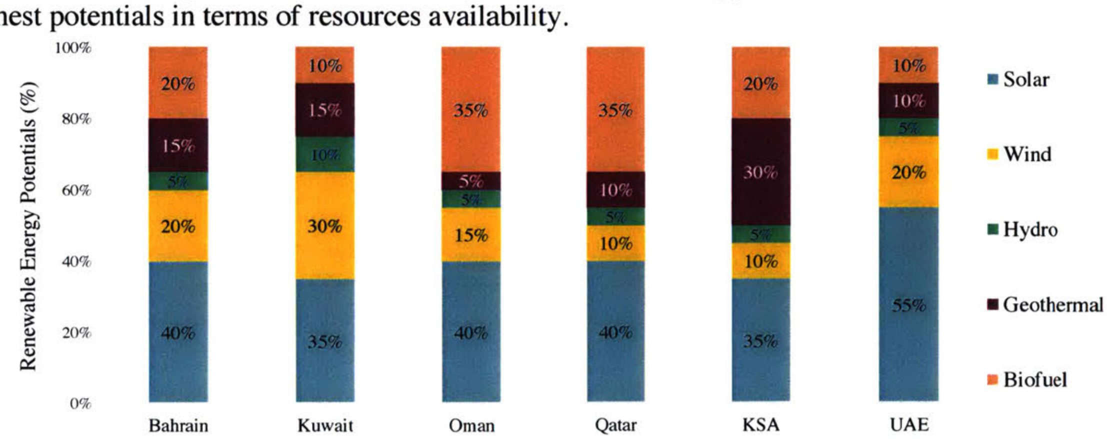


Figure 2.14: Availability of different renewable energy resources in some of the Middle East countries. Based on (Abdmouleh et al., 2015).

2.4.3 Renewable Energy Strategies

As discussed above Middle Eastern countries are largely dependent on oil and natural gas to supply their domestic energy needs, however, it has been predicted that by the year of 2020, natural gas will overtake oil in supplying future demands and oil will be freed up for exports. With that, several countries in the Middle East started to establish plans to increase renewable penetration in their total energy mix, along with other energy efficiency measures. In 2013, around 13 GW of renewable capacity representing an increase of almost 4.5 folds from existing renewable capacity (IRENA, 2013). Solar and wind energy accounted for about 2% of total installed capacity while hydropower accounted for the largest share with about 12 GW. Most of hydropower installed-capacity came from five countries, Iran, Iraq, Lebanon, Jordan and Syria. Iran and Iraq alone accounted for 89% of the total Middle East installed hydropower capacity in 2013 (IRENA, 2013). Biomass represented about 0.4% of total installed capacity with Jordan accounted for 8% and Qatar 92% as presented in figure 2.15.

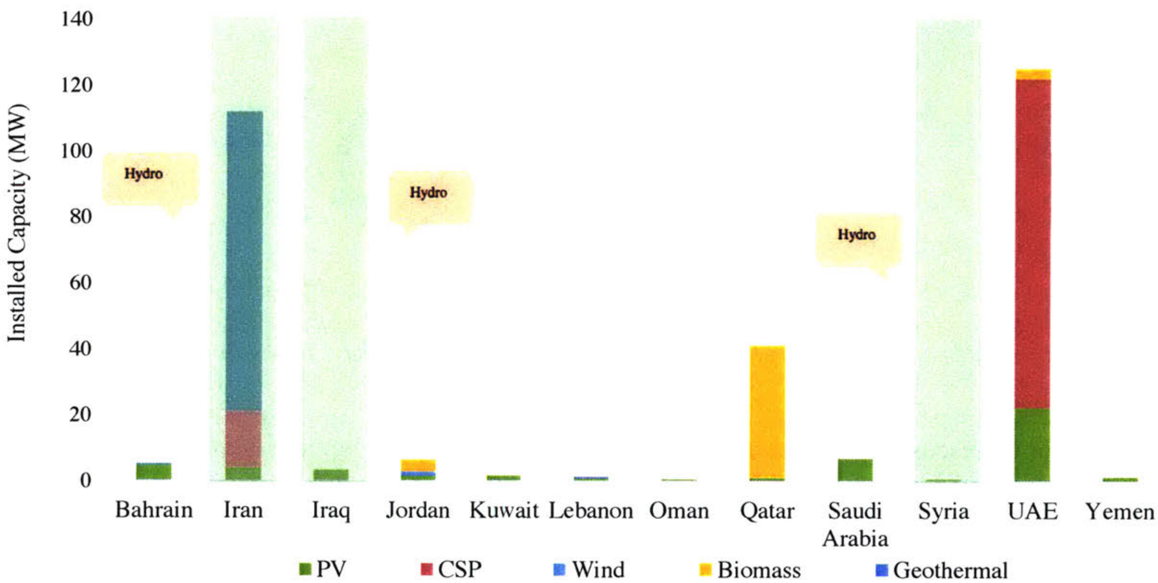


Figure 2.15: Total installed capacity from renewable technologies across the twelve Middle Eastern Countries. Bubble refers to installed capacity from hydropower in GW. Based on data from (IRENA, 2013, 2015a).

Along with the projected capacities, policies to support renewable energy are found across the twelve countries with most of the planned targets cover the period of 2020 to 2020. About 50% of the policy strategies are for renewable power generation. By the year 2020, the share of renewables will range from 5% in Bahrain and Kuwait to 24% in the UAE. Targets for 2030 vary from 10% of total electricity generation in countries like Iraq, between 12% and 15% in Kuwait, Lebanon and Yemen and 30% in the UAE. Figure 2.16 illustrates planned renewable targets and associated technologies. On the technology side, some countries have announced technology specific targets, others have only specified an overall target with no technology specifications (IRENA, 2013, 2015a; OECD, 2013). Qatar has set a plan of 640 MW of solar power specifically PV by 2020; Yemen also announced targets of 6 MW of biomass and 400 MW of wind. Iraq has announced a target of 200 MW of installed electricity capacity from solar and wind power (figure 2.16-b).

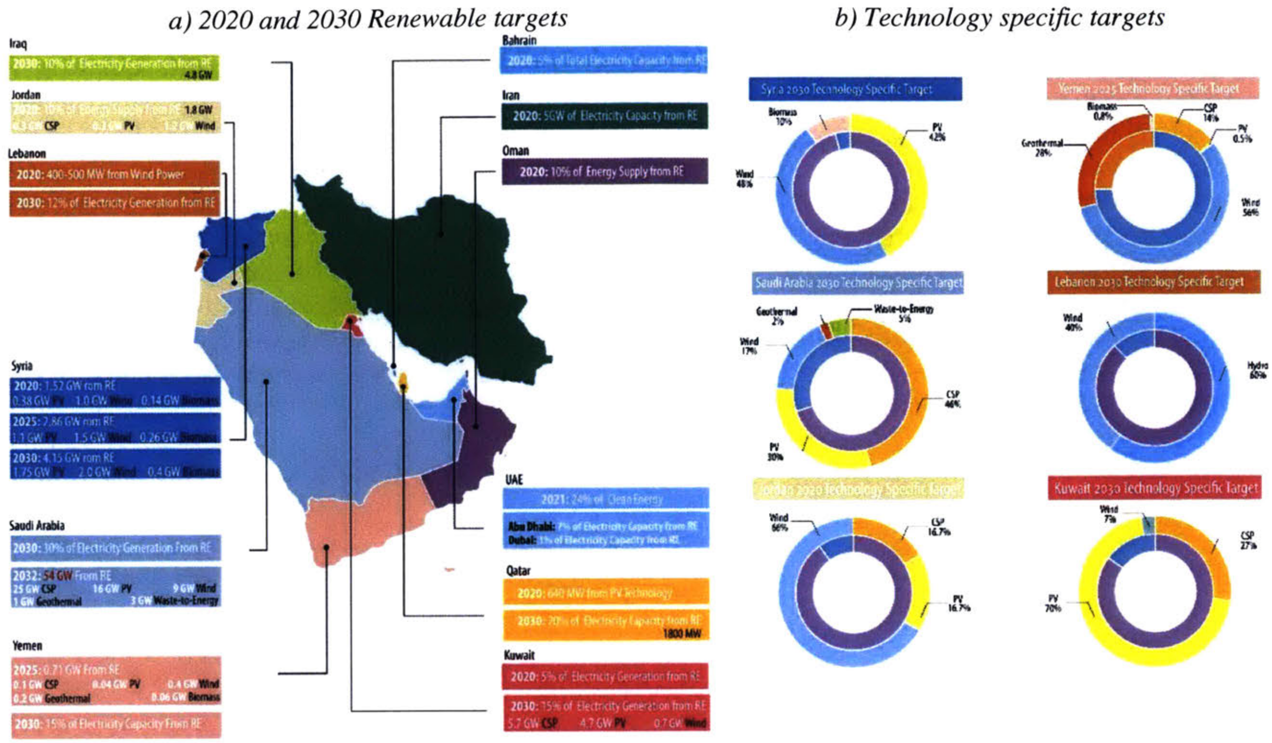


Figure 2.16: Renewable energy targets set for 2020-2030 across the Middle East. Based on data from (Bryden, Riahi, & Zissler, 2013).

Based on the above discussion, solar and wind are the main technology options across the Middle East. Although solar CSP technology has a higher cost, it offers a larger share compared to solar PV due to significant potential for energy storage. Along with solar and wind technologies, geothermal, hydropower and waste-to energy are relatively considered within the majority of planned polices. While planned targets look promising, there is a wide range of barriers that may hinder the development of vigorous renewable energy market in the Middle East. Such barriers are directly linked to different factors such as technology choices, technical expertise and financial resources needed to purse larger deployment. Most importantly, subsidized fossil fuel energy is considered a major obstacle when it comes to renewable deployment. Although the cost of renewable technologies have significantly dropped during the past five years, underpricing conventional energy will encourage its use at the expense of other energy options.

2.4.4 Barriers to Renewable Energy Deployment

As discussed throughout the chapter, there is a significant potential for renewable energy resources in the Middle East, yet renewable technologies face various technical, social and economic barriers. One of the main obstacles is politically subsidized prices for electricity and fossil fuels. Recently, some countries have taken serious steps to formulate proper legislative framework like the UAE and Qatar, yet the majority of the Middle East's countries are still lagging behind. Some of the obstacles hindering the deployment of RETs in the Middle East can be listed as follows:

- Heavily subsidized electricity and fuel prices make renewable technologies less appealing for power generation sector.
- Electricity grids in the majority of Middle East's countries are not equipped enough to face the dynamics of renewable integration.
- Limited Research and Development capacity (R&D) to develop and adapt renewable technology to the climatic conditions of the Middle East.

- Environmental obstacles facing solar technology deployment including high ambient temperature, dust accumulation and high humidity.
- Land availability in countries like Bahrain and Qatar, where most of the available land area is located in scarce places that may increase the cost of renewable deployment (OECD, 2013).

These barriers will influence the success of renewable strategies. It is only up to governments to push the development of renewable technologies and provide a suitable political climate that assists in reducing the reliance of fossil fuel resources.

2.5 Middle East Contributions under the Paris Agreement

Global sustainable development action had a landmark in 2015. This year marked the adoption of 2030 Sustainable development Agenda, followed by Paris Climate Agreement COP21 in December. The objective of this agreement was to assure that countries maintain a suitable level of GHG emissions by 2050 that limits the increase of global mean temperature below 2 degrees. This was framed into "stabilization of GHG emissions to a level that would limit dangerous interference with the climate system" (UNFCC, 2016). For energy systems, Paris Climate Agreement has significantly tipped the energy balance in favor of renewable energy resources that will place fossil fuel energy with an accelerated rate. It has become a global essential that each country submits mitigation strategies explaining plans to limit the increase of GHG emissions, which is denoted as "Intended Nationally Determined Contributions (greenhouse gases reduction)" or INDCs. Although the Middle East represents about 7% of total GHG emissions, around 32 giga tons of carbon dioxide are emitted annually (World Bank, 2016). In 2015, eleven countries across the region have submitted their national pledges towards reducing GHG emissions and increasing the share of renewable energy deployment. Most of these pledges had two targets: conditional target that will be achieved contingent on financial funding and technical support, and unconditional target that could be achieved through domestic resources as shown listed in table 2.5.

Table 2.5: Middle East countries pledges against Climate Change by 2030. Based on data from (UNFCC, 2016).

Country	Mitigation Target		Target Year	Implementation Period	Base Year
	Unconditional	Unconditional +Conditional			
Bahrain	**No quantified pledges, Economy Diversification with sectoral targets**				
Iran	-4%	-12%	2030	2021-2030	BAU
Iraq	-14%	-14%	2035	2020-2035	BAU
Jordan	-1.5%	-12.5%	2030	Until 2030	BAU
Kuwait	**To avoid increasing CO_2 Emission**				
Lebanon	-15%	-30%	2030	N.A.	BAU
Oman	-2%	-2%	2030	2020-2030	BAU
Qatar	No quantified pledges, INDC mentions policies and actions				
Saudi Arabia	-130 Mt CO_2e (annually)		2030		BAU
Syria	**No quantified pledges**				
UAE	24% Clean energy (sectoral Target)		2021	N.A.	N.A.
Yemen	-1%	-14%	2030	2016-2030	BAU

Planned targets encompass quantified economy-wide emission saving plans that will assist towards a low-carbon future. One of the first countries to submit its INDC was Jordan that committed to reduce its GHG emissions by 1.5% by 2030 below Business As Usual (BAU). In addition, the country has planned to satisfy around 11% of its energy demand in 2025 from renewable resources, mainly hydropower, solar and wind, accompanied with an increase in energy efficiency of 20% by 2020. On the contrary, countries like Bahrain and Qatar announced an economy wide diversification plan to reduce reliance on oil and natural gas with no quantified emission reductions (table 2.5). Oman and Lebanon have set a target of reducing their emissions by 2% and 15% respectively, through increasing renewable energy in power sector (UNFCC, 2016).

Saudi Arabia has set a very ambitious target of 130 million tons of carbon dioxide equivalent annual reduction by 2030. The plan includes adjustments in national energy supply mix and reduction in reliance on oil. The UAE also has set an ambitious goal of increasing renewable energy share from 0.2% in 2014 to 27% by 2021. Finally, Yemen's target was relatively modest with a 1% reduction in GHG emissions below BAU levels and a conditional target of increasing clean power to 15% by 2025. Modest targets like Yemen and Lebanon's could level up to larger percentage depending on financial funding and technical support. From this discussion, it can be concluded that countries across the Middle East have set efforts towards climate change goals with ambitious commitments. More importantly is that resource rich countries, like Saudi Arabia, have articulated their pledges in a way that would not put large burden on their economies. Their pledges have shown strong economic interest in maintain their global economic role based on fossil fuels yet at the same time reduce the reliance on fossil fuels for domestic energy supply.

2.6 Discussion

The chapter presented an overview on current energy trends across the Middle East. Generally, fossil fuels play the main role in the region's energy development. It has been highlighted that the way energy supply intersects with climate change is one of the growing concerns that the region will face in the near future. Tackling these issues will require a significant contribution from governments, stakeholders, societies' behavior and policy makers. The rapid growth in Middle East's energy consumption indicates that these trends will be highly expected in the next few years. In addition, growth will be underpinned by subsidized fuel prices, which will hinder the transition to clean energy sources. In addition, rapidly increasing domestic energy requirements will immensely limit the capacity to export to global market. All these factors will lead to an increase in the region's share in global CO_2 emissions.

As discussed throughout the chapter, the use of energy in the Middle East will bring up new challenges that societies and government will have to develop corresponding strategies to tackle them. The consequences of climate change on the Middle East energy matrix underline the urgency for more efficient use of energy resources. Although the region holds a large share of the global fossil fuel production, the future of its energy supply mix will significantly depends on low carbon and renewable resource in order to meet climate targets. The current trends of energy found across the Middle East pose a threat to the region's economic and competitive position. Finally, it has been shown that several countries have set ambitious goals to reduce their energy use; yet, it will be up to governments to ensure that those targets are met. This could happen by developing policies and institutional frameworks that carefully consider the trade-offs between surging energy consumption, subsidized energy prices and incentives crafted to reduce growing demands.

References

Abdmouleh, Z., Alammari, R. A. M., & Gastli, A. (2015). Recommendations On Renewable Energy Policies For The GCC Countries. *Renewable and Sustainable Energy Reviews*, *50*, 1181–1191. http://doi.org/10.1016/j.rser.2015.05.057

Alnaser, W. E., & Alnaser, N. W. (2015). Solar And Wind Energy Potential In GCC Countries. *Journal of Renewable and Sustainable Energy*, *1*(2), 1–29. http://doi.org/10.1063/1.3076058

Arouri, M. E. H., Ben Youssef, A., M'henni, H., & Rault, C. (2012). Energy Consumption, Economic Growth and CO2 Emissions in Middle East And North African Countries. *Energy Policy*, *45*, 342–349. http://doi.org/10.1016/j.enpol.2012.02.042

British Petroleum. (2011). *BP Energy Outlook 2030. Annual Energy Outlook* (Vol. 383). London, United Kingdom. Retrieved from www.eia.doe.gov/oiaf/aeo/

British Petroleum. (2015). *BP Statistical Review of World Energy*.

Bryden, J., Riahi, L., & Zissler, R. (2013). *Renewables Status Report MENA*.

El-katiri, L. (2012). *Energy Subsidies in the Arab World Energy Subsidies in the Arab World*. New York.

Exxon Mobil. (2016). *Energy: A view to 2040*. Texas, USA.

Farzaneh, H., Mclellan, B., & Ishihara, K. N. (2016). Toward a CO 2 zero emissions energy system in the Middle East region. *International Journal of Green Energy*, *13*(7), 682–694. http://doi.org/10.1080/15435075.2014.889014

Ferroukhi, R., Doukas, H., Androulaki, S., Menichetti, E., Masini, A., & Khalid, A. (2013). EU-GCC Renewable Energy Policy Cooperation: Exploring Opportunities. *EU-GCC Renewable Energy Policy Experts' Workshop*, (December), 1–44

IEA. (2015). *Energy Balances of non-OECD Countries*. Paris, France.

International Energy Agency. (2016). *Key World Energy Statistics*. Paris, France. Retrieved from http://www.iea.org/statistics/statisticssearch/

International Energy Agency (IEA). (2004). *World Energy Outlook 2004* (Vol. 23). Paris.

International Energy Agency (IEA). (2005). *Middle East and North Africa Insights. Middle East North Africa Insights*. Paris, France.

International Energy Agency (IEA). (2012). *IEA Statistics - Energy balances of non-OECD countries*. Paris, France. http://doi.org/10.1787/energy_bal_non-oecd-2013-en

International Energy Agency (IEA). (2014). *Energy, Climate Change & Environment: 2014 Insights*. Paris, France. Retrieved from http://www.oecd-ilibrary.org/

IRENA. (2013). *MENA Renewables Status Report*. Abu Dhabi, United Arab Emirates.

IRENA. (2015). *Renewable Energy Market Analysis in GCC. IRENA*. Abu Dhabi, United Arab Emirates.

Jalilvand, D. R. (2012). *Renewable Energy for the Middle East and North Africa Policies for a Successful Transition*. Washingston, D.C.

Kearney, A. T., Hauff, J., Verdonck, M., Derveaux, H., Dumarest, L., Alberich, J., & Malherbe, and J.-C. (2010). *Unlocking the Sunbelt Potential of Photovoltaics*. Brussels, Belgium.

Munawwar, S., & Ghedira, H. (2015). A Review of Renewable Energy and Solar Industry Growth in the GCC region. In *The International Center for Water and Energy Systems (ICWES)* (Vol. 57, pp. 3191–3202). AbuDhabi, UAE: Elsevier B.V. http://doi.org/10.1016/j.egypro.2015.06.069

Nematollahi, O., Hoghooghi, H., Rasti, M., & Sedaghat, A. (2016). Energy Demands and Renewable Energy Resources in the Middle East. *Renewable and Sustainable Energy Reviews*, *54*, 1172–1181. http://doi.org/10.1016/j.rser.2015.10.058

OECD. (2013). *Renewable Energies in the Middle East and North Africa*. Paris, France.

OECD, & IEA. (2011). *World Energy Outlook 2011*. Paris, France.

Schaeffer, G. J. (2015). Energy Sector in Transformation, Trends and Prospects. *Procedia Computer Science*, *52*(1), 866–875. http://doi.org/10.1016/j.procs.2015.05.144

Tolba, M., & Saab, N. (2009). *Arab environment: Climate change. Beirut, Arab Forum for Environment*

World Bank. (2016). *World Development Indicators*. Washingston, DC. Retrieved from http://data.worldbank.org/sites/default/files/wdi-2016-highlights-featuring-sdgs-booklet.pdf

3. *Energy and Emissions in the Middle East: A View from Four Major Emitters*

The contribution of the Middle East to global GHG emissions is relatively modest, about 7% (World Bank, 2016), however on a regional level, there are a number of countries who significantly account for the largest emission share. In 2010, the Middle East GHG emissions reached almost 0.5 $GtCO_2eq$, however, 60% of total emissions were emitted from four countries, Iran, Kuwait, Saudi Arabia and the UAE (International Energy Agency, 2016; World Bank, 2016). In addition, the four countries have a potent import-export energy system and play a significant role within the region's energy trading system. Also, power generation sector in these four countries alone accounts for nearly 30% of total Middle East GHG emissions and about 76% of power-related CO_2 emissions. Due to the significant role that these countries play, this chapter provides an overview on energy structure and CO_2 emissions, specifically in these four countries, denoted as "major emitters". The analysis presented in this chapter will work as a foundation towards the prospects of regional emission reduction examined in chapter four and the development of the optimal portfolio mix presented in chapter six.

3.1 Fossil Energy: A Review

The Middle East has been always known for its energy wealth. As previously discussed in chapter two, the abundance of low-cost energy resources has significantly pushed the growth in energy demand. Oil and natural gas took the lead in supplying the majority of the region's energy needs, a historical trend since that 1950's that has always been closely tied to the region's role as a global supplier of both oil and natural gas (World Bank, 2016). The highest proven oil reserves in the Middle East including oil deposits are located in Saudi Arabia (18% of global reserves) followed by Iran (10.6% of global reserves). The following section presents an overview of the total available fossil fuel energy resources across the four countries. The analysis covers two fossil fuel resources: oil and natural gas. Coal will be discussed briefly since the region does not hold significant coal reserves and its share in the primary energy mix is relatively modest compared to oil and natural gas.

3.1.1 Oil

As previously mentioned, the Middle East holds about 78% of the global proven crude oil reserves that situated the region in an elite position in the global oil market. The large oil reserves are spread out differently across the four countries. The differences between the four countries in their production and available reserves are discussed as follow.

Iran. According to recent reserves estimates, Iran's total proven oil reserves are about 155 billion barrels of oil (bbl) that account more than 10% of the global oil reserve (Diefenderfer et al., 2016). It is also considered the third largest oil reserve holder in the world after Saudi Arabia. However, the expected life span of the country's total reserves is estimated to be approximately 94 years (Nejat et al., 2013a). Iran's total crude oil production in 2012 reached 1236 million barrels of oil (mmbl) with a decrease of 19.5% compared to 2008. Out of the total annual production in 2012, around 838 million barrels were exported (Diefenderfer et al., 2016). In 2012, Iran's domestic consumption of oil was 680 mmbl as presented in table 3.1. On the other hand, total CO_2 emissions from domestic oil consumption totaled 256 million metric ton (Mt) with an average increase of 7% from 2008 (Diefenderfer et al., 2016).

Kuwait. By the end of 2012, Kuwait's total proven crude oil reserves were estimated to be around 104 bbl, contributing 8% of the global oil reserves (Ramadhan & Hussain, 2012). Oil is considered a vital component in Kuwait's energy supply system. In 2012, the country produced around 2634 million barrels of oil per day (total of 962 million barrels of oil). In addition, its energy consumption estimated to be around 166 mmbl in the same year as presented in table 3.1 below (British Petroleum, 2011). Although the country is considered among the major oil exporters in the Middle East, exported 545 mmbl by the end of 2012, it consumes a huge bulk of its total production to meet rising energy demands, particularly from electricity generation sector. It also should be noted that, most of oil fields in Kuwait are over 60 years old that could possibly limit the expansion of production capacity in the future (Ramadhan & Hussain, 2012).

Table 3.1: Oil reserves, production, consumption and related emissions across the four major emitters.

	Iran	**Kuwait**	**Saudi Arabia**	**UAE**
Total Oil Reserves - 2013 Estimates (Billion Barrels of Oil)	155	104	267	97.8
Share of Global Oil Reserves (%)	10%	8%	16%	5.8%
Oil Production in 2012 (Million Barrels of Oil)	1236	962	3588	1032
Oil Exports in 2012 (Million Barrels of Oil)	838	545	2281	796
Oil Consumption in 2012 (Million Barrels of Oil)	680	166	1051	248
CO_2 Emissions from oil consumption in 2012 (Million Metric Tons)	256	71	389	102

Saudi Arabia. With oil reserves around 16% of the world's total, Saudi Arabia is by far the largest oil producer and exporter (62 Mtoe of oil exports in 2014) in the Middle East and that puts the country on the top of the list compared to the other three as shown in table 3.1. In addition, it's economy is significantly based on oil, as oil revenues account for 90% of the total national income and about 50% of Gross Domestic Product (GDP) (Mezghani & Ben Haddad, 2016). At the end of 2012, total proved oil reserves were 267 bbl, while oil production was estimated at 1051 mmbl (representing 13.3% of the world's oil production) (BP Statistical, 2016). On the consumption side, the country is ranked as the world's sixth largest oil consumer with total energy consumption higher than the global average (Alyousef & Abu-ebid, 2012). In 2012, total oil consumption in Saudi Arabia reached almost 1051 mmbl, accounting for 3.1% of the global oil consumption (Alshehry & Belloumi, 2015). In addition, CO_2 emissions from oil consumption reached around 389 Mt in 2012 with an increase of 45% than 2008 levels (The International Energy Agency IEA, 2012).

UAE. Currently ranked as the eighth largest oil reserve in the world, holding about 5.8% of the global oil reserves. In addition, its production levels are among the highest in the world, ranked as the 4^{th} largest oil producer (1032 mmbl) and accounting for 4% of global oil production (British Petroleum, 2011). While the UAE's total population represent only 0.1% of the global population, the country consumes around 0.8% of world's total oil consumption (Sgouridis et al., 2016a). In 2012, the country's oil consumption reached 248 mmbl with an average increase of 12% compared to 2008 (International Energy Agency (IEA), 2012). CO_2 emissions from oil consumption have been rapidly increasing due to rising energy demand and vast economic development. In 2012, total emissions from oil consumption reached 102 Mt, with an increase of 32% from 2008 levels.

Across the four countries, oil is a vital component in both energy supply and demand. Saudi Arabia is contributing the largest bulk in the region's oil production. By examining oil resources across the four countries, Saudi Arabia is topping the list in both reserves, production and related CO_2 emissions. Although the UAE has a smaller reserve than Kuwait, its total oil production and consumption is much higher than

Kuwait. Moreover, during the past thirty years, oil demand has been growing faster than production in the four countries. Saudi Arabia and Kuwait's oil production has been growing with an average annual rate of 1.5%, while Iran and the UAE growth rate reached 2% annually (figure 3.1-a). On the other hand, UAE's oil demand is the fastest, growing at an average annual of 7.20% since 1980 followed by Saudi Arabia as illustrated in figure 3.1. Such rates underline that growing oil requirements will be a challenge to low carbon transition in the next few years.

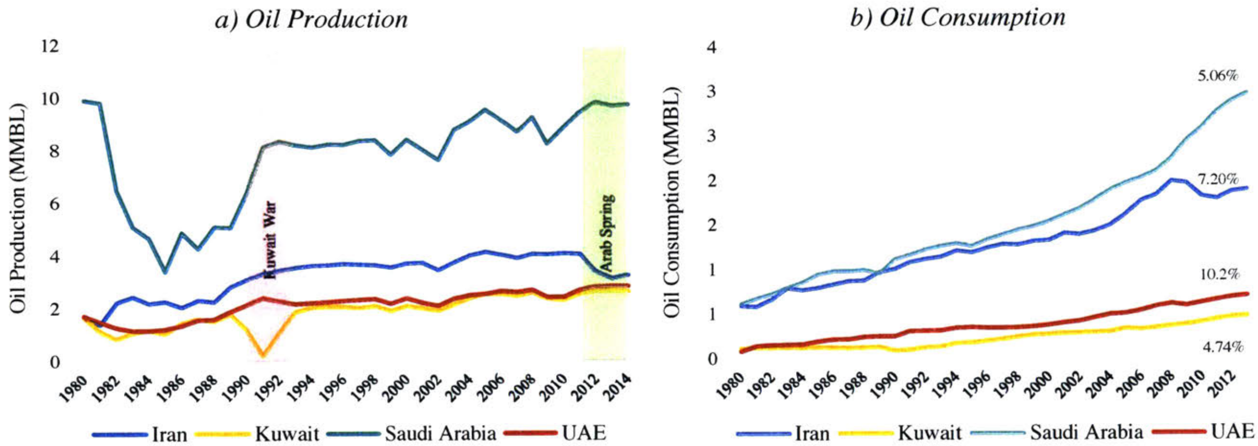


Figure 3.1: a) Total oil production (1980-2014), b) Total oil consumption (1986-2012). Percentages refer to annual growth rate over the analysis period. Based on data from (Abdul-hamid & Bayer, 2016; British Petroleum, 2016; IEA, 2014b).

3.1.2 Natural Gas

According to the recent estimates of gas reserves in the Middle East, Iran, Saudi Arabia, UAE and Kuwait are among the largest natural gas reserves, contributing around 63% of the region's total. Iran tops the list with a total 34 trillion m^3 of available gas reserves (19.7% of world's total), followed by Saudi Arabia with 8.3 trillion m^3, and UAE with 6.1 trillion m^3 as presented in table 3.2 below (Abdul-hamid & Bayer, 2016; British Petroleum, 2016). During the past ten years, natural gas production in Iran and Saudi Arabia has almost doubled. Iran's total production has risen from 4.2 trillion cubic feet (TCF) in 2002 to 8.0 TCF in 2012 and Saudi Arabia's grew from 2.1 TCF to 4.0 TCF in 2012 (British Petroleum, 2016). On the contrary, natural gas production in UAE and Kuwait has been growing steadily. Over the period of 2002-2012, Kuwait's natural gas production has risen from 0.3 TCF to 0.5 TCF, while UAE's increased from 2.2 TCF to 2.9 (Abdul-hamid & Bayer, 2016).

Table 3.2: Natural Gas reserves, production, consumption and related emissions across the four major emitters.

	Iran	Kuwait	Saudi Arabia	UAE
Total Natural Gas Reserves - 2013 Estimates (TCM)	34	1.8	8.3	6.1
Share of Global Natural Gas Reserves (%)	19.7%	0.9%	4.4%	3.3%
Natural Gas Production in 2012 (TCF)	8.0	0.55	4.0	2.9
Natural Gas Consumption in 2012 (TCF)	5.5	0.57	3.5	2.3
CO_2 Emissions from Natural Gas in 2012 (Mt)	343	32	194	130

On consumption side, domestic natural gas consumption in Iran and the UAE has been growing rapidly since 1980 with an average rate of 10.4 % annually to reach 5.5 TCF and 3.5 TCF respectively in 2013 (Figure 3.2-b). Although Iran holds the largest reserves bulk among the four, it is projected that under these consumption rates, Iran's gas reserve will have an average life span of 166 years (Schaefer, 2016). For Kuwait, its domestic natural gas consumption has always equaled production. However, in the last ten year, Kuwait's natural gas demand has surpassed domestic consumption due to surging demands from electricity generation especially during the summer months (Abdul-hamid & Bayer, 2016; IEA, 2015a).

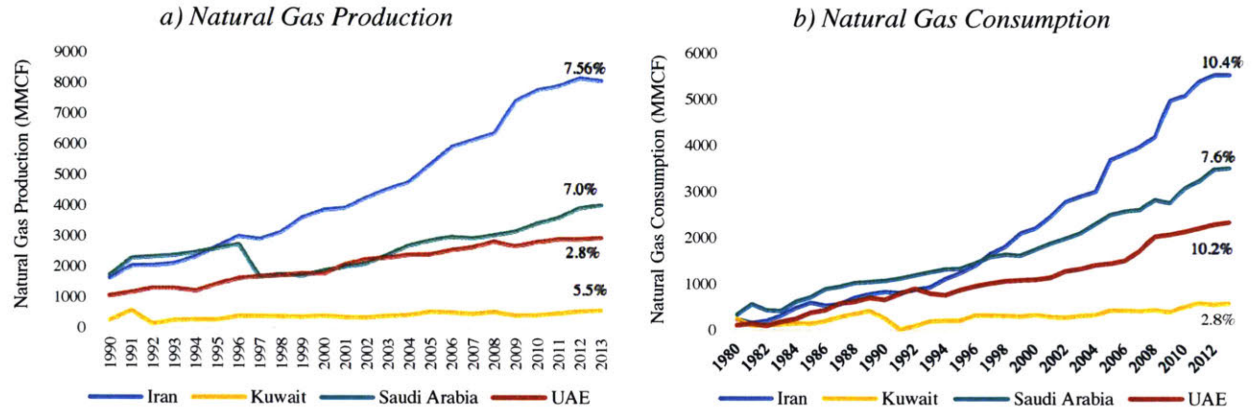


Figure 3.2: a) Total natural gas production over the period (1990-2013), b) natural gas consumption from 1980 to 2013. Percentages refer to annual growth rate over the analysis period. Based on data from (Abdul-hamid & Bayer, 2016; British Petroleum, 2016; IEA, 2014b).

On average, CO_2 emissions from gas consumption reached more than 100 Mt, except in Kuwait that has the lowest consumption levels among the four. It is also important to underline that natural gas growth rates have surpassed oil, which indicate that there is a faster growing trend for natural gas demand than for oil. However, the capacity of natural gas production to satisfy demand will represent a major challenge in future. Finally, as previously mentioned coal's share in the total Middle East primary energy mix is relatively modest compared to oil and natural gas. Across the four countries, Iran and the UAE are the only two countries depending on coal in their total energy mix. Iran's total coal reserves are estimated at 1.2 million short tons but it only accounted for 0.21% of its total energy mix in 2008 (Statistical Center of Iran, 2012). For the UAE, coal supply is mainly coming from imports with a share of 2.5% (International Energy Agency, 2016). Based on this overview, the four countries have a large fossil fuel reserves that resulted in the heavy reliance on hydrocarbon resources. However, countries like the UAE is planning to adapt clean coal technology like Carbon Capture and Storage (CCS) to continue using coal in the future. The following section will discuss energy production, consumption and demand from different economic sectors.

3.2 Energy Profile

During the past three decades, the Middle East region has experienced remarkable increase in economic development, population growth and associated energy demands. Over the period of 1980-2015, the Middle East's real GDP grew at an average annual rate of 3.5%, while primary energy production and demand grew at an average annual rate of 2% and 5% respectively (British Petroleum, 2011; International Energy Agency, 2016). Also, demand for oil and natural gas grew at annual average rate of 4.2% and 7.8% over the same period (BP Statistical, 2016; OPEC, 2012). As previously discussed in chapter two, the Middle East is largely reliant on fossil fuels to supply domestic energy demands. This trend has been ongoing since 1980's, where oil accounted for about 96% of total energy production and natural gas for about 4%. However, natural gas production has been growing faster than oil (average annual rate of 8% compared to 2%) which underlines the gradual transitioning towards using more natural gas than oil in the region's primary energy mix (Exxon Mobil, 2016).

Projections indicate that the rapid increase in energy demand will continue in the future. It is expected that under reference scenario, the region's total primary energy demand will reach 1276.6 Mtoe by 2040 with an average rate of 2.3% annually (IEA, 2015e). Thus, expanding production capabilities in order to sustain energy exports will be a major challenge for the region's energy security. The following section will focus on energy production and consumption trends in the four countries of interest to understand past trends and possible implications on energy development in these countries.

3.2.1 Energy Production

Energy production mix varies across the four countries in terms of fuel type and its share within total primary energy production, however, the contribution of renewable resources is equally negligible compared to fossil fuels. Iran's primary energy production consists of five main resources: coal, oil, natural gas, hydro and nuclear energy. The country's energy sector is largely dependent on oil and natural gas to supply domestic energy demands. Though, the share of crude oil has decreased during the past two decades, dropping from 87% in 1990 to 51% in 2014 as presented in figure 3.3-a. The contribution of natural gas on the contrary has risen from 12% to 48% by 2014 (figure 3.3-b). On the contrary, the share of other resources such as coal, nuclear and hydropower is only 1%. In 2012, Saudi Arabia was acknowledged as the world's largest producer of petroleum liquids (Bahgat, 2016). Saudi Arabia's total primary energy production has been growing at an average annual of 5% between 1990-2014 (IEA, 2015e). Where, oil has been supplying more than 50% of Saudi Arabia's primary energy production since 1980. However, in the past ten years, the contribution of oil in total primary energy production has witnessed a slight decrease from 66% in 1990 to 63% in 2014 (figure 3.3-a). Conversely, the share of natural gas has been increasing to reach 37% in 2014, growing at annual average of 5.2% annually since 1990 (BP Statistical, 2016).

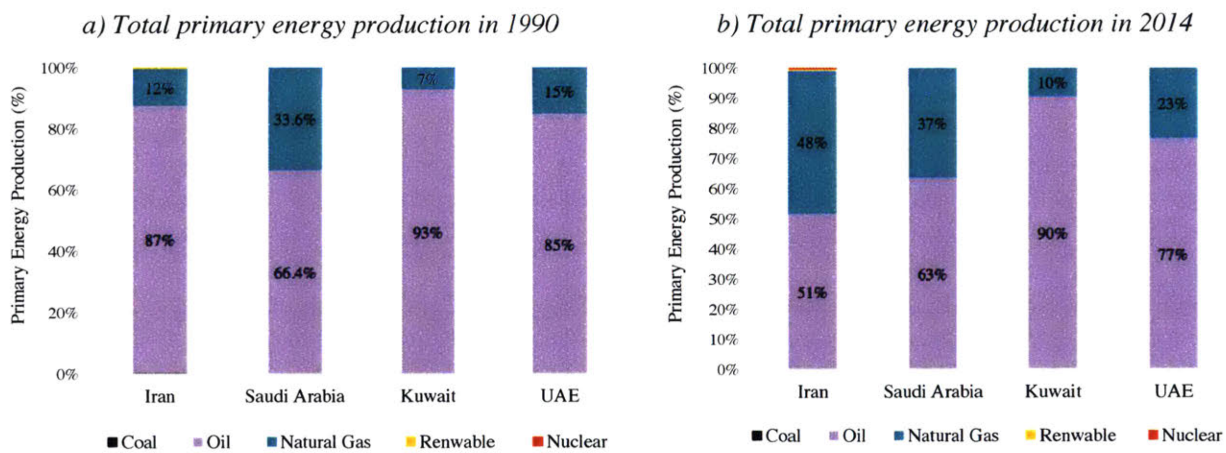


Figure 3.3: a) Primary energy production by energy source in 1990, b) primary energy production in 2014. Based on data from (BP Statistical, 2016; IEA, 2015e; OPEC, 2012).

Similar to Saudi Arabia, Kuwait relies exclusively on fossil fuels for its energy supply, primarily oil and natural gas. Also, its primary energy production has been growing at an average 3.4% annually, growing from 67 Mtoe in 1990 to reach 155 Mtoe in 2014 (BP Statistical, 2016). Although oil accounted for more than 90% of total Kuwait's primary energy production, natural gas has been growing at a faster annual rate of 5% compared to oil (3.5%) as presented in figure 3.3. Finally, oil exports represented more than 89% of total Kuwait's export revenue and more than 50% of the national GDP in 2015 (U.S Energy Information Administration, 2016a). For the UAE, the country has two main sources of energy: oil and natural gas. Other sources such as coal and solar energy contribute marginally (less than 0.1%) (BP Statistical, 2016). For the year 2014, the UAE's primary energy production (230 Mtoe) has increased by 20% compared to 2010, with an annual growth rate of 2.35% since 1990 (BP Statistical, 2016; IEA, 2015e). Between 1990-2014, the share of natural gas in the total primary energy production has not changed significantly, whereas, oil's share has relatively decreased from 85% in 1990 to 76% in 2014 (BP Statistical, 2016).

3.2.2 Energy Consumption

Like other developing countries, population growth, industrialization and economic development have driven the increase of energy consumption in the four countries. During the past decade, Iran's final energy consumption has grew at an annual growth rate of 5.50 % to increase from 74.4 Mtoe in 1990 to 255 Mtoe in 2014 (International Energy Agency, 2016; International Energy Agency (IEA), 2012). Since 2004, Iran's primary energy consumption has grown by almost 50%. Residential sector contributes the largest share of 28%, followed by transportation at 26%. Industry sector accounts for around 24% of the total final energy consumption, whereas other sectors (commercial, agriculture and non-energy use) represent only 22%. Natural gas has significantly replaced oil in supplying Iran's energy demand. In 1990 oil accounted for 68% of total energy consumption, dropping to 37% in 2014 (figure 3.4-b) (British Petroleum, 2011; International Energy Agency, 2016). Most of Iran's natural gas consumed by the household sector that accounts for 39% of total gas consumption, mainly used for heating during the winter months.

In Saudi Arabia, per capita energy consumption is relatively high compared to world average (ABB Group, 2012). In recent years Saudi Arabia's per capita energy consumption has been rising, reaching four times higher than the world average in 2014. Since 1990, total energy consumption has been growing steadily and very rapidly, at an average annual rate of 5.10%; and has tripled between 1990 and 2014. The largest consuming sector is industry, including petrochemical use, with a share of 51% of total energy consumption in 2014 (growing from 44% in 1990). Transportation sector represented 31% of total energy consumption in the same year, while other sectors (residential, commercial, agriculture and non-energy use) accounted for only 18% (IEA Energy Balance, 2014). Saudi's oil consumption was about 129.7 Mtoe in 2012 (representing 3.1% of total world consumption) while natural gas was 92.5 Mtoe in 2012 (representing 3.1% of total world consumption).

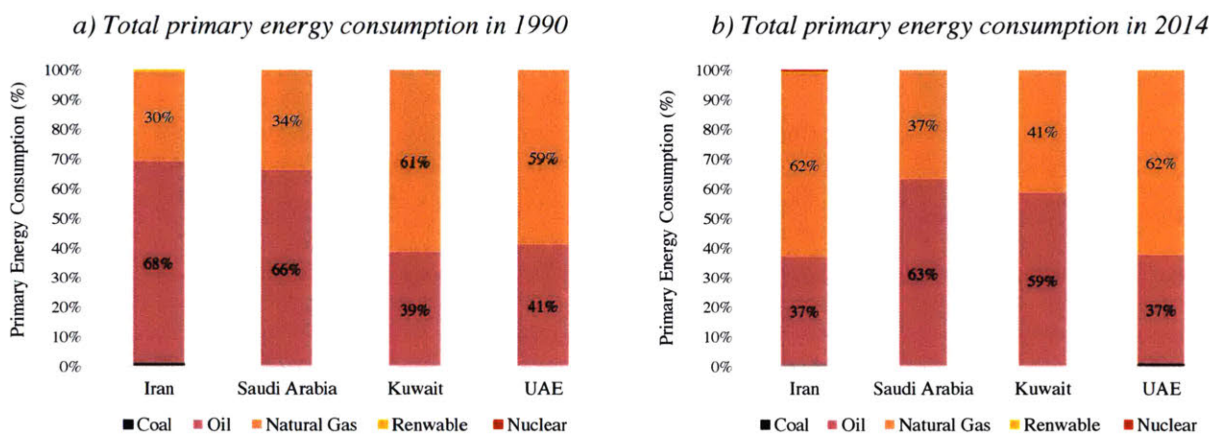


Figure 3.4: a) Primary energy consumption by energy source in 1990, b) primary energy consumption in 2014. Based on data from (BP Statistical, 2016; IEA, 2015e; OPEC, 2012).

Kuwait has experienced significant changes since 1990. These changes have induced the rapid increase in energy demand, with household consumption growing substantially from about 11 Mtoe in 1990 to reach 40 Mtoe in 2014, at an annual growth rate of 5.7%. Kuwait's energy consumption is largely dominated by oil, which accounts for 58.7%. Industry sector represents the largest segment of consumption, of around 34%, transport 26%, household 15%, and other sectors (commercial, agriculture, and non-energy use) 25%, as illustrated in figure 3.5 (IEA, 2015e).

According to the IEA energy balance, the UAE's energy consumption in 2014 totaled 48.83 Mtoe; natural gas accounted for 48% and oil 32%. Industry is the largest consuming sector, accounting for 56% of the total energy consumption in 2014. Transport accounted for 25%, household for 6%, and other sectors (commercial, agriculture, and non-energy use) 13% (IEA, 2015e). Based on the current energy balance across the four countries, fossil fuels largely dominate both demand and supply energy mix. In addition, the contribution of oil and natural gas varies greatly across the four countries. As some countries rely more on natural gas than oil such as Iran and the UAE, others use more oil than natural gas such as Saudi Arabia and Kuwait.

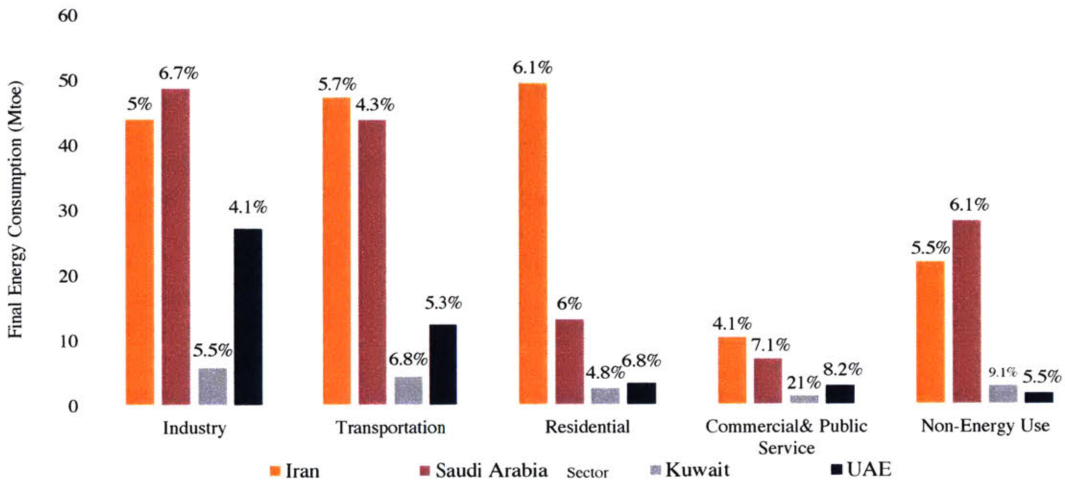


Figure 3.5: Final energy consumption by sector in 2014, percentage refers to annual growth rate since 1990. Based on data from (IEA, 2015e).

3.2.3 Energy Subsidy

Securing energy to meet demand is a growing concern for countries in the Middle East. According to International Monetary Fund (IMF) estimates in 2011, pre-tax energy subsidies[7] in the Middle East accounted for about 48% of the global energy subsidies and 8.6% of the region's GDP costing almost 237 billion dollars compared to a global total of US$481 billion (IMF, 2013). Fossil-fuel subsidies are frequently justified on the basis that they provide support and protection to the poor, through lowering direct and indirect fuel costs. Generally, energy subsidies are useful for low-income groups, for uses such as household daily activities and personal commuting. However, it is highly inequitable when they are provided with the same rates to upper-income groups.

By early 2000's, Iran was considered among the world highest energy intensity, which was strongly tied to high-energy subsidies system. The domestic gasoline price sold 0.40 cents per liter, which pushed the domestic energy increase across the country (IMF, 2013). Under such low energy prices, Iran's oil exports were largely affected. By mid-2000's, the country's oil exports were declining rapidly and imports were mounting to meet domestic demand (Guillaume, Zytek, & Reza Farzin, 2011). In 2010, Iran was the first oil-exporting country to increase significantly its energy prices by almost 20 times and reform its subsidies framework. The reform was preceded by a communication campaign to educate the population on the growing costs of low energy prices. This large reform has affected domestic consumption levels, where consumption decrease went up to 20% in gasoline and 11% in electricity as presented in table 3.3 below.

[7]7 **Pre-tax energy subsidies:** Any government action that lowers the price paid by energy consumers. Usually it is measured as the difference between the value of consumption at world and domestic prices (Richard Bridl et al., 2014).

Table 3.3: Energy subsidies in Iran and new prices reform impact on consumption decrease.

	Old Price (Before 2010 Reform)	New Price (After 2010 Reform)	Decrease in consumption In 2011
Gasoline	40 Cents/ liter (Guillaume et al., 2011)	70 Cents/ liters (Guillaume et al., 2011)	**5 - 20%** in total consumption (64-53 million liters/day) (Iran Daily, 2010)
Diesel	0.06 $/gallon (Rezaian, 2010)	1.4 $/ gallons (Rezaian, 2010)	20% (54-41 million liters/day) (Rezaian, 2010)
Natural Gas	1 - 1.3 cents/m3 for household and 0.5 cents/ m3 for power plants. (Rabii, 2009)	More than 500% increase, 7 cents/ m3 increase for household and 8 cents/ m3 for power plants. (Rabii, 2009)	**6%** decrease of household natural gas consumption. (Rabii, 2011)
CNG	4 cents/m3 (Rabii, 2009)	30 cents/m3 (Rabii, 2009)	
Electricity	1.6 cents/KWh (Kheradpir, 2010)	More than 300% increase (Mehr News Agency, 2010)	**11%** decrease in electricity consumption. (Rabii, 2011)

Although Iran was the first country among the four to initiate subsidies reform, Saudi Arabia have recently adopted a new reform framework for its domestic energy prices. According to the IMF estimates, energy subsidies in Saudi Arabia have costed about 107 billion dollars in 2015, which represent almost 13.3% of its GDP same year as shown in figure 3.6-b below (IMF, 2016). In 2015, the cost of a gallon of high grade gasoline in Saudi Arabia was $0.90, when in 2014 it costed $0.60 (Bast et al., 2015). The Saudi government announced a plan for fuel prices reform in 2016, where it will include higher prices for individuals, industry and government sectors based on consumption rates. The system will allow household to benefit from lower rates with a consumption limit of 4000 KWh (Reed, 2016).

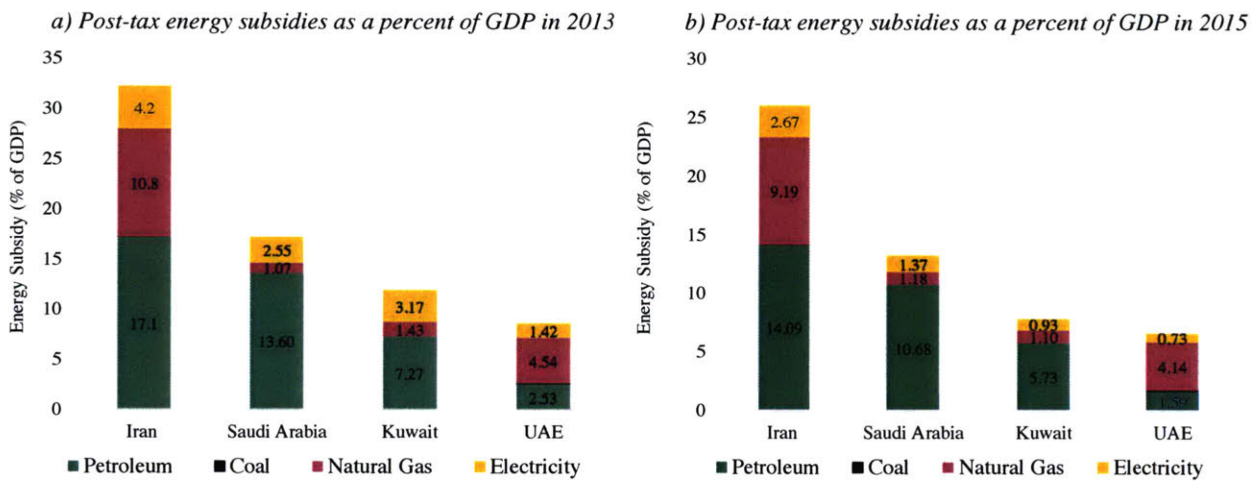


Figure 3.6: a) Energy subsidy across the four countries as percentage of total GDP in 2013, b) energy subsidies as percentage of total GDP in 2015. Based on data from (IMF, 2013, 2016).

Kuwait is the most challenging among the four countries, where energy prices are below international benchmarks and Middle East's average. Energy subsidies in Kuwait costed about 12.3 billion dollars in 2015, representing 7.7% of the country's GDP (IMF, 2015). By the end of 2015, diesel and gasoline prices were 20% below the Gulf Countries' average prices and 66% below U.S. In addition, electricity tariffs are considered the lowest at 0.01 USD/KW whereas production costs around 0.14 USD/KW (IMF, 2015). Recently, the Kuwaiti government has announced a new reform policy for energy subsidy that will include an increase between 40% to 80% from current fuel prices (Oxford Business Group, 2016a). Under this new reform policy, the price of low-octane petrol will rise by 41% to $0.28/ liter, while high-grade petrol will increase by 61% to cost $0.35 per liter (Oxford Business Group, 2016a).

Although energy subsidies in the UAE accounted for 8.6% of national GDP in 2013 (figure 3.6-a), the country is taking strong leaps towards cutting fuel subsidies (IMF, 2013). In 2015, the government announced a plan to cut transport fuels to be the first country in the Middle East to fully remove fuel subsidies from transportation sector (Carpenter, 2015). According to the Ministry of Energy in the UAE, The new reform plan will be set on a monthly basis that corresponds to global market prices (Hoffmann, 2015). Although UAE is pushing efforts to reform its prices framework, oil prices and electricity tariffs are still below international market levels (Boslaugh, 2013). From this overview, it can be concluded that energy subsidies have largely affected energy consumption across the four countries. It can be also observed from Iran's case that cutting energy subsidies has significantly influenced the growth of energy consumption (World Bank, 2014).

3.3 An Overview of CO_2 Emissions

Iran is considered among the top ten CO_2 emitters in the world (Bast et al., 2015). Between 1970 and 2010, Iran's CO_2 emission grew at an average annual rate of 6.69% (IEA, 2015e). Emissions from power generation sector represented 30% of Iran's total CO_2 emissions same year as presented in figure 3.7. Over the past two decades, emissions from transportation and power generation grew at an average annual rate of 7.3% (World Bank, 2016). Residential and commercial sectors accounted for 22% of total emissions in 2010 whereas industry represented 16% growing at an average rate of 6.6% and 5.7% respectively.

Between 1995 and 2015, Saudi Arabia's CO_2 emissions increased by an average 5.2% annually (IEA, 2015e). In addition, its global share of CO_2 emissions has risen from 0.7% in 1990 to reach 1.4% in 2015. The largest increase happened between 2008 and 2010, where emission grew by an average annual of 7.5%. About 70% of Saudi Arabia's fossil fuel-related CO_2 emissions are coming from the combustion of oil products and the remaining 30% are from natural gas (PBL Netherlands Environmental Assessment Agency, 2016). In 2013, emissions from power generation sector accounted for 45% of total CO_2 emissions out of which 25% were emitted from oil-fired power stations (World Bank, 2016).

Carbon dioxide emissions in Kuwait are among the highest in the world. Since 1970, emissions grew by an average of 5.3% per year (IEA, 2015e). In 2010, electricity and water desalination sector accounted for 68% of total Kuwait's CO_2 emissions (figure 3.7-c) (Alsayegh et al., 2012). Transportation sector comes as the second largest contributor to national emissions, with a share of 16% in 2012 rising at an average annual of 4.7% (World Bank, 2016). Since 1970, carbon dioxide emissions per capita grew at rate of 1.13% annually to reach 39 metric tons in 2010, compared to world average of 4.54 tons and U.S. of 18 tons (Alotaibi, 2011b).

The UAE is ranked among the world's largest per capita emissions from fossil fuel combustion (Bast et al., 2015). Since 1980, emissions per capita grew at an average annual of 1.3% to reach 44 tons in 2010. Yet, the country's absolute emissions correspond to 0.7% of worldwide CO_2 emissions (Bast et al., 2015). Electricity generation sector and industry are the two largest contributors to emission growth in the UAE. In 2010, the two sectors alone accounted for 40% and 43% of total CO_2 emissions respectively as presented above in figure 3.7-d. On the other hand, transportation sector represented 18% increasing by an average annual rate of 7.8% since 2000.

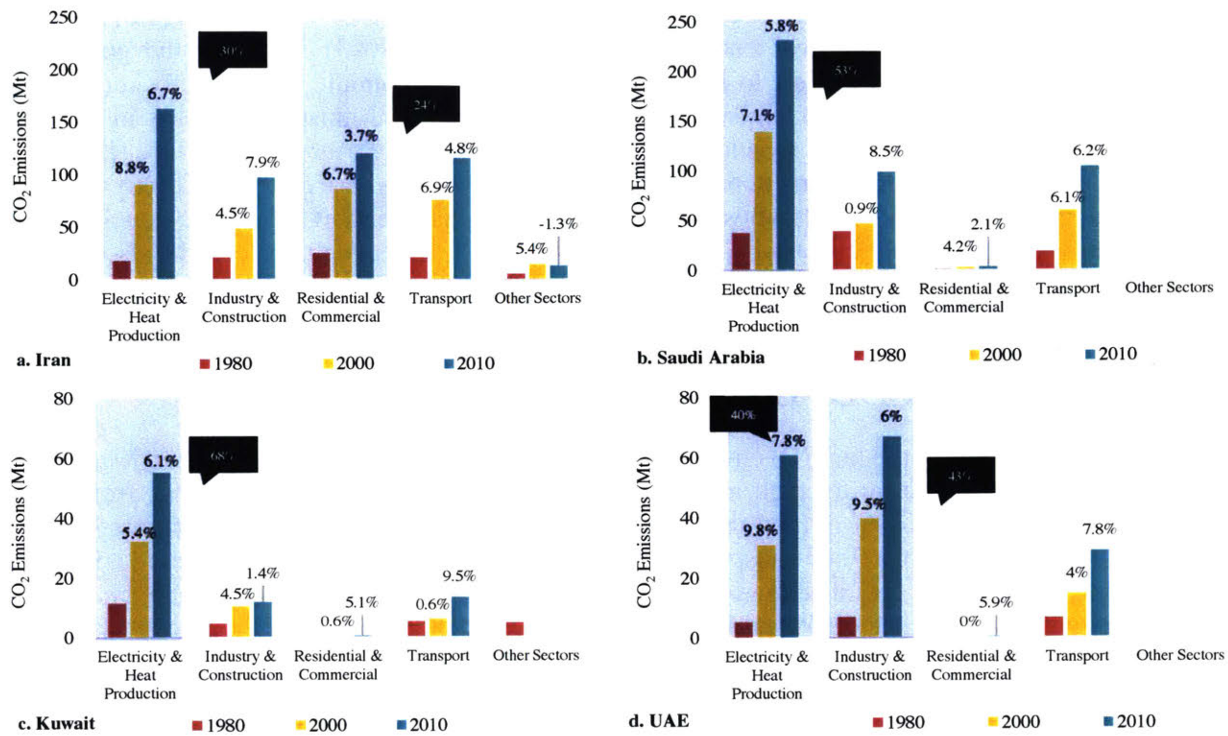


Figure 3.7: CO_2 emissions by sector across the four major emitters, percentage refers to annual growth rate from the previous year. Highlighted sectors accounted for more than 50% of total CO_2 emissions in 2010.
Emissions from building sector (commercial and residential) refer to emissions from onsite power generation and burning fuels for heat. In addition, emissions from electricity use are excluded from building sector and covered in electricity and heat production. Other sectors refer to emissions from energy sector that are not associated with electricity and heat production. Based on data from (World Bank, 2016).

3.4 STEEP Analysis

In this section, STEEP analysis is applied to understand past and current trends of energy based on determined factors. This will help to gain insights of key factors that may have an influence on the development of energy systems in the future. STEEP stands for five main categories: Social, Technological, Economical, Environmental and Political[8] (Tofigh & Abedian, 2016a). This analysis is commonly used to understand the impacts of development by gaining insights from past trends (Kolios et al., 2013; Tofigh & Abedian, 2016). In the field of energy development, STEEP has been used to identify what are the suitable mechanisms needed for sustainable energy development (Tofigh & Abedian, 2016a). Here, STEEP structure is used to examine energy performance by analyzing a key factor in each group. The selection criteria for these indicators is based on changes that are most likely to affect the energy status significantly. Five key factors are selected in this analysis: from social (Total Primary Energy Consumption per Capita), Technological (Percentage of Electricity Distribution Losses), Economical (Energy Intensity), Environmental (Carbon Dioxide Emission) and Political (Total Renewable Electricity Net Generation). The analysis will compare these indicators to global average over the period 1990 to 2010.

[8] **STEEP: Social** includes factors like population, consumption behavior, income level and lifestyles), **Technological** (new technology that would influence the development of energy systems, consumption and efficiency), **Economical** (economic factors like income level, international trade and taxes), **Environmental** (includes factors from natural systems such as: wind, water and food) and **Political** (political changes or development that would have an impact on environmental and energy policies, trades, carbon taxes and energy supply) (PESTLE Analysis, 2015)

As presented in table 3.3 below, the four countries are lagging behind the world average across the five indicators. The twenty years average in the five categories indicates that there is a gap in suitable energy strategies to push the sustainable development of their energy system. However, in some cases, some countries are performing better than others. For Instance, Iran is the closest to the world average under the indicator of renewable electricity generation. Although the share is lower than the global average, the average growth rate of renewable electricity in Iran (3.38%) during the past ten years was significantly higher than the global average (0.84%).

Table 3.4: STEEP comparison between Iran, Saudi Arabia, Kuwait, UAE and world between 1990 & 2010. Based on data from (British Petroleum, 2011; International Energy Agency (IEA), 2012).

	World	Iran	Saudi Arabia	Kuwait	UAE
S: *Primary Energy Consumption per capita (QBtu/Capita)*	*1.53*	2.08	6.1	9.5	15.8
T: *% of Electricity Losses*	*9%*	16%	7%	11%	8%
E: *Energy Intensity (Btu per Year (2005 U.S. Dollars)*	*8334*	9835	12047	9153	14858
E: *Emission Intensity (Metric tons of Carbon Dioxide per thousand USD)*	*80.8*	274.4	138.5	113.3	114.7
P: *% of Renewable Electricity Generation*	*20%*	8%	0.0%	0.0%	0.0%

For the first indicator, Iran is the only country close to the world average and the UAE is the highest. This is linked to the vast economic growth and the large expansion in non-hydrocarbon economic sectors in the UAE mostly manufacturing especially during the past ten year, putting the country as the second largest economy in the Middle East (Rahman, 2013). The twenty-year average of energy intensity in the UAE is ten times higher than the global one as shown in table 3.4 above. However, on the scale of annual growth rates, the UAE energy intensity has been decreasing (average annual rate of 2.3%), compared to an increase in world's average of 0.7% annually (figure 3.8-a). This underlines the impact of the recent energy efficiency strategies planned by the government. On the other hand, Iran and Kuwait have the highest average growth rates, 4.56% and 3.9% respectively, that are almost 5 times higher than the global average annual growth rate (0.71%) as shown in figure 3.8-a .

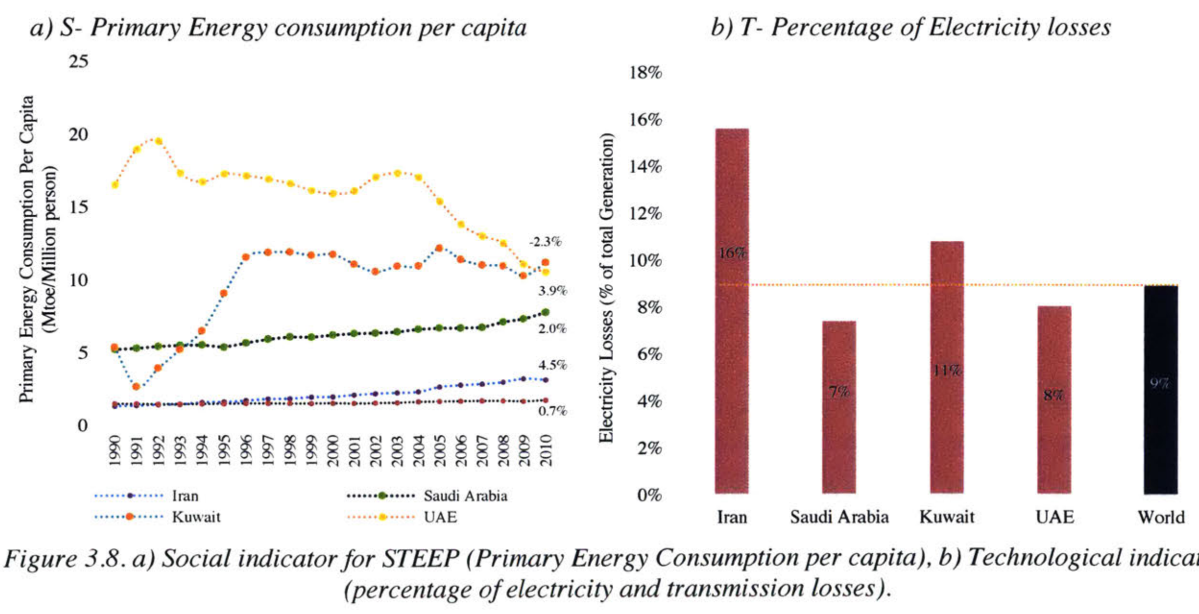


Figure 3.8. a) Social indicator for STEEP (Primary Energy Consumption per capita), b) Technological indicator (percentage of electricity and transmission losses).

In the second indicator, electricity losses[9] are highest in Iran. Since 1990 to 2006, Electricity losses' rate has increased 4.5% annually. However, by 2007, electricity losses have decreased by an average annual of 14%. By the end of 2009, losses in Iran reached around 27.17 TWH at a cost of 2.19 Billion Dollars (Arefi et al.2012). With the high cost of electricity losses, the country has set a plan to reduce transmission losses from 16% in 2010 to 7% by 2025. Kuwait is the second largest with average electricity losses of 1.2 times higher than the world average (figure 3.8-b). Saudi Arabia and the UAE are both below the world average, yet Saudi Arabia's average annual growth is 7 times higher than the world average (growing at an average of 2.6% compared to world 0.36%). On the contrary, the UAE's average annual rate indicates noticeable improvement in electric power distribution. Since 2008, total electricity losses decreased by an average annual of 5%.

Regarding the third indicator, the UAE has the lowest performance among the four (figure 3.9-a). The twenty- year average energy intensity is 1.5 times higher than global average (table 3.4). Although Iran and the UAE had almost the same average growth rate over the past twenty years, Kuwait is closer to world average (figure 3.9-b). This large difference between the four countries and global average is directly linked to varying dependence on fossil fuel for supplying energy demand. For instance, Iran has a heavy reliance on energy-intensive industries for domestic economic production and export. It is also largely reliant on oil products to meet domestic demand as well as requirements from energy-intensive petrochemical and metal industries. On the other hand, UAE is more reliant on natural gas but uses nearly 481 tons of oil equivalent to produce only 1 million US. dollars of GDP that is four times higher than the United States (World Bank, 2016). In addition, climatic conditions, high levels of desalination needs and poor energy efficiency have driven the high levels of energy intensity in the four countries. Finally, large fuel subsidies have affected demand increase from energy-intensive products such as automobiles and air-conditioners.

a) E- Energy Intensity of the Economy *b) E- Twenty years average Energy Intensity*

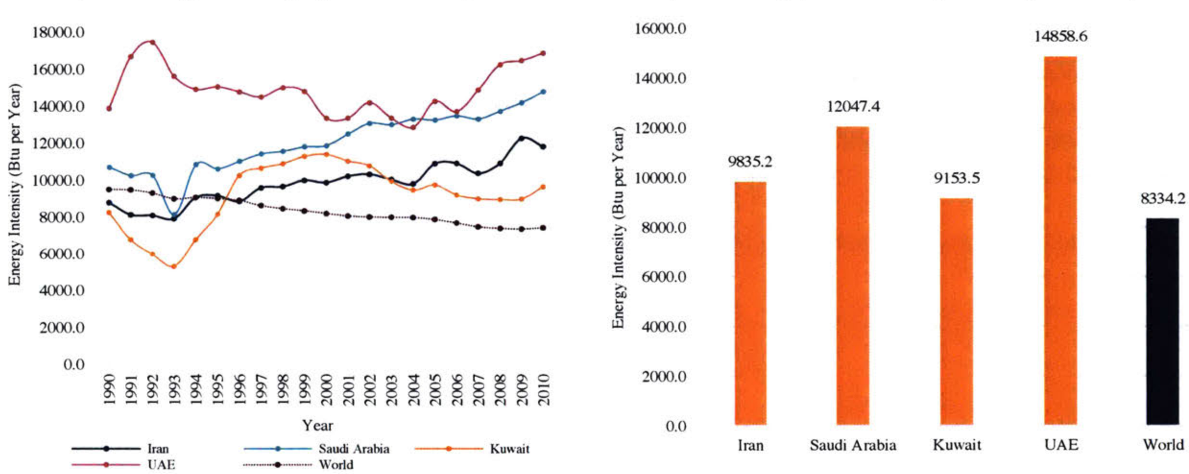


Figure 3.9: a) Economic indicator for STEEP (Energy Intensity), b) Environmental indicator (carbon emission intensity).

Carbon intensity is strongly linked to both energy intensity and primary energy consumption. By examining the four countries relative to the world average, growing energy consumption discussed previously has induced the growth of carbon dioxide emissions. Iran and Kuwait have the lowest levels among the four. Between 1990 and 2010, Iran's carbon emissions from energy consumption have increased 0.6% annually, reaching 280 $KtCO_2$ per billion, that is almost 3.5 times higher than the world average (figure3.10-a).With

---

[9] Electricity Losses: Include transmission losses between generation point to distribution point and distribution to consumers.

regard to average growth rate, Kuwait is the fastest, growing at an average of 3% annually, followed by the UAE (0.93%) and Saudi Arabia (0.72%). The high levels of carbon emissions correlate with major changes required in both energy production and consumption to meet world's average.

Across the four countries, Iran is the only country with a large share of renewables in its total electricity mix. Recently, the UAE has realized the importance of renewable utilization to promote and mandate energy efficiency to become at the forefront of renewable deployment in the Middle East. Kuwait and Saudi Arabia are lagging behind in terms of renewable generation (figure 3.10-b), however, both countries have set ambitious targets to increase renewable electricity generation and reduce dependence on fossil fuels.

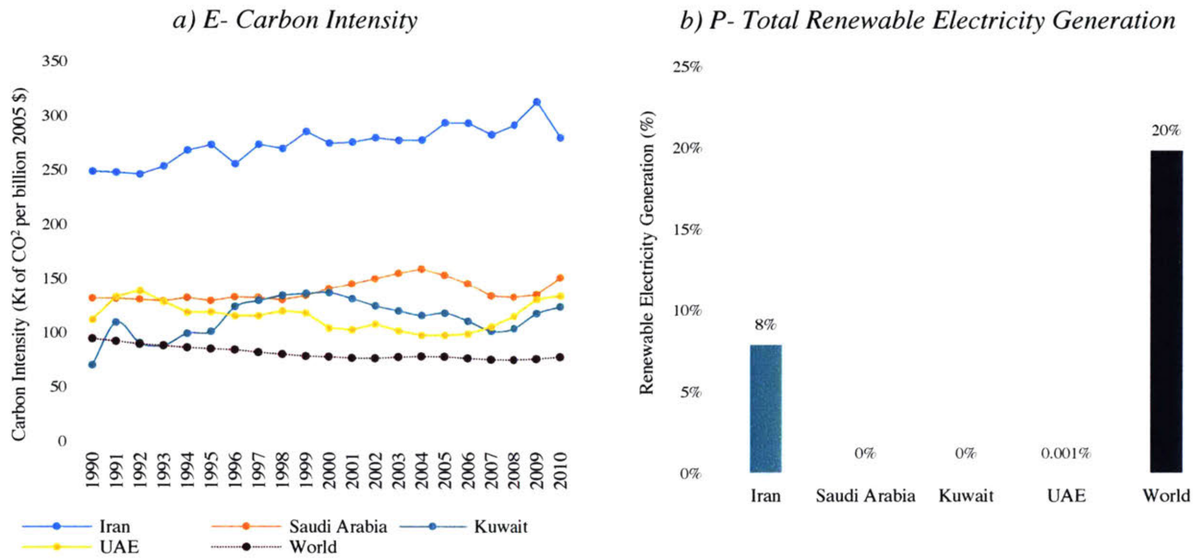


Figure 3.10. a) Environmental indicator for STEEP (Carbon Intensity), b) Political indicator (Renewable Electricity Generation).

From the analysis, it can be seen that high-energy intensity is a huge challenge facing the four countries analyzed in this chapter. Large dependence on fossil fuel and carbon intensive economies will threaten the success of future environmental and energy policies. Some countries have witnessed a decreasing trend in some indicators; however, their situation is still higher than the world average. For example, UAE showed a decreasing trend in primary energy consumption per capita and percentage of electricity losses, yet the values of these two indicators are still higher than the world's average. Figure 3.11 below compares between beginning and end of the analysis period for the four countries. Countries are ordered based on their proximity to world's average in 2010. Renewable electricity generation is not included as the relative changes from 1990 are very modest compared to other indicators.

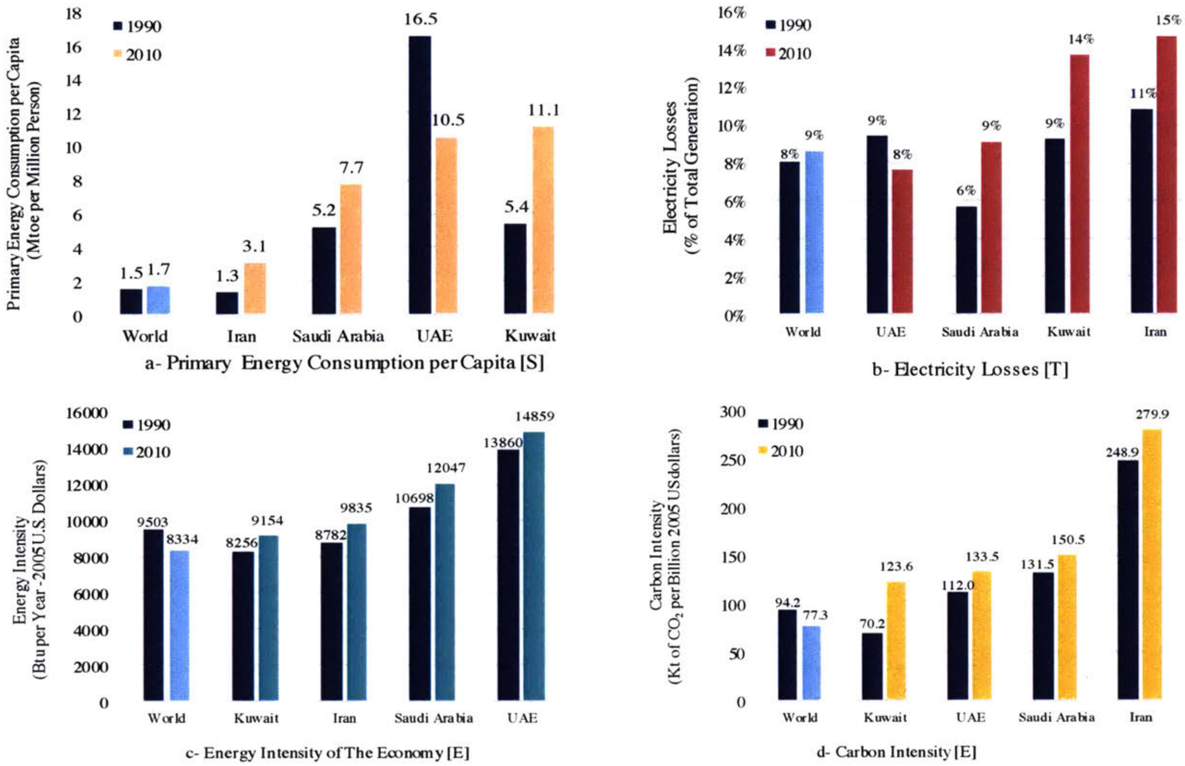


Figure 3.11: STEEP comparison between 1990 and 2010 values.

Although the UAE values was much higher than world's average across some indicators as discussed above, the country's both energy consumption per capita and electricity losses has decreased significantly over the analysis period. The UAE has already started to take serious steps towards integrating nation-wide energy efficiency strategies that are reflected in the decrease of energy consumption per capita since 1990. On the other hand, the four factors illustrated above have been increasing rapidly in Iran, Saudi Arabia and Kuwait. In the social indicator, Kuwait had the largest increase with about 105% from 1990. This underlines required efficiency plans that encourage less energy-intensive activities to attain sustainable development on the near and long term, this in parallel to structural changes in both energy and industry sectors.

Analysis presented in this section, shows that the development of energy sector and sustainability policies were largely ineffective during the past twenty years. There are some exception in countries like the UAE, but in general, there is a huge need for these countries to pay attention to energy policies to improve their performance and mandate the way energy is consumed on a national level. The large fossil fuel reserves in these countries like other Middle East's countries have caused harm than good. Reliance on fossil fuel encouraged low-cost fuel prices and induced the increase in GHG emissions that is one of the most perilous threats to sustainable growth. As previously mentioned, carbon intensity and energy consumption are strongly tied. Inefficient energy production and consumption have played a role in the deterioration of energy systems in the four countries discussed in this chapter. Thus, developing new energy technologies parallel to diversifying energy sources will assist in harnessing future climate targets and will drive the sustainable development of energy sector.

3.5 Discussion

High population growth and increased living standards for many people in the Middle East are causing strong growth in energy demand. Urban expansion, lack of proper implementation of laws, and extremely low-cost energy are the key drivers of energy consumption. Therefore, a strong national commitment along with more serious plans are required to manage growing demands. Moreover, significant energy subsidies in the Middle East keep prices for consumers below market levels, resulting in excess energy consumption as well as energy waste. In this chapter, an overview of the energy sector in four major emitters is presented; it showed that fossil fuels supplies more than 95% on average across the four countries. Such reliance on fossil fuels will stand as one of the critical challenges on the near-long term. It is also worth recalling that, energy consumption and electricity demand have been rising rapidly in the past ten years. Knowing that power generation sector is based either on natural gas or on mix of oil and natural gas, the adoption of renewable resource is rather essential. It was also discussed that more than 50% of total energy and electricity are consumed in industry, transportation and building sector underlining the important role of these sectors in reducing energy intensity and related emissions.

References

ABB Group. (2012). *Saudi Arabia energy report*. Retrieved from https://library.e.abb.com/public/7795755e7e232f38c12579e60039434d/Saudi Arabia Energy efficiency Report.pdf

Abdul-hamid, O. S., & Bayer, C. (2016). *OPEC Annual Statistical Bulletin*.

Alotaibi, S. (2011). Energy Consumption In Kuwait: Prospects And Future Approaches. *Energy Policy*, *39*(2), 637–643. http://doi.org/10.1016/j.enpol.2010.10.036

Alshehry, A. S., & Belloumi, M. (2015). Energy Consumption, Carbon Dioxide Emissions And Economic Growth: The Case Of Saudi Arabia. *Renewable and Sustainable Energy Reviews*, *41*, 237–247. http://doi.org/10.1016/j.rser.2014.08.004

Alyousef, Y., & Abu-ebid, M. (2012). Energy Efficiency Initiatives for Saudi Arabia on Supply and Demand Sides. *Energy Efficiency - A Bridge to Low Carbon Economy, Dr. Zoran Morvaj (Ed.), ISBN: 978-953-51-0340- 0*, 280–308. http://doi.org/10.5772/38660

Arefi, A., Olamaei, J., Yavartalab, A., & Keshtkar, H. (2012). Loss Reduction Experiences In Electric Power Distribution Companies Of Iran. *Energy Procedia*, *14*, 1392–1397. http://doi.org/10.1016/j.egypro.2011.12.1107

Bahgat, G. (2016). *The Changing Saudi Energy Outlook. The Middle East Instittute*. Washingston, DC.

Bast, E., Doukas, A., Pickard, S., van de Burg, L., & Whitley, S. (2015). Empty Promises: G20 Subsidies To Oil, Gas And Coal Production. *Oil Change International*, (November), 103.

Boslaugh, S. (2013). *IMF Selected Issues: United Arab Emirates* (Vol. 2013). Washington, DC.

BP Statistical. (2016). *Review of World Energy*. London, United Kingdom.

British Petroleum. (2011). *BP Energy Outlook 2030. Annual Energy Outlook* (Vol. 383). London, United Kingdom. Retrieved from www.eia.doe.gov/oiaf/aeo/

British Petroleum. (2016). BP Statistical Review of World Energy, (June).

Carpenter, C. (2015). U.A.E. Removes Fuel Subsidy as Oil Drop Hurts Arab Economies. Retrieved January 3, 2017, from https://www.bloomberg.com/news/articles/2015-07-22/u-a-e-to-link-gasoline-price-to-global-markets-effect-aug-1

Diefenderfer, J., Arora, V., & Singer, L. E. (2016). *International Energy Outlook: Liquid Fuels* (Vol. 484). United States.

Exxon Mobil. (2016). *Energy: A view to 2040*. Texas, USA.

Guillaume, D. M., Zytek, R., & Reza Farzin, M. (2011). Iran: The Chronicles of the Subsidy Reform. *IMF Working Papers*, *11*(167), 1. http://doi.org/10.5089/9781462303212.001

Hoffmann, R. (2015). Subsidy cuts in the UAE, (May), 2–5.

IEA. (2014). *World Energy Outlook*. Paris, France. http://doi.org/10.1787/weo-2014-en

IEA. (2015a). *Energy Balances of non-OECD Countries*. Paris, France.

IEA. (2015b). *World Energy Outlook*. Paris, France. http://doi.org/10.1787/weo-2014-en

IMF. (2013). *Case Studies on Energy Subsidy Reform: Lessons and Implications*. Washington, DC. Retrieved from http://www.imf.org/external/np/pp/eng/2013/012813a.pdf

IMF. (2015). *Kuwait Country Report*. Washingston, DC.

IMF. (2016). *Energy Subsidy Reform: Lessons and Implication*. Washington, DC.

International Energy Agency. (2016). *Key World Energy Statistics*. Paris, France. Retrieved from http://www.iea.org/statistics/statisticssearch/

International Energy Agency (IEA). (2012). *IEA Statistics - Energy balances of non-OECD countries*. Paris, France. http://doi.org/10.1787/energy_bal_non-oecd-2013-en

Iran Daily. (2010). Subsidy Cuts Leads to Lower Fuel Consumption. Retrieved January 3, 2017, from http://old.iran-daily.com/1389/10/8/MainPaper/3857/Page/4/Index.htm

Kheradpir, A. (2010). Blackouts Threaten Iran. Retrieved January 3, 2017, from http://www.payvand.com/news/10/apr/1189.html

Kolios, A., & Read, G. (2013). A Political, Economic, Social, Technology, Legal and Environmental (PESTLE) Approach For Risk Identification of The Tidal Industry In The United Kingdom. *Energies*, *6*(10), 5023–5045. http://doi.org/10.3390/en6105023

Mehr News Agency. (2010). Cost Repercussions of Iran's Subsidy Reform Plan. Retrieved January 3, 2017, from http://www.payvand.com/news/10/dec/1206.html

Mezghani, I., & Ben Haddad, H. (2016). Energy Consumption and Economic Growth: An Empirical Study of The Electricity Consumption in Saudi Arabia. *Renewable and Sustainable Energy Reviews*, (October), 1–12. http://doi.org/10.1016/j.rser.2016.10.058

Nejat, P., Morsoni, A. K., Jomehzadeh, F., Behzad, H., Saeed Vesali, M., & Majid, M. Z. A. (2013). Iran's Achievements In Renewable Energy During Fourth Development Program In Comparison With Global Trend. *Renewable and Sustainable Energy Reviews*, *22*, 561–570.

OPEC. (2012). *Annual Statistical Bulletin*. Vienna, Austria.

Osamah Alsayegh, Fatma Fairouz, K. A. (2012). Toward Fossil Fuel and CO2 Savings in Kuwait. *GSTF Journal on Engineering Technology*, *1*(1). http://doi.org/10.5176/2251-3701_1.1.9

Oxford Business Group. (2016). Kuwait's Drive Toward Fuel Subsidy Rationalisation. Retrieved January 3, 2017, from http://www.oxfordbusinessgroup.com/news/kuwait's-drive-toward-fuel-subsidy-rationalisation

PBL Netherlands Environmental Assessment Agency. (2016). *Trends in global CO2 Emissions*. The Hague, Netherlands.

PESTLE Analysis. (2015). What is STEEP Analysis? *Pestle Analysis*. Retrieved from http://pestleanalysis.com/what-is-steep-analysis/

Rabii, R. (2009). Iran Investment. *Exchange Organizational Behavior Teaching Journal*, *5*(51).

Rabii, R. (2011). Iran Investment. *Exchange Organizational Behavior Teaching Journal*, *5*(52).

Rahman, S. (2013). UAE's Per Capita Energy Consumption Among The Highest.

Ramadhan, M., & Hussain, A. (2012). Kuwait Energy Profile for Electrical Power Generation. *Strategic Planning for Energy and the Environment*, *32*(1), 18–25. http://doi.org/10.1080/10485236.2012.10531825

Reed, M. (2016). Saudi Arabia Reins in Runaway Energy Subsidies. Retrieved January 3, 2017, from http://energyfuse.org/saudi-arabia-reins-in-runaway-energy-subsidies/

Rezaian, J. (2010). Iran Remains Stable Despite Dramatic Price Increases. Retrieved January 3, 2017, from https://www.pri.org/stories/2010-12-20/iran-remains-stable-despite-dramatic-price-increases

Richard Bridl, Kitson, L., & Wooders, P. (2014). *Fossil-Fuel Subsidies: A Barrier To Renewable Energy In Five Middle East And North African Countries*. Winnipeg, Canada.

Schaefer, K. (2016). Iran and Natural Gas: Who Are They Kidding. Retrieved May 15, 2016, from https://oilandgas-investments.com/2016/natural-gas/iran-and-natural-gas-who-are-they-kidding/

Sgouridis, S., Abdullah, A., Griffiths, S., Saygin, D., Wagner, N., Gielen, D., … McQueen, D. (2016). E-Mapping The UAE's Energy Transition: An Economy-Wide Assessment Of Renewable Energy Options And Their Policy Implications. *Renewable and Sustainable Energy Reviews*, *55*, 1166–1180. http://doi.org/10.1016/j.rser.2015.05.039

Statistical Center of Iran. (2012). *Statistical Pocket Book of The Isalmic Republic of Iran* (Vol. 1390). Tehran, Islamic Republic of Iran.

The International Energy Agency IEA. (2012). *Key World Energy Statistics*. Paris, France. Retrieved from http://www.iea.org/publications/freepublications/publication/kwes.pdf

Tofigh, A. A., & Abedian, M. (2016). Analysis of Energy Status in Iran For Designing Sustainable Energy Roadmap. *Renewable and Sustainable Energy Reviews*, *57*, 1296–1306. http://doi.org/10.1016/j.rser.2015.12.209

U.S Energy Information Administration. (2016). *Kuwait: Country Analysis Brief*. Washingston, DC. Retrieved from http://www.eia.gov/beta/international/analysis_includes/countries_long/Nigeria/nigeria.pdf

World Bank. (2014). *Corrosive subsidies. MENA Economic Monitor*. Washington, DC.

World Bank. (2016). *World Development Indicators*. Washingston, DC. Retrieved from http://data.worldbank.org/sites/default/files/wdi-2016-highlights-featuring-sdgs-booklet.pdf

4. *Electricity Sector and Renewable Energy Resources*

Power sector in the Middle East is undergoing a large transition driven by climate change and environmental policies. During the past decade, many countries across the Middle East have experienced a significant increase in their peak load and annual electricity demand caused by economic development and rapid urbanization. Projections indicate that the rapid growth in power requirements is expected to continue in the future (Farhani & Shahbaz, 2014). Electricity generation sector in the Middle East is significantly challenged by the heavy reliance on fossil fuels alongside the aging generation infrastructure. Such factors will largely affect power production capacity in the future. Thus, development of power sector that is coupled with variability in generation technologies is critical to the security of electricity supply. This chapter provides an overview on power generation sector in the four countries examined in the thesis. Analysis will cover the structure of power generation sector, electricity consumption and renewable energy potential. Review presented here will be used towards the formulation of the optimization model in chapter six.

4.1 Power Generation Sector: Overview

Power generation in the Middle East is traditionally based on the burning of hydrocarbon resources, specifically natural gas and oil. Yet, burning finite resources for power generation has become challenging not only environmentally but also economically. Using fossil fuels for domestic consumption poses cost burdens for fuel importers and decrease costs' opportunities for fuel exporters (Mezher et al. 2014). Accordingly, many countries in the Middle East have realized that diversifying their energy sector is important to sustain their role in the global energy market in conjunction with expanding their power supply. The section presents an overview of power generation in the four countries of interest with respect to generation technologies, power capacity and associated fuel consumption.

4.1.1 Electricity Production

Electricity production is increasingly becoming a critical component in the Middle East's energy system. The power sector alone accounts for the largest share of the Middle East total primary energy and CO_2 emissions (International Energy Agency, 2016). In 2014, the region generated around 950 TWh, under an average growth rate of 6% annually since 1990 (IEA, 2015e). Iran and Saudi Arabia alone, accounted for 50% of total electricity generation in 2014, followed by the UAE with a share of 10% and Kuwait 6% (International Energy Agency, 2016). As illustrated in figure 4.1, fossil fuels dominate electricity generation mix in the four countries. On the contrary, the contribution of renewable generation in general is very modest except in Iran, where hydroelectricity accounted for nearly 6% of total generation in 2014. It can be noted that the power mix is generally based on hydrocarbons with variation between oil and gas. Yet, natural gas is accounting for the largest share.

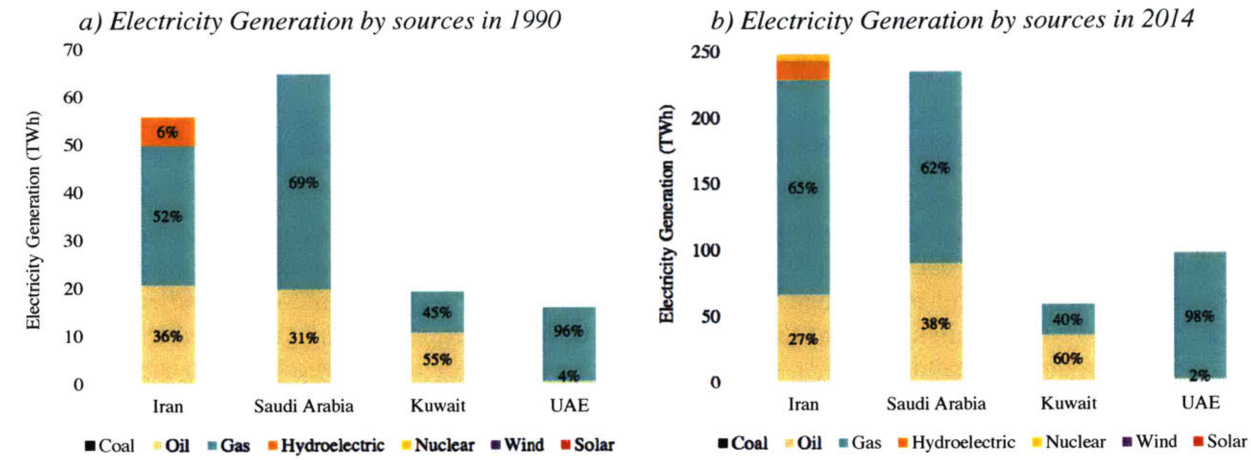


Figure 4.1: Electricity generation source in 1990 (a) and 2013 (b). Percentages refer to share of different fuel in the generation mix. Based on data from (International Energy Agency, 2016).

On the basis of fuel type and related generation technologies, Saudi Arabia has been relying significantly on oil as the basic fuel for gas and steam turbines (KFUPM, 2011). Thus, crude oil alone accounted for almost 44% of Saudi Arabia's total generation in 2014, followed by natural gas 32% and the remaining 24% is a split between heavy fuel oil (13%) and diesel (11%) (ECRA, 2014). In Kuwait, electricity generation relies on a mix of fuels including fuel oil and high sulfur fuel mainly that are used in steam plants and gas turbines. Figure 4.2 below illustrates power generation based on fuel type and generation technologies. For the UAE, generation mix encompasses steam turbines, gas turbines (GT) and Combined Cycle (CCGT) that are almost 90% gas-based. On the contrary, Kuwait's mix is largely based on multi-fueled steam plants (SP) and gas turbines coupled with desalination plants and significantly based on oil (Jandal & Sayegh, 2015).

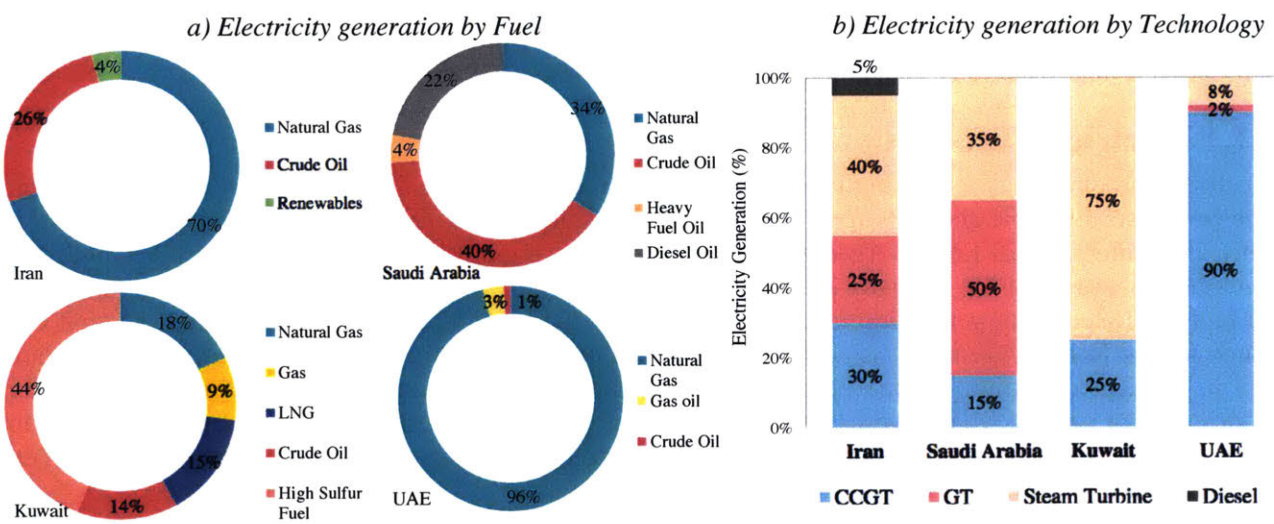


Figure 4.2: a) Electricity generation by fuel type in 2014, b) Electricity generation by Technology. Based on data from (Mezher et al., 2014).

4.1.2 Electricity Consumption

Between 1980 and 2005, Iran's electricity consumption has increased nearly 8.7 times (Feng, 2014). Most of this increase is coming from industry and household sectors. By 2014, Iran's electricity consumption reached 221 TWh, out of which household share was 32%, and industry 34% (IEA, 2015e). For Saudi Arabia, electricity consumption has far accelerated due to rapid economic development and increase in real

GDP per capita. In the 1970's and 1980's, electricity consumption in Saudi Arabia grew around 12 % to 25% respectively and by nearly 6% annually from 1990 to 2000 (Mezghani & Ben Haddad, 2016). Residential sector alone consumes around 50% of total electricity production with around 70% is consumed in air-conditioning (ECRA, 2014). Likewise, Kuwait has been experiencing a rapid increase in electricity consumption. In 2014, domestic electricity consumption reached 43 TWh, growing from 26 TWh in 2004. While around 64% of Kuwait's electricity production is consumed by the household sector (IEA, 2015a). Similar to Kuwait, electricity and water desalination demands in the UAE are strongly interlinked. Over 80% of total electricity demand is coming from air conditioning and water needs for both residential and commercial sectors (Sgouridis et al., 2013). Between 2006 and 2010, electricity consumption in the UAE has increased at an average annual growth rate of 9.5% (World Bank, 2016). By 2014, annual consumption reached 95 TWh, out of which household and commercial sectors represented 74%. Figure 4.3 illustrates changes in electricity consumption from different sectors in 1990 and 2014. Clearly, building sector (household and commercial) is the largest consuming sector across the four countries, with over 50% share in Kuwait and Saudi Arabia.

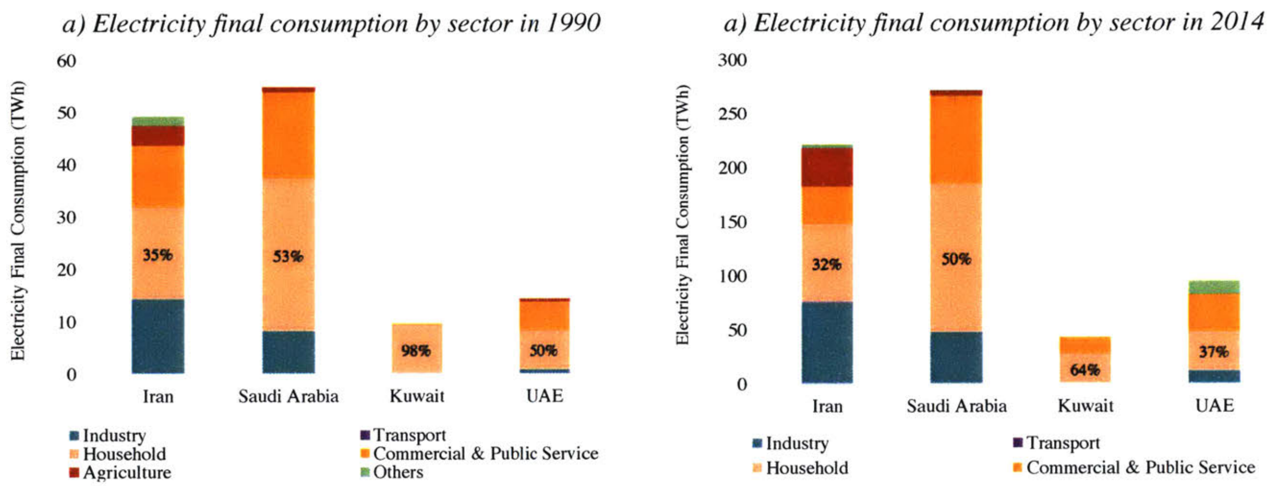


Figure 4.3: Electricity consumption by sector in 1990 (a) and 2013 (b). Based on data from (International Energy Agency, 2016).

The high levels of electricity consumption presented above are relatively linked to two critical factors. First, economic development and rapid urbanization currently happening in the Middle East (Richard et al., 2014). Second, low electricity prices and fuel subsidies that have driven higher consumption in end-use sectors (Alshehry & Belloumi, 2015). If current trends continue, a supply gap can be expected especially under the huge dependence on finite hydrocarbon resources (McGlade et al. 2013).

4.2 Nuclear Power and Renewable Energy Potential

As previously discussed, the Middle East is predominantly based on hydrocarbons for power generation. Thus, in order to meet rapidly increasing demands, larger penetration of clean and reliable resources is essential. In 2013, Middle East's demand for solar (PV) has increased by over 625% (CleanTechnica, 2013). This implies that low-carbon and renewable resources will play a key role as power alterative in the next coming years. The following section reviews the status of nuclear and renewable energy potentials in the four countries of interest and underlines possible capacity expansions. This is useful towards the understanding of what technologies are more suitable for large deployment and to what extent can these countries expand renewable penetration in the future.

4.2.1 Iran

Iran is among the countries who have a technical potential to set up 40,000 MW of renewable power plants, out of which 15,000 MW of have been proved to be economically viable (Financial Tribune, 2016). After the sanctions removal, Iran's power capacity is expected to significantly increase, which infers possibly larger renewable output (Iran Renewable Energy Congress, 2016). During the Paris Climate Agreement in 2015, Iran has officially committed to 4% cut in total GHG emissions by 2030. The climate plan was linked to a renewable energy target of 5 GW by 2020 and additional 7.5 GW in 2030 (Green World, 2017); however, the country has the ability for even larger deployment. According to the study of Iran-German cooperation (2009), Iran has a potential of increasing renewable penetration from 3% to over 38% by 2030 and over 100 GW of renewable capacity (Aghahosseini, Bogdanov, & Breyer, 2016). Table 4.1 summarizes estimations of RE technologies and their share in 2030-generation mix relative to Business As Usual (BAU).

Table 4.1: Electricity Generation from renewable and non-renewable sources (GWh). Numbers are reported based on (Iran-German Cooperation, 2009).

	2005	2030 BAU	2030 High Renewable
Total Electricity Generation (million kWh)	**186,537**	**346,375**	**346,375**
Renewable Sources	4,720	10,111	
Hydro power	4,500	7,030	17300
Wind power	220	2,730	22000
Photovoltaic	0	7	7
Geothermal	0	303	5250
Solar thermal power	0	4	94000
Biomass	0	18	18
Total	4,720	10,111	138,575
RE/Total Electricity Generation (%)	*3%*	*3%*	*38%*

A. Nuclear Power

Nuclear power is considered among the economically viable options that Iran is currently exploring. There are other several countries in the Middle East; among them, the UAE and Saudi Arabia, are considering nuclear programs for power and water supply. In the early 1970's, Iran established a diversification energy plan that was directed towards nuclear power development. However, after the Islamic revolution in 1979, the plan was completely frozen (Atabi, 2004b). In 2012, nuclear program became active again and the country announced two nuclear power plants; Bushehr power (pressurized water reactor- PWR) with a generation capacity of 1000 MW and the Siahbisheh pumped storage plant with a 1000 MW capacity (Soltanieh et al., 2017). Between 2015 and 2016, total nuclear generation reached 2,950,000 MWh (Iran's Ministry of Power, 2016). In addition, the country has announced a target of installing 20 GW nuclear capacity by 2020 (Soltanieh et al., 2017). Figure 4.4 below represents planned and proposed nuclear reactors in the next five years and their locations. Nevertheless, political challenges may hinder Iran's power program again and possibly restrict the development of effective policies for larger penetration in the future.

a) Planned nuclear power plants

Location	Type	MWe Gross	Construction Start (Planned)
Bushehr 2	VVER[10]-1000	1057	2018
Bushehr 3	VVER-1000	1057	2020
Makran Coast	ACP[11]100	100	2018
Makran Coast	ACP 100	100	Unavailable
Darkhow in	LWR[12] (IR-360)	360	Unavailable
Bushehr 4	VVER	Unavailable	Unavailable
Bushehr 5	VVER	Unavailable	Unavailable

b) Location distribution across Iran

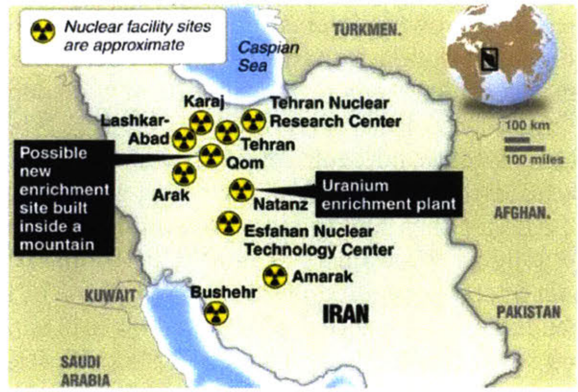


Figure 4.4: Planned nuclear reactors and their locations until 2020. Based on data from (Languages of The World, 2015; WNA, 2016).

B. Solar Energy

As it has been previously noted in chapter two, the Middle East has a huge potential for solar deployment. Iran is one of the countries with high solar radiation availability under an average annual of 13.23 MJ/m^2 (Mirzahosseini et al. 2012) and a direct normal radiation (DNI) of 5.5 KWh/m^2/day under an annual solar radiation hours up to 2800h/year (Najafi et al. 2015). Studies have reported that Iran has the potential to increase solar capacity to over 10 GW and wind to 30 GW (Fathi et al., 2017; REVE, 2016). In 2009, the country tendered Shiraz solar plant to be the first solar plant to produce heated steam. By 2012, total solar power capacity reached 3000 kW and generated around 82 MWh (Nejat et al., 2013b). The Ministry of Energy in Iran is currently considering over 11 solar energy projects for utilization. This in addition to 7.5 GW of solar (CSP) capacity are under construction and additional 8.5 GW are planned (G. Najafi et al., 2015). Figure 4.5 presents planned solar capacity and total generation from 1998 to 2012.

a) Planned solar capacity and associated technologies

Type	Technology	Capacity (kW)
Solar power plant	PV	27
Solar power plant		5
Solar power plant		12
Solar power plant		92
Photovoltaic		3.5
Shiraz power plant	CSP	250
Solar lighting		0.45
Photovoltaic	PV	30
Receiver system	CSP	1000
Photovoltaic	PV	4.5
Solar water heater	CSP	4312
Photovoltaic& Solar lighting	PV	12.6
Rural electrification to 60 households		50
Rural electrification 634 households		650

b) Solar electricity generation (1998-2012)

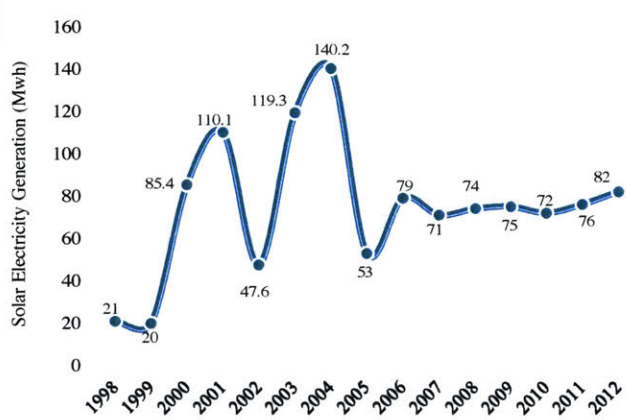


Figure 4.5: a) planned solar power capacity and under-development in Iran, b) Total solar electricity generation from 1998 to 2012. Based on data from (G. Najafi et al., 2015; Nejat et al., 2013b).

---

10 **VVER**: Russian Pressurized Water Reactor

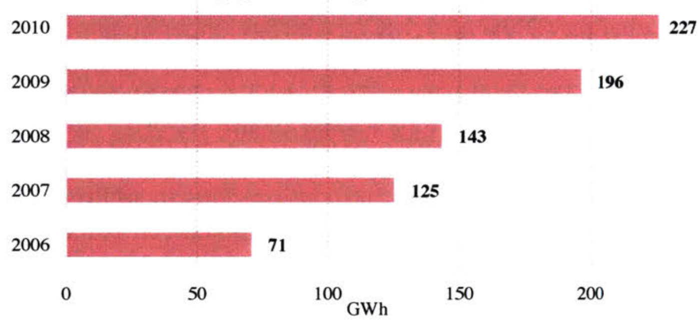
11 **ACP:** Chinese Pressurized Water Reactor

12 **LWR:** Light Water Reactor

C. Wind Energy

There is a growing interest in wind power technology across the Middle East, as it represents the most economical option for large renewable deployment. (World Wind Energy Association (WWEA), 2014). Iran is considered among the pioneers in wind deployment across the Middle East as it was the first country to install large-scale wind turbine (Tofigh & Abedian, 2016b). Across Iran, there are at least 26 suitable locations for wind deployment (Bahrami et al. 2013). In addition, the average estimated wind density reached around 275 W/m^2 along with a potential capacity between 6.5 to 20 GW (Fadai, 2007; G. Najafi et al., 2015). Other studies have shown that Iran has the technical potential to push wind capacity up to 30 GW (Global Wind Energy Council, 2010). In 2010, Iran's total installed wind capacity reached 90.6 MW under a total generation of 226.8 GWh (0.1% of total generation) (Nejat et al., 2013b). By 2012, Iran had three large wind stations: Manjil station (61180 kW capacity), Binalood (28640 kW) and Ventiz Dizbad (260 kW) with total capacity of 92,000 kW (Hosseini, Andwari, Wahid, & Bagheri, 2013). Figure 4.6 presents total wind generation since 2006 and installed capacity. Although wind represents a small share of Iran's current capacity, the 2020 plan envisions wind as the main priority to increase renewable output. Wind power alone will account for nearly 4500 MW out of the total target of 5000 MW by 2020 (IRAN Renewable Energy Congress, 2016).

a) Electricity generation from wind (2006-2010)



b) Installed wind capacity

Wind Farm	Installed Capacity
Manjil- (Gilan province)	60.58 MW
Binalood (Mashhad City)	8.4 MW
Dizbad (Nishabur City)	260 kW
Sahand (Tabriz city)	10 kW
Eon (Tabriz city)	660 kW
Lutak (Zabol City)	660 kW

Figure 4.6: a) Total wind electricity generation since 2006, b) Installed wind capacity by site. Based on data from (G. Najafi et al., 2015).

D. Geothermal Energy

Studies on Iran's geothermal production indicate that the country has a substantial potential. There are around 15 geothermal fertile areas in Iran with average temperature up to 85^{0}C (Saffarzadeh et al. 2010). These locations have a technical capability to produce up to 800 MW (Richter, 2015). In addition, other studies have proven that nearly 8.8% of Iran's area is suitable for geothermal deployment (Najafi et al. 2011). In 2005, Iran established its two first geothermal thermal power plants in Ardabil province. By 2010 Meshkinshahr plant was fully operational under a total capacity of 5 MW (generating 410 GWh) (Najafi et al. 2011). The second power plant was frozen because of financial limitations, but it is expected to be operational by 2020.

E. Biomass Energy

Biomass is the only renewable source that delivers energy in different forms including heat, electricity and gaseous and liquid fuels (Bahrami & Abbaszadeh, 2013). Thus, the role of biomass in the global energy system is growing and it is projected that biomass can account for around 15% to 50% by 2050 (Kazem, 2011). Biomass can offer a great source of energy for Iran through agriculture wastes, municipal solid wastes and livestock wastes (Kim & Dale, 2004). Studies on biomass potential in Iran estimated that the average energy potential is around 700 PJ (194 TWh) (Mehrdad, 2012). Further studies have estimated that out of the total energy potential, agriculture wastes can supply 45% followed by livestock wastes with 40% and municipal solid wastes 15% (Moshiri, 2015). Total agriculture and forestry wastes in 2009 reached 33.4 million tons with a potential biomass energy of 167 TWh (Hamzeh et al. 2011). Furthermore, crops' wastes offer additional source for biofuel production that has not been explored. Yet recent studies have found that oil seeds production have the capacity to replace nearly 2% of Iran's total diesel consumption (Ardebili et al. 2011). Currently, Iran has two biomass power plants based on municipal solid wastes; Shiraz power plan with capacity of 7455 MWh/y and Mashhad with a capacity of 4875 MWh/year (Mehrdad, 2012). This in addition to a biogas power plant with a total capacity of 1665 kW and gross generation of 5967 GWh (Bahrami et al. 2013).

F. Hydro Power

Hydropower is considered the most important power source for Iran's renewable generation mix. Between 2000 and 2012, hydroelectricity generation increased at an average annual rate of 12% that is almost 9 folds the global average rate (World Bank, 2016). Currently, hydropower capacity in Iran encompasses three types of hydropower plants. Large size plants with capacity greater than 100 MW (91% of total hydro-capacity), medium power plants with capacity between 10 and 100 MW (8%) and micro-size plants under 10 MW capacity (1%) (Mohammadnejad et al.2011). In 2014, Iran had 44 hydro power plants under a capacity of 7704 MW and gross generation of 7232 GWh (Nejat et al., 2013b). By the end of 2015, total hydropower capacity increased to 11,196 MW and gross generation to 13,785 GWh (International Hydropower Association, 2016). Currently, Iran's government is developing a number of strategies to intensify hydropower penetration in the national energy mix. Where, there are around 14 large hydropower projects seeking investments with potential capacity of 5831 MW and another 28 projects are being studied under a potential capacity of 13 GW(International Hydropower Association, 2016). As a result, the largest hydropower project in the Middle East is currently constructed in Iran with a total capacity of 2000 MW (Hosseini et al., 2013). However, it should be noted that a reduction in the overall hydropower capacity is expected to happen because of dropping rivers' levels that may halt generation capacity (Kayhan, 2015).

From this review, wind and hydropower, and to some extent solar, provide the most efficient alternatives for Iran to expand power capacity away from hydrocarbons. In addition, the country offers attractive feed-in tariffs that could largely push renewable deployment. However, according to Renewable Energy organization in Iran (SUNA), obtaining financial support is the largest obstacle to renewable deployment. This is mainly because of high interest rates offered by local banks alongside insufficient liquidity for large investments (Khonsari, 2016) .

4.2.2 Saudi Arabia

Saudi Arabia's electric energy consumption is nearly 256 TWh/y, the highest consumption of all Gulf Cooperation Council (GCC) countries (IEA, 2015e). In addition, peak power demand is expected to grow from 55 GW to 121 GW by 2032, with a gap of 61 GW between output and demand volume (Ramli et al. 2017). Yet, the country has huge potential for renewable resources, especially solar, that can be exploited to cover this gap. Initially, Saudi Arabia has set a target 54 GW of renewables by 2032 (REN21, 2015).The target was projected to support the country's plan to increase generation capacity to 120 GW as presented in table 4.2 below. Yet, recently the plan has been relaunched under 10% of renewable generation and more focus on natural gas usage. The new target includes a target capacity of 9,500 MW of renewable by 2023 (KSA, 2016; Norman, 2017).

Table 4.2. Saudi Arabia's target from non-hydrocarbon capacity in 2040. (REN21, 2015)

Technology	Capacity (GW)	Total Capacity (%)
Nuclear	17.6	**12.2**
Photovoltaic (PV)	16	**11.2**
Concentrated Solar Power (CSP)	25	**17.5**
Wind	9	**6.3**
Geothermal	1	**0.7**
Waste-to-energy	3	**2.1**

A. Nuclear Power

Nuclear power has gained a limited interest in Saudi Arabia until 1978. Early that year, the kingdom joined a nuclear technical cooperation with the International Atomic Energy Agency (IAEA) titled "Nuclear Energy Planning" (IAEA, 1984). Yet, the country began seriously to consider nuclear power after 2006, when the Gulf Cooperation Council (GCC) announced a joint nuclear energy development program within the Gulf countries (Perkovich, 2008). At the end of 2010, Saudi Arabia launched its first nuclear program through King Abdullah City for Atomic and Renewable Energy (KA-CARE) in Riyadh (Center for Energy & Security Studies, 2016). The center announced afterwards the national renewable and nuclear vision for 2032. The vision includes a total capacity of 123 GW by 2030 out of which 17 GW will be from nuclear power (World Nuclear Association, 2017a). Although nuclear target was pushed back to 2040, the kingdom is planning to have its first operational nuclear plant by 2020 and additional 60 reactors by 2030 (WND, 2012).

B. Solar Energy

Saudi Arabia is among Middle East's countries with enormous solar potential. Being located at the center of the SunBelt region, the country receives more than 5500 W/m^2 of solar radiation within 3,000h/year (Alyahya et al. 2016). In addition, the mean annual solar density in areas like Arar and Tabuk reaches up to 9.5 kWh/m^2/day (Alawaji, 2001a). Figure 4.7 below presents the distribution of direct normal irradiance (DNI) in Saudi Arabia, where values range from 5.5 Wh/m^2/day to 9.5 Wh/m^2/day, especially in the northern parts of the country (Alyahya , 2014). Due to large solar potential in addition to widespread desert land suitable for deployment, the country has been exploring the potentials of generating power with solar photovoltaic (PV) and fulfilling desalination needs from Concentrated solar power (CSP) (Alyahya et al., 2016).

a) Distribution of Direct Normal Irradiance in January *b) Distribution of Direct Normal Irradiance in July*

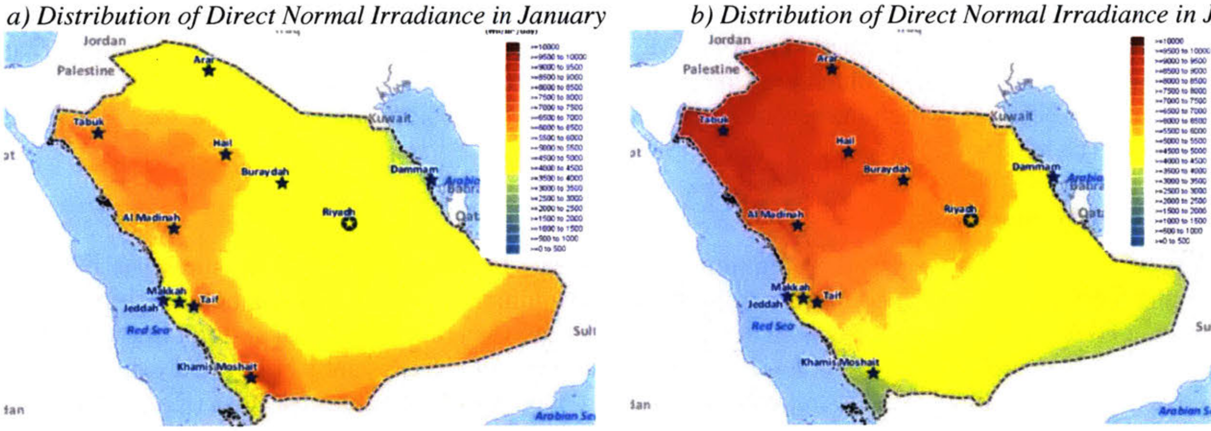


Figure 4.7: a) DNI of Saudi Arabia in January, b) DNI of Saudi Arabia in July in 2015 (Alyahya, 2014).

In 2010, Saudi Arabia established its first solar plant as part of a three-year program to boost solar power penetration and increase desalination capacity (Mohammad, 2011). Afterwards, Saudi Aramco announced a solar power plant with a capacity of 10 MW that was followed by a 20 MW power plant to be deployed at King Abdullah University of Science and Technology (KAUST) (Hepbasli & Alsuhaibani, 2011). Currently, Saudi Arabia has a total installed solar capacity of 25 MW, yet the country has recently launched additional 700 MW of renewable projects with 300 solar PV Park for tender as part of the 3.5 GW target by 2020. (Ramli et al., 2017). Although there is a huge potential for solar energy in Saudi Arabia, there are some technical challenges that should be considered in case of larger penetration. A simulation study on solar PV efficiency in Saudi Arabia indicated that under high ambient temperature, system efficiency can drop from 15.0% to 8.5%, which could potentially influence system efficiency during the summer (Alyahya & Irfan, 2016).

C. Wind Energy

Wind energy represents a potential alternative to generate power in Saudi Arabia. Studies on wind energy across the kingdom estimated that, the average wind speed ranges between 5.5 and 10.0 m/s that is significantly suitable for large deployment (K.A.CARE, 2017). Figure 4.8 illustrates wind speed distribution in October and average monthly wind density. Clearly, the average monthly wind density is nearly over 50 W/m^2 throughout the year. In addition, the western coastal line of the country has the biggest potential for wind deployment compared to other locations. An earlier study of (Rehman, 2005) indicated that large wind deployment is economically feasible in the western borders of the country in Yanbu and over the eastern border in Dhahran. Along with the technical and economic viability, Saudi Arabia has a vast uninhabited land area available for large deployment. By the end of 2016, the country announced 400 MW wind projects as part of the 2020 plan (REVE, 2017).

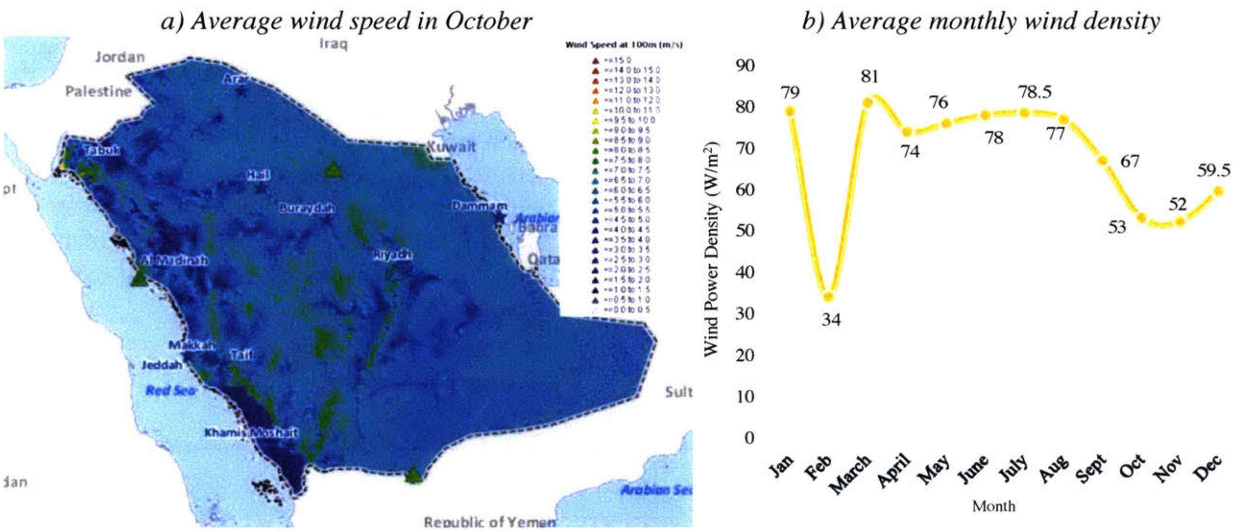


Figure 4.8: a) Average wind speed (m/s) in October, b) Average monthly variation of wind power density (2002 to 2012). (Bassyouni et al., 2015; KA-CARE, 2017)

D. Geothermal Energy

The potentials of geothermal energy in Saudi Arabia are significant. According to the study of (Rehman, 2010), the country has large low-enthalpy reserves that can be utilized for water heating and desalination. In addition, there are a number of hot springs located in the southern regions of the country where surface temperature ranges between 46 to 79 ^{0}C (Tlili, 2015). However, so far geothermal has not been considered for actual deployment in Saudi Arabia. This is mainly due to high costs and associated CO_2 emissions compared to other renewable technologies affecting any prospects for large deployment (Taleb, 2009).

E. Biomass Energy

Unlike Iran, biomass energy deployment in Saudi Arabia is significantly challenging due to drought and desertification. However, potentials for solid wastes utilization is enormous through either industrial wastes or sewage sludge. As presented in figure 4.9 below, the country has one of the biggest per capita waste generation across the MENA region (Khan et al. 2013). According to the study of (Ouda et al. 2013), total biomass energy potential in Saudi Arabia is estimated to be around 3.0 Mtoe/year. In addition, Khan (2013) reported that under large biomass deployment, energy cost can drop to 101$/MWh, which is almost 65% cheaper than solar technologies.

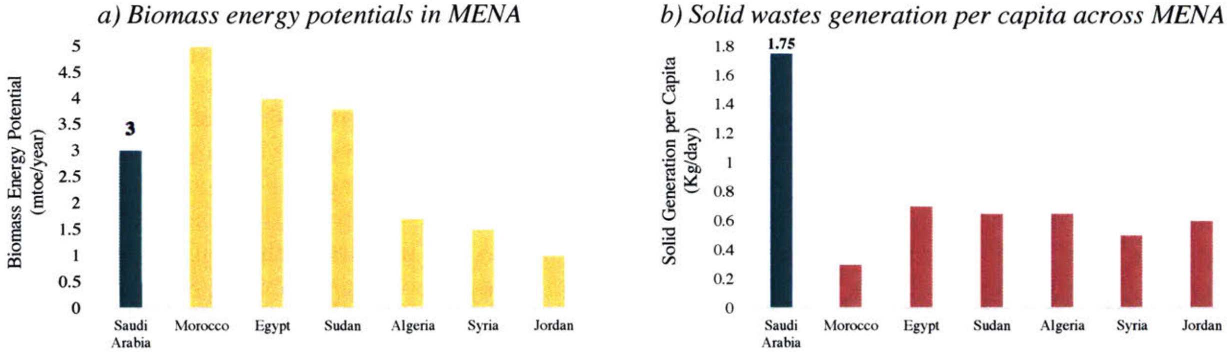


Figure 4.9: a) Biomass energy potential for Saudi Arabia compared to other countries in MENA, b) Solid waste generation rates per capita (Khan et al. 2013).

F. Hydro Power

Hydropower deployment in Saudi Arabia can be effectively utilized for power and desalination within the coastline of the western borders (Tlili, 2015). However, drought and extreme temperature are challenging the technical viability of hydropower compared to other RETs. From this review, it can be noted that, solar and wind have a significant potential for deployment in Saudi Arabia given its geographic characteristics. Also, the recent study of (AlGarni et al. 2016), estimated a potential of over 1 GW of biomass power can be achieved in Saudi Arabia. On the contrary, geothermal is not as appealing due to economic and technical limitation for larger penetration. Table 4.3 summarizes resource availability for different RETs according to available literature.

Table 4.3. Renewable resources potentials in Saudi Arabia. Based on data from (Al-Nassar et al. 2005; Said et al. 2004)

Technology	*Resource Potential (kWh/m²/year)*
Solar PV	2130
Solar CSP	2200
Wind	570
Geothermal	100
Biomass	200

4.2.3 Kuwait

As previously discussed, Kuwait's power system is largely based on hydrocarbon resources. In addition, an expected increase of power demand to reach 30 GW by 2030 will significantly challenge power supply in the future (Lude et al., 2015a). Thus, the country adopted a diversification plan with a goal to increase the share of renewable generation to 15% by 2030 and focus on only solar and wind technologies (Jandal & Sayegh, 2015). Currently the country is launching tenders for Shagaya Park that is planned towards 2030 renewable target. Table 4.4 presents a breakdown for the expected capacity of different RETs in Shagaya Park.

Table 4.4: Kuwait's renewable energy target achieved through Shagaya Park. Based on data from (IEA, 2015b; Lude et al., 2015a; Phys Org, 2015).

	Shagaya Phase (1)			**Shagaya Phase (2)**	**Shagaya Phase (3)**
2000 MW by 2020	70 MW of installed capacity			930 MW	1000 MW
	Technology	**Installed Capacity**	**Share (%)**		
	Concentrated Solar Power (CSP)	50 MW	72%	**No technology specific target has been announced yet**	
	Photovoltaic (PV)	10 MW	14%		
	Wind	10 MW	14%		
	Scheduled to be finished by 2017			**2500 MW by 2025**	**4500 MW by 2030**

A. Nuclear Power

The interest in nuclear energy in Kuwait is mainly driven by the rapid growth of oil and gas consumption in addition to heavy reliance on limited associated gas for power generation. The first attempt to launch a nuclear power program was in the 1970's with the support of IAEA and UK Atomic energy authority (DLIFLC, 2016). However, recently Kuwait decided to slow down its nuclear energy development concerning about becoming a target for larger nuclear conflict in the Middle East (Katzman, 2016). Thus, by 2012, Kuwait formally cancelled plans announced in 2011 to build four nuclear power reactors, passing any nuclear power research to Kuwait Institute for Scientific Research (KISR).

B. Solar Energy

The geographic characteristics of Kuwait make solar energy the most appropriate compared to other renewable resources. Although sand storms are very frequent, the average yearly solar radiation is very high compared to other countries with larger solar deployment like Germany and Spain (Ramadhan et al. 2013). The country receives around 2100-2200 KWh/m^2 of solar radiation every year (IRENA, 2016). Studies on the technical viability of solar energy in Kuwait found that both DNI levels and Global Horizontal Irradiance (GHI) are suitable for large solar penetration (Al-Sahhaf, 2016). Yet it should be noted that, harsh weather, sandstorm and high humidity can negatively affect the efficiency of solar power systems in Kuwait (Alsayegh et al., 2011).The country has recognized the importance of renewable penetration in the energy supply mix and launched the project of *Shagaya Renewable Energy Multi-technology Park*. The project is expected to have a total capacity of 2 GW by 2020 and 4.5 GW by 2030 (Lude et al., 2015b) with solar technologies, PV and CSP, accounting for nearly 86% of total expected capacity.

C. Wind Power

Studies on wind energy potential in Kuwait estimated that, at a height of 10 m, the average wind velocity ranges between 3.7 and 5.5 m/s with a corresponding power density of 105 and 122 W/m^2 (Al-Nassar et al. 2005). The same study also highlighted that wind power density can even further increase by 70% at higher altitude, especially in the northern part of the country, to reach 282 W/m^2. Notably, the highest power density was recorded during the summer when peak demand occurs (Al-Nassar et al., 2005a). As it has been previously noted, the country is only focusing on solar and wind technologies in its national renewable plan. Out of the 2 GW target by 2020, wind represents around 14% of total expected capacity.

D. Geothermal Power

No studies were found on geothermal potential in Kuwait, which makes the country under a limited capability for geothermal utilization.

E. Biomass Power

Similar to Saudi Arabia, Kuwait is considered among the Middle East's countries with high per capita waste generation. The average solid waste generation in Kuwait is around 2 million tons a year (Zafar, 2015). However, the potentials of biomass energy utilization is not considered by the government, as the country prioritized solar and wind as the main renewable alternatives.

F. Hydro Power

Harsh climate conditions and drought significantly restrain the potential of hydropower deployment in Kuwait. Water resources in Kuwait are very scarce and mainly devoted to desalination needs which make the technology unsuitable for energy utilization (Aloughani, 2015). From this review, solar and wind technologies will have the lion's share in case of large renewable deployment. This is also observed in the country's plan to expand their capacity in the next few year. Still, technical challenges like high temperature and sand storms may influence their efficiency. However, through Shagaya Park, the country will be able to evaluate the performance these technologies under climatic conditions to identify possible limitations and technical deficiencies.

4.2.4 United Arab Emirates (UAE)

Electricity consumption in the UAE has increased exponentially in the last three decades (Sgouridis et al., 2016c). With a large reliance on hydrocarbon resources for energy supply, the UAE has planned to increase the share of low-carbon resources over the next few years. The country has set three targets; 24% of RETs by 2020, 30% by 2030 and recently 50% from renewables by 2050 (McKernan, 2017). A study conducted by Masdar Institute to examine viability of different RETs in the UAE reported a potential of 28 GW (40% of total capacity) from renewables can be achieved by 2030 compared to BAU scenario (Sgouridis et al., 2016c). Table 4.5 below presents the distribution of different RETs in the Re-map scenario proposed in the study and BAU projection. Results also indicated that under this level of deployment a reduction of 8.5% in oil consumption and 15.6% in natural gas can be attained by 2030 (IRENA, 2015b).

Table 4.5. Installed power capacity under reference scenario and REmap scenario by 2030.

	Reference Case (GW)		REmap Scenario	
Solar PV (Utility)	1.6	3%	17.5	25%
Solar PV (Rooftop)	0.5	1.0%	3.6	5.0%
Solar CSP	1.3	2.5%	5.8	8.2%
Wind onshore	0.2	0.3%	0.8	1.1%
Total Renewable %	**3.6 GW- (6.8%)**		**28 GW – (40%)**	
Nuclear	5.6	10.7%	5.6	8%
Hydrocarbons	**42.9**	**82.5%**	**36.4**	**52%**

A. Nuclear Power

In March 2008, the UAE's government allocated 100 million dollars for nuclear power development. By the end of 2009, the UAE established the Nuclear Energy Corporation program to be responsible of nuclear plants operation (Permanent Mission of the UAE to the IAEA, 2010). Later in 2012, the country became the world first new comer from the Middle East in nuclear power development after the announcement of Barakah power plant (Center for Energy & Security Studies, 2016). Currently, two out of the four planned reactors are under construction and expected to be operational by 2020. The two plants will have a total capacity of 2800 MW and will constitute around 20% of total national demand in 2020 (Center for Energy & Security Studies, 2016; IRENA, 2015b).

B. Solar Energy

The UAE is blessed with large solar potential, with more than 300 sunny days annually (Mezher et al. 2011). The levels of GHI in the UAE (required for PV deployment) ranges from 657W/m^2 to 929 W/m^2 (El Chaar et al. 2010), while, DNI ranges between 4 and 6 kWh/m^2 as presented in figure 4.10 below (Bachellerie, 2012). Currently, the total installed solar capacity in the country is around 130 MW (Sgouridis et al., 2016c). Shams 1, a CSP power plant, is currently operational and generates around 220,000,00 Kwh of electricity annually under operational hours of 2200 a year (MESIA, 2015). In addition, Masdar institute is planning additional CSP plant with a capacity 1500 MW to be installed on a yearly basis up to 2020 (IRENA, 2015b). Future projections indicate that power generation capacity in the UAE will increase to 42 GW in 2020 and 52 GW in 2030, with the largest growth happening in solar power capacity (IRENA, 2015b).

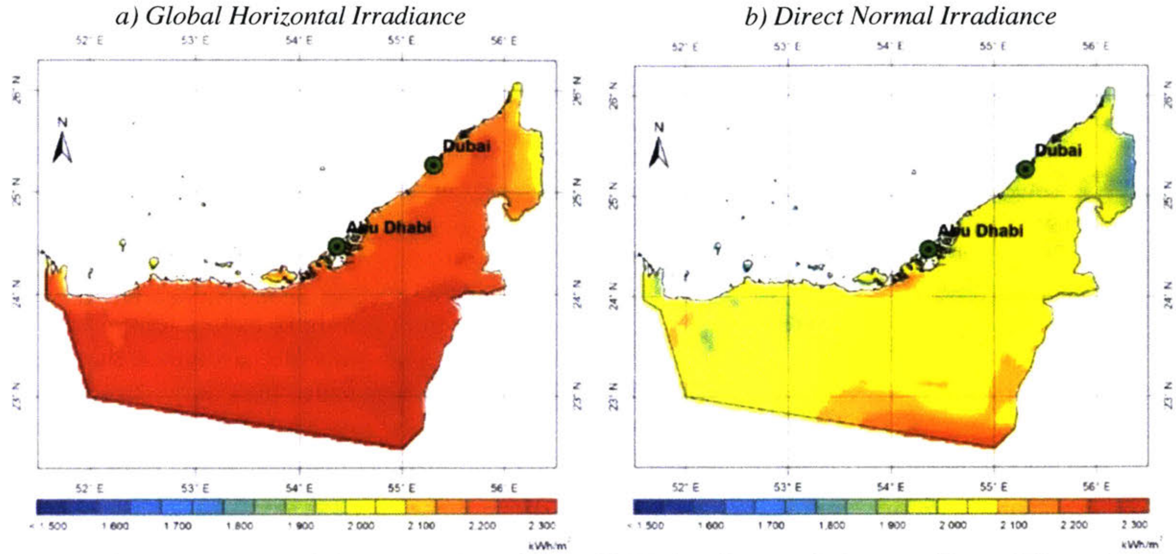


Figure 4.10: a) Average Global Horizontal Irradiance (GHI) distribution, b) Average Normal Direct Irradiance (DNI) distribution. (Masdar Institute Research Center, 2017a).

C. Wind Energy

Wind energy resources in the UAE are less abundant compared to solar energy. However, there is a large potential for wind deployment especially within the northern emirates (Al-Tajer & Poullikkas, 2015). Moreover, the country has widespread uninhabited land areas that could be utilized for large wind deployment. Studies on wind energy potential in the UAE reported that, within 13.5% of the year, wind power density is suitable for operation (Al-Tajer & Poullikkas, 2015). The results also reported that wind speed ranges between 3.3 up to 6.5 m/s at heights bigger than 100m. Figure 4.11 illustrates the distribution of wind speed across the UAE and mean speed variations at different heights. Currently, there is wind power plant operational in Sir Bani Yas Island in addition to another onshore wind farm proposed in the same island (Sgouridis et al., 2016b). The two wind farms in Yas island will be considered the largest onshore wind turbine installed in the Middle East with a production capacity of 30 MW (Sgouridis et al., 2016c).

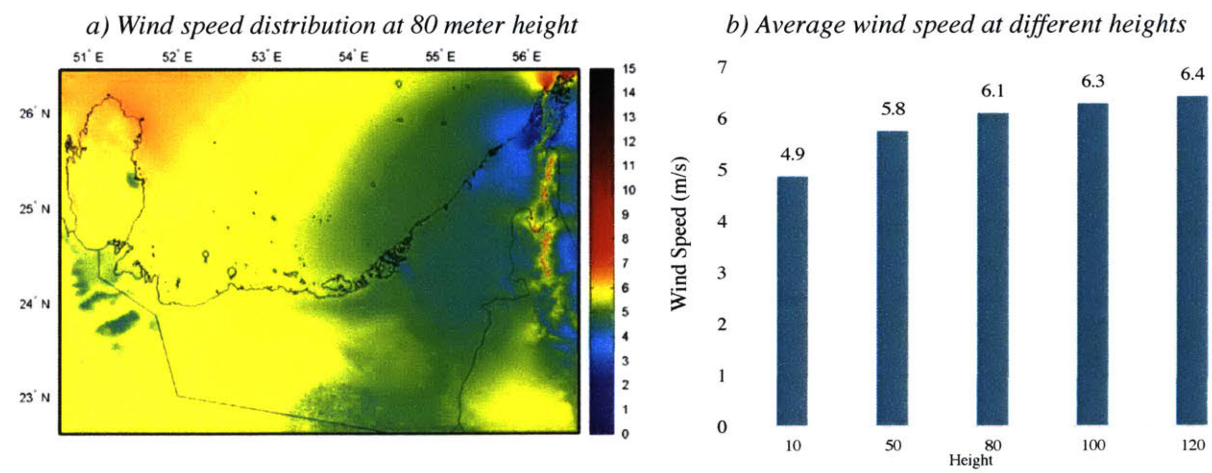


Figure 4.11: a) Wind Resource in Average Wind Speed in m/s at 80 m Height, b) Mean wind speed at different heights (Masdar Institute Research Center, 2017b).

D. Geothermal Energy
Geothermal energy resources in the UAE are very limited due to its geographical characteristics. The geologic morphology shows no thermal gradient appropriate for baseload generation (Sgouridis et al., 2016c). Earlier studies have reported that in the emirates of Ras Al Khaimah and Abu Dhabim, geothermal energy can be exploited through hot dry rocks (Kazim, 2004). Yet, no studies were found on the potentials of geothermal energy to generate power in addition to it has cost disadvantage against other abundant resources like solar and wind.

E. Biomass Energy
Studies on the potentials of biomass energy in the UAE, found that there is a significant potential to generate power and hydrogen through biomass gasification (Kazim, 2004). The study also estimated that the UAE has an average annual biomass production of $75*10^6$ GJ of energy per year. This energy can be utilized from either agricultural wastes or municipal solid wastes. Currently, the country generates around 5 million tons of solid wastes that can be effectively used for biomass power generation (EcoMENA, 2015).

F. Hydro Power
High temperature and low rainfall rates make hydropower inapplicable for deployment in the UAE. However, a recent study on wave energy potential in the UAE found that there is a power potential of 16.9 kW/m that can be exploited from Dubai alone during the winter (Kazim, 2010).

From the above review, it can be concluded that there is a significant potential for renewable deployment across the four countries. Solar and wind power are considered among the most robust options in terms of base load and availability, followed by biomass and to lesser extent geothermal. The UAE is considered the most advanced based on total installed capacities and ongoing research to support renewable energy development. Yet, the four countries are taking serious steps to reduce their reliance on fossil fuels and there is a growing trend towards renewable energy especially solar and wind. However, interest in renewable energy has been subject to the volatility in oil prices that could largely influence renewable penetration in the future. Table 4.6 below summarizes renewable energy potential and possible renewable penetration reported in the literature.

Table 4.6: Renewable potential summary for solar, wind and biomass across the four major emitters.

	Global Solar Radiation (kWh/m2/day)	Direct normal solar radiation (kWh/m2/day)	Hours of full-load wind per year	Biomass (Mtoe/year)	Renewable Target Potentials
Iran	6.5	5.5	2000	14.3	*Potential up to 38% of total generation by 2030* (Iran-German Cooperation, 2009)
Saudi Arabia	7.0	6.5	1789	3.0	*50% of total installed capacity by 2040*
Kuwait	6.2	6.5	1605	0.37	*15% of generation by 2030*
UAE	6.5	6.0	1176	0.33	*Potential up to 40% of installed capacity in 2030*

4.3 Discussion

The chapter presented an overview on the power generation sector and renewable energy potential in the four countries of interests. From the analysis, it is clear that power generation sector is significantly reliant on hydrocarbon resources that may challenge energy supply on the long-term. On the contrary, the four countries have significant potential for renewable energy development, especially solar and wind energy. Shifting towards more renewable utilization will yield several economic and environmental benefits. Yet, the development of energy efficiency standards, along with renewable resources, is considered a major step towards reducing energy demand in the future.

As it has been pointed throughout the chapter, rapidly increasing domestic energy requirements will immensely limit the capacity of these countries to export to the global market. In addition, current consumption patterns that are characterized by high-energy intensity will challenge ongoing sustainability plans and the development of low-carbon economy. Thus, long-term sustainable growth will rely on how well these countries introduce energy efficiency measures, especially in the building sector, invest in low-carbon energy supplies, and improve power generation efficiency.

Although analysis presented in this chapter focused on reviewing possible energy alternatives from a supply side perspective, demand side is equally important. Managing demand side is key to transition away from carbon-intensive economy. As it has been pointed, building sector and industry constitute the largest share of total power consumption. One viable alternative would be electrification, which can provide a cleaner solution than fossil fuel consumption. In addition, developing energy efficiency programs that could help auditing and managing energy consumption in these sectors. Recently, a number of countries in the Middle East have launched their own energy efficiency programs. Saudi Arabia has launched a national energy efficiency strategy that focuses on reducing energy needs through management plans, auditing strategies and energy efficiency labels (Saudi Energy Efficiency Center (SEEC), 2015). In addition, the UAE has launched the National Energy Efficiency and Conservation program that aims at promoting energy efficiency in the building sector. Alongside these efforts, there are number of additional measures that could boost energy efficiency for other sectors as follows:

A. Industrial Sector

- Incentives for different industries to meet energy performance standards;
- Policies that would encourage the incorporation of biofuel in industrial processes as a viable alternative to oil and natural gas;
- Development of energy efficiency standards for different industrial processes.

B. Transportation Sector

- Planning aggressive vehicle and fuel technology efficiency strategies, such as biofuel and hydrogen that could help reducing energy demand;
- Developing policies that could promote electric motors to reduce demand for fossil fuels.

C. Building Sector (Residential and Commercial)

- Developing Building standards (Building Codes) that provide technical guidelines and the minimum requirements for building performance;
- Incentives to target small-scale renewable technology deployment, such as rooftops solar PV;
- Regulation to enforce energy efficiency standards in the building sector;
- Financial incentives for the commercial sector (i.e., direct and private-public investment) to retrofit commercial buildings.

Finally, renewable energy strategies presented in this chapter highlight the question of, what is the probability of meeting the goal of 2 degrees under planned strategies. A recent article by McGlade and Ekins (2015) underscored that in order to meet 2°C goal, large proportion of fossil fuel reserves should remain unexploited in the Middle East. This will pose large uncertainty over the future of power generation in Middle Eastern countries that coincides with the anticipated reduction in fossil fuel consumption (Pidcock, 2015). Thus, economic developments coupled with decarbonized power sector will have a huge impact on energy security in the future.

References

Aghahosseini, A., Bogdanov, D., & Breyer, C. (2016). The Role of a 100 % Renewable Energy System for the Future of Iran : Integrating Solar PV , Wind Energy , Hydropower and Storage. In *11th International Energy Conference*. Tehran, Islamic Republic of Iran.

Al-Nassar, W., Alhajraf, S., Al-Enizi, A., & Al-Awadhi, L. (2005). Potential Wind Power Generation In The State of Kuwait. *Renewable Energy*, *30*(14), 2149–2161. http://doi.org/10.1016/j.renene.2005.01.002

Al-Sahhaf, T. (2016). Sustainable Energy Research and Development. In *International Conference on New Trends for Sustainable Energy (ICNTSE)* (pp. 1–17). Alexandria, Egypt.

Al-Saleh, Y., Upham, P., & Malik, K. (2008). *Renewable Energy Scenarios for the Kingdom of Saudi Arabia*.

Al-Tajer, Y., & Poullikkas, A. (2015). Parametric Analysis For The Implementation of Wind Power in United Arab Emirates. *Renewable and Sustainable Energy Reviews*, *52*, 635–644. http://doi.org/10.1016/j.rser.2015.07.169

Alawaji, S. H. (2001). Evaluation of Solar Energy Research and Its Applications in Saudi Arabia: 20 Years of Experience. *Renewable and Sustainable Energy Reviews*, *5*(1), 59–77. http://doi.org/10.1016/S1364-0321(00)00006-X

AlGarni, H., Kassem, A., Awasthi, A., Komljenovic, D., & Al-Haddad, K. (2016). A Multicriteria Decision Making Approach For Evaluating Renewable Power Generation Sources In Saudi Arabia. *Sustainable Energy Technologies and Assessments*, *16*, 137–150.

Alotaibi, S. (2011). Energy Consumption In Kuwait: Prospects and Future Approaches. *Energy Policy*, *39*(2), 637–643. http://doi.org/10.1016/j.enpol.2010.10.036

Aloughani, M. (2015). *Renewable Energies Management Strategy Challenges in the Arabian Gulf Countries*. Brunel University in London. Retrieved from http://bura.brunel.ac.uk/bitstream/2438/11533/1/FulltextThesis.pdf

Alsayegh, O. A., Fairouz, F. A., & Overview, A. (2011). Renewable Energy Supply Options in Kuwait, *5*(12), 871–876.

Alshehry, A. S., & Belloumi, M. (2015). Energy Consumption, Carbon Dioxide Emissions And Economic Growth: The Case Of Saudi Arabia. *Renewable and Sustainable Energy Reviews*, *41*, 237–247. http://doi.org/10.1016/j.rser.2014.08.004

Alyahya, S., & Irfan, M. A. (2016). The Techno-Economic Potential of Saudi Arabia's Solar Industry. *Renewable and Sustainable Energy Reviews*, *55*, 697–702. http://doi.org/10.1016/j.rser.2015.11.017

Alyahya S, I. M. (2014). *New Solar Radiation Atlas for Saudi Arabia*. *ICRERA*. Milwauke USA.

Aryanpur, V., & Shafiei, E. (2015). Optimal Deployment of Renewable Electricity Technologies in Iran And Implications for Emissions Reductions. *Energy*, *91*, 882–893. http://doi.org/10.1016/j.energy.2015.08.107

Atabi, F. (2004). Renewable Energy in Iran: Challenges And Opportunities for Sustainable Development. *International Journal of Environmental Science & Technology*, *1*(1), 69–80. http://doi.org/10.1007/BF03325818

Ataei, A., Choi, J., Shamshiri, S., & Torabi, H. (2015). Evaluating of the Energy Consumption in Iran During 1980-2030 Using the Leap Model Evaluating of the Energy Consumption in Iran During 1980-2030 Using the Leap Model. *American Journal of Renewable and Sustainable Energy*, *1*(2), 72–85.

Bachellerie, I. J. (2012). *Renewable Energy in the GCC Countries*. Masdar City, UAE: Gulf Research Center. Retrieved from www.fes.de/cgi-bin/gbv.cgi?id=09008&ty=pdf

Bahrami, M., & Abbaszadeh, P. (2013). An Overview Of Renewable Energies in Iran. *Renewable and Sustainable Energy Reviews*, *24*, 198–208. http://doi.org/10.1016/j.rser.2013.03.043

Bassyouni, M., Gutub, S. A., Javaid, U., Awais, M., Rehman, S., Hamid, S. M. A.-, & Shafeek, H. (2015). Assessment And Analysis of Wind Power Resource Using Weibull Parameters. *Energy Eploration & Exploitation*, *33*(1).

Center for Energy & Security Studies. (2016). *Prospects for Nuclear Power in the Middle East : Russia ' S Interests*. Moscow, Russia.

Chandhoke, A., & Kaur, R. (2015). Iran is on an Aggressive Growth Path to Develop Renewable Energy to Manage with Capacity Shortages, notes Frost & Sullivan. Retrieved August 25, 2016, from http://ww2.frost.com/news/press-releases/iran-aggressive-growth-path-develop-renewable-energy-manage-capacity-shortages-notes-frost-sullivan/

Chitchian, H. (2014). Iran's Electricity Generation Capacity to Reach 100,000 MW. Retrieved March 23, 2016, from http://www.iran-daily.com/News/56429.html

CleanTechnica. (2013). Middle East-Africa Solar PV Demand Will Grow 625% This Year Solarbuzz. Retrieved December 3, 2017, from https://cleantechnica.com/2013/03/22/middle-east-africa-solar-pv-demand-will-reach-1-gigawatt-this-year-solarbuzz/

DLIFLC. (2016). *Kuwait in Perspective: An Orientation*. Kuwait, Kuwait.

EcoMENA. (2015). MSW Generation in the Middle East. Retrieved August 12, 2016, from http://www.ecomena.org/solid-waste-middle-east/

El Chaar, L., & Lamont, L. A. (2010). Global Solar Radiation: Multiple On-Site Assessments in Abu Dhabi, UAE. *Renewable Energy*, *35*(7), 1596–1601. http://doi.org/10.1016/j.renene.2009.10.007

Electricity & Cogeneration Regulatory Authority (ECRA). (2014). *Electricity Annual Report*. Riyadh, Saudi Arabia.

Fadai, D. (2007). The Feasibility Of Manufacturing Wind Turbines in Iran. *Renewable and Sustainable Energy Reviews*, *11*(3), 536–542. http://doi.org/10.1016/j.rser.2005.01.012

Farhani, S., & Shahbaz, M. (2014). What Role Of Renewable And Non-Renewable Electricity Consumption And Output Is Needed To Initially Mitigate CO2 Emissions In MENA Region? *Renewable and Sustainable Energy Reviews*, *40*, 80–90. http://doi.org/10.1016/j.rser.2014.07.170

Fathi, S., & Lavasani, A. M. (2017). A Review of Renewable and Sustainable Energy Potential and Assessment of Solar Projects in Iran. *Journal of Clean Energy Technologies*, *5*(2), 126–130. http://doi.org/10.18178/JOCET.2017.5.2.356

Feng, B. (2014). Investment Prioritization in Renewable Energy Resources with Consideration to the Investment Criteria in Iran, *29*(1).

Financial Tribune. (2016). Iran's Installed Renewable Production Capacity Tops 240 MW. Retrieved September 3, 2017, from https://financialtribune.com/articles/energy/48290/iran-s-installed-renewable-production-capacity-tops-240-mw

Global Wind Energy Council. (2010). Global Wind Energy Outlook 2010. *Global Wind Energy Council*, (October), 1–60.

Green World. (2017). Renewable Iran 2017: Green World Conferences.

Gulf Business. (2015). UAE's Electricity Demand To Exceed 40,000MW By 2020. Retrieved April 6, 2016, from http://gulfbusiness.com/uaes-energy-demand-to-exceed-40000mw-by-2020/

Hamzeh, Y., Ashori, A., Mirzaei, B., Abdulkhani, A., & Molaei, M. (2011). Current And Potential Capabilities Of Biomass For Green Energy In Iran. *Renewable and Sustainable Energy Reviews*, *15*(9), 4934–4938. http://doi.org/10.1016/j.rser.2011.07.060

Hepbasli, A., & Alsuhaibani, Z. (2011). A Key Review On Present Status And Future Directions Of Solar Energy Studies And Applications In Saudi Arabia. *Renewable and Sustainable Energy Reviews*, *15*(9), 5021–5050. http://doi.org/10.1016/j.rser.2011.07.052

Hosseini, S. E., Andwari, A. M., Wahid, M. A., & Bagheri, G. (2013). A Review On Green Energy Potentials In Iran. *Renewable and Sustainable Energy Reviews*, *27*, 533–545. http://doi.org/10.1016/j.rser.2013.07.015

IAEA. (1984). *The Agency's Technical Co-operation Activities in 1983*.

IEA. (2015). *Energy Balances of non-OECD Countries*. Paris, France.

IEA. (2015). Kuwait's Renewable Energy Target. Retrieved January 1, 2017, from http://www.iea.org/policiesandmeasures/pams/kuwait/

IEA. (2015). *World Energy Outlook*. Paris, France. http://doi.org/10.1787/weo-2014-en

International Energy Agency. (2016). *Key World Energy Statistics*. Paris, France. Retrieved from http://www.iea.org/statistics/statisticssearch/

International Hydropower Association. (2016). *Hydropower Status Report*.

Iran-German Cooperation. (2009). *Energy Scenarios for Iran*. Tehran, Islamic Republic of Iran.

Iran's Ministry of Power. (2016). *Statistical Report of Iran's Electricity Industry*. Tehran, Islamic Republic of Iran.

IRAN Renewable Energy Congress. (2016). *Enewable Energy Opportunities in Iran*. Tehran, Islamic Republic of Iran.

IRENA. (2015). *Renewable Energy Prospects: United Arab Emirates*. Abu Dhabi, United Arab Emirates.

IRENA. (2016). *Renewable Energy in the Gulf: Facts and Figures*. Abu Dhabi, United Arab Emirates.

Jandal, S. Al, & Sayegh, O. Al. (2015). Clean Energy Policy Options: Modeling Possible Deployment Scenarios. In *EcoMod Conference*. Boston, MA.

Jeddah Chamber. (2015). *Sectorial Report on Saudi Arabia Electricity*. Jeddah, Kingdom of Saudi Arabia.

John, I. (2017). Power up: UAE needs $35b.

K.A.CARE. (2017). Renewable Resource Atlas. Retrieved September 3, 2017, from https://rratlas.kacare.gov.sa/RRMMPublicPortal/

KA-CARE. (2015). Saudi Arabia's Nuclear Energy Program for Electricity Generation.

KA-CARE. (2017). Renewable Resource Atlas. Retrieved December 3, 2017, from https://rratlas.kacare.gov.sa/

Katzman, K. (2016). *Kuwait : Governance , Security , and U.S . Policy*.

Kayhan. (2015). Drought Takes a Toll on Iran's Hydropower.

Kazem, H. A. (2011). Renewable Energy In Oman: Status and Future Prospects. *Renewable and Sustainable Energy Reviews*, *15*(8), 3465–3469. http://doi.org/10.1016/j.rser.2011.05.015

Kazim, A. (2004). Feasibility Of Hydrogen Energy Production Through Natural Gas Steam Reformation Process In The UAE. *Hydrogen Materials Science and Chemistry of Carbon Nanomaterials*, *172*, 467–472.

Kazim, A. (2010). Potential Of Wave Energy In The United Arab Emirates: A Case Study Of Dubai's Coasts. *WSEAS Transactions on Environment and Development*, *1*(2), 187–192. Retrieved from http://bura.brunel.ac.uk/bitstream/2438/11533/1/FulltextThesis.pdf

KFUPM. (2011). *Updated Generation Planning for the Saudi Electricity Sector Report*. Dhahran, Saudi Arabia.

Khajehpour, B. (2016). Will New 5-Year Plan Solve Iran's Economic Problems? Retrieved August 8, 2016, from http://www.al-monitor.com/pulse/originals/2016/06/iran-sixth-five-year-development-plan-rouhani-parliament.html

Khan, M. S. M., & Kaneesamkandi, Z. (2013). Biodegradable Waste to Biogas: Renewable Energy Option for The Kingdom Of Saudi Arabia. *International Journal of Innovation and Applied Studies*, *4*(1), 101–113. Retrieved from http://www.ijias.issr-journals.org/abstract.php?article=IJIAS-13-142-18

Khonsari, A. (2016). *Briefing Renewable Energy in Iran*. Tehran, Islamic Republic of Iran.

Kim, S., & Dale, B. E. (2004). Global Potential Bioethanol Production From Wasted Crops And Crop Residues. *Biomass and Bioenergy*, *26*(4), 361–375. http://doi.org/10.1016/j.biombioe.2003.08.002

Kingdom of Saudi Arabia. (2016). *Vision 2030*. Riyadh, Saudi Arabia. Retrieved from http://vision2030.gov.sa/sites/default/files/report/Saudi_Vision2030_EN_0.pdf

KISR. (2016). Kuwait Innovative & Renewable Energy Program. Retrieved August 8, 2016, from http://www.kisr.edu.kw/en/research/energy-and-building/programs/innovative-and-renewable-energy-program

Languages of The World. (2015). Iran's Nuclear Program—And the Possibility of a Military Strike.

Lude, S., Fluri, T. P., Alhajraf, S., Jülch, V., Kühn, P., Marful, A., & Contreras, J. R. S. (2015a). Optimization of the Technology Mix for the Shagaya 2 GW Renewable Energy Park in Kuwait. *Energy Procedia*, *69*, 1633–1642. http://doi.org/10.1016/j.egypro.2015.03.120

Lude, S., Fluri, T. P., Alhajraf, S., Jülch, V., Kühn, P., Marful, A., & Contreras, J. R. S. (2015b). Optimization of the Technology Mix for the Shagaya 2 GW Renewable Energy Park in Kuwait. *Energy Procedia*, *69*, 1633–1642. http://doi.org/10.1016/j.egypro.2015.03.120

Malek, C. (2016). Nuclear Power is the Answer To Growing Energy Demands.

Mansouri, N. Y., Crookes, R. J., & Korakianitis, T. (2013). A Projection Of Energy Consumption And Carbon Dioxide Emissions In The Electricity Sector For Saudi Arabia: The Case For Carbon Capture And Storage And Solar Photovoltaics. *Energy Policy*, *63*, 681–695. http://doi.org/10.1016/j.enpol.2013.06.087

Masdar Institute Research Center. (2017a). UAE Solar Atlas. Retrieved January 1, 2017, from http://atlas.masdar.ac.ae/

Masdar Institute Research Center. (2017b). UAE Wind Atlas. Retrieved January 1, 2017, from https://windatlas.masdar.ac.ae/

McAuley, A. (2017). Saudi Arabia's Slow Pace On Renewables A Risk to Oil Exports. Retrieved March 25, 2017, from http://www.thenational.ae/business/energy/saudi-arabias-slow-pace-on-renewables-a-risk-to-oil-exports

McGlade, C., & Ekins, P. (2015). The Geographical Distribution Of Fossil Fuels Unused When Limiting Global Warming To 2 °C. *Nature*, *517*(7533), 187–190. http://doi.org/10.1038/nature14016

McGlade, C., Speirs, J., & Sorrell, S. (2013). Unconventional Gas : A Review of Regional And Global Resource Estimates. *Energy*, *55*, 571–584. http://doi.org/10.1016/j.energy.2013.01.048

McKernan, B. (2017). UAE Invests £134bn In Renewables In Push To Reach 50% Clean Energy Target. Retrieved December 3, 2017, from http://www.independent.co.uk/news/world/middle-east/uae-invest-134-billion-renewable-energy-oil-and-gas-producer-clean-energy-target-a7522086.html

Mehrdad, A. (2012). Bioenergy Business Models in Iran : the Role of Innovations. In *4th International Conference on Applied Energy*. Suzhou, China.

MESIA. (2015). MENA Solar Outlook 2015, (January).

Mezghani, I., & Ben Haddad, H. (2016). Energy Consumption and Economic Growth: An Empirical Study of The Electricity Consumption in Saudi Arabia. *Renewable and Sustainable Energy Reviews*, (October), 1–12. http://doi.org/10.1016/j.rser.2016.10.058

Mezher, T., Goldsmith, D., & Choucri, N. (2011). Renewable Energy in Abu Dhabi : Opportunities and Challenges, *137*(December), 169–176. http://doi.org/10.1061/(ASCE)EY.1943-7897.0000042.

Mezher, T., Griffiths, S., Zahra, M. A., & Abbas, Z. (2014). Outlook for a Power Generation Fuel Transition in the MENA Region. *Journal of Energy Engineering*, *1*(1), 4014026. http://doi.org/10.1061/(ASCE)EY.1943-7897.0000204

Mirzahosseini, A. H., & Taheri, T. (2012). Environmental, Technical And Financial Feasibility Study Of Solar Power Plants By Retscreen, According To The Targeting Of Energy Subsidies In Iran. *Renewable and Sustainable Energy Reviews*, *16*(5), 2806–2811. http://doi.org/10.1016/j.rser.2012.01.066

Mohammad, T. bin S. bin. (2011). Saudi Arabia Launches Solar Energy Program. Retrieved March 8, 2016, from http://www.go-green.ae/greenstory_view.php?storyid=971

Mohammadnejad, M., Ghazvini, M., Mahlia, T. M. I., & Andriyana, A. (2011). A Review On Energy Scenario And Sustainable Energy in Iran. *Renewable and Sustainable Energy Reviews*, *15*(9), 4652–4658. http://doi.org/10.1016/j.rser.2011.07.087

Mokri, A., Aal Ali, M., & Emziane, M. (2013). Solar Energy in The United Arab Emirates: A Review. *Renewable and Sustainable Energy Reviews*, *28*, 340–375. http://doi.org/10.1016/j.rser.2013.07.038

Mondal, M. A. H., Kennedy, S., & Mezher, T. (2014). Long-term Optimization Of United Arab Emirates Energy Future: Policy Implications. *Applied Energy*, *114*, 466–474. http://doi.org/10.1016/j.apenergy.2013.10.013

Moshiri, S. (2015). *Sustainable Energy Strategy for Iran*.

Najafi, G., & Ghobadian, B. (2011). Geothermal Resources In Iran: The Sustainable Future. *Renewable and Sustainable Energy Reviews*, *15*(8), 3946–3951. http://doi.org/10.1016/j.rser.2011.07.032

Najafi, G., Ghobadian, B., Mamat, R., Yusaf, T., & Azmi, W. H. (2015). Solar Energy In Iran: Current State and Outlook. *Renewable and Sustainable Energy Reviews*, *49*, 931–942. http://doi.org/10.1016/j.rser.2015.04.056

Nejat, P., Morsoni, A. K., Jomehzadeh, F., Behzad, H., Saeed Vesali, M., & Majid, M. Z. A. (2013). Iran's Achievements In Renewable Energy During Fourth Development Program In Comparison With Global Trend. *Renewable and Sustainable Energy Reviews*, *22*, 561–570. http://doi.org/10.1016/j.rser.2013.01.042

Norman, M. (2017). Saudi Renewables Reset and Launch. Retrieved December 2, 2017, from http://www.renewableenergyworld.com/articles/2017/02/saudi-renewables-reset-and-launch.html

Ouda, O. K. M., & Cekirge, H. M. (2013). Roadmap for Development of Waste-to Energy Facility in Saudi Arabia. *American Journal of Environmental Engineering*, *3*(6), 267–272. http://doi.org/10.5923/j.ajee.20130306.01

Parajuli, R., Hussong, C., Ntoka, C., Charisoulis, G., Tulucan, T., & Sperling, K. (2015). Beyond Oil And Gas: Possible Future Scenarios For The Electricity Sector In Saudi Arabia. *International Journal of Sustainable Energy*, *34*(2), 71–92. http://doi.org/10.1080/14786451.2013.821991

Perkovich, G. (2008). *Nuclear Developments in the GCC: Risks and Trends*.

Permanent Mission of the UAE to the IAEA. (2010). United Arab Emirates ' Nuclear Power Plant Project. Retrieved September 3, 2017, from http://uae-mission.ae/Editor/Fact_Sheet_Barakah NPP.pdf

Phys Org. (2015). Kuwait Signs $385 mn Solar Energy Project. Retrieved from http://phys.org/news/2015-09-kuwait-mn-solar-energy.html

Pidcock, R. (2015). Meeting Two Degree Climate Target Means 80 Per Cent Of World's Coal is "Unburnable." Retrieved January 1, 2016, from https://www.carbonbrief.org/meeting-two-degree-climate-target-means-80-per-cent-of-worlds-coal-is-unburnable-study-says

Pourhossein, M., & Nahavandi, N. (2014). Transition in Iran ' s Electricity Market Considering the Policies on Elimination of Electricity Subsidies : System Dynamics Application.

Ramadhan, M., Hussain, A., & Behbehani, D. (2013). The Prospect of Solar Energy in the Development of Power Stations in the State of Kuwait. *Journal of Renewable Energy*, *2013*(ii), 1–6. http://doi.org/10.1155/2013/374265

Ramadhan, M., & Naseeb, A. (2011). The Cost Benefit Analysis of Implementing Photovoltaic Solar System in The State of Kuwait. *Renewable Energy*, *36*(4), 1272–1276. http://doi.org/10.1016/j.renene.2010.10.004

Ramli, M. A. M., Twaha, S., & Al-Hamouz, Z. (2017). Analyzing The Potential And Progress Of Distributed Generation Applications in Saudi Arabia: The Case of Solar And Wind Resources. *Renewable and Sustainable Energy Reviews*, *70*(March 2016), 287–297. http://doi.org/10.1016/j.rser.2016.11.204

Rehman, S. (2005). Prospects of Wind Farm Development in Saudi Arabia. *Renewable Energy*, *30*(3), 447–463. http://doi.org/10.1016/j.renene.2004.04.008

Rehman, S. (2010). Saudi Arabian Geothermal Energy Resources: An Update. *World Geothermal Congress 2010*, (April), 1–6. Retrieved from http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0107.pdf

REN21. (2015). *Renewables 2015-Global Status Report. REN21 Renewables* (Vol. 4). Paris, France. http://doi.org/10.1016/0267-3649(88)90030-1

REVE. (2016). Wind energy in Iran: 4th Iranian Wind Power Congress.

REVE. (2017). Saudi Arabia Will Award Its First Tender to Build 700 Megawatts of Solar And Wind Energy. Retrieved September 3, 2017, from http://www.evwind.es/2017/02/02/saudi-arabia-will-award-its-first-tender-to-build-700-megawatts-of-solar-and-wind-energy/58686

Richard Bridl, Kitson, L., & Wooders, P. (2014). *Fossil-Fuel Subsidies: A Barrier To Renewable Energy In Five Middle East And North African Countries*. Winnipeg, Canada.

Richter, A. (2015). Iran Sees 800 MW Geothermal Development Potential.

Saffarzadeh, A., Porkhial, S., & Taghaddosi, M. (2010). Geothermal Energy Developments in Iran. *World Geothermal Congress 2015*, (April), 25–29.

Safieddin Ardebili, M., Ghobadian, B., Najafi, G., & Chegeni, A. (2011). Biodiesel Production Potential From Edible Oil Seeds in Iran. *Renewable and Sustainable Energy Reviews*, *15*(6), 3041–3044. http://doi.org/10.1016/j.rser.2011.03.004

Said, S. A. M., El-Amin, I. M., & Al-Shehri, A. M. (2004). *Renewable Energy Potentials in Saudi Arabia. Beirut regional Collaboration Workshop on Energy Efficiency and Renewable Energy Technology, American University of Beirut.*

Saudi Energy Efficiency Center (SEEC). (2015). *Energy Efficiency Annual Report*. Riyadh, Saudi Arabia.

Sgouridis, S., Abdullah, A., Griffiths, S., Saygin, D., Wagner, N., Gielen, D., … McQueen, D. (2016a). RE-mapping the UAE's energy transition: An economy-wide assessment of renewable energy options and their policy implications. *Renewable and Sustainable Energy Reviews*, *55*, 1166–1180. http://doi.org/10.1016/j.rser.2015.05.039

Sgouridis, S., Abdullah, A., Griffiths, S., Saygin, D., Wagner, N., Gielen, D., … McQueen, D. (2016b). RE-mapping the UAE's Energy Transition: An Economy-Wide Assessment Of Renewable Energy Options And Their Policy Implications. *Renewable and Sustainable Energy Reviews*, *55*, 1166–1180. http://doi.org/10.1016/j.rser.2015.05.039

Sgouridis, S., Griffiths, S., Kennedy, S., Khalid, A., & Zurita, N. (2013a). A sustainable energy transition strategy for the United Arab Emirates: Evaluation of options using an Integrated Energy Model. *Energy Strategy Reviews*, *2*(1), 8–18. http://doi.org/10.1016/j.esr.2013.03.002

Sgouridis, S., Griffiths, S., Kennedy, S., Khalid, A., & Zurita, N. (2013b). A Sustainable Energy Transition Strategy for The United Arab Emirates: Evaluation of Options Using An Integrated Energy Model. *Energy Strategy Reviews*, *2*(1), 8–18. http://doi.org/10.1016/j.esr.2013.03.002

Soltanieh, A. A., & Rezaeian, M. (2017). Nuclear And Renewable Energy In Iran: Nuclear Challenges And Opportunities. *International Journal of Hydrogen Energy*, 2–6. http://doi.org/10.1016/j.ijhydene.2017.02.075

Taleb, H. M. (2009). Barriers Hindering The Utilisation of Geothermal Resources In Saudi Arabia. *Energy for Sustainable Development*, *13*(3), 183–188. http://doi.org/10.1016/j.esd.2009.06.004

TAVANIR. (2014). *Statistical Report on 47 Years of Activities of Iran Electric Power Industry*. Tehran, Islamic Republic of Iran.

Tlili, I. (2015). Renewable Energy in Saudi Arabia: Current Status and Future Potentials. *Environment, Development and Sustainability*, *17*(4), 859–886. http://doi.org/10.1007/s10668-014-9579-9

Tofigh, A. A., & Abedian, M. (2016). Analysis Of Energy Status in Iran for Designing Sustainable Energy Roadmap. *Renewable and Sustainable Energy Reviews*, *57*, 1296–1306.

World Bank. (2016). *World Development Indicators*. Washingston, DC. Retrieved from http://data.worldbank.org/sites/default/files/wdi-2016-highlights-featuring-sdgs-booklet.pdf

World Net Daily (WND). (2012). Saudi Arabia Looks To NREL For Solar Power Expertise. Retrieved September 3, 2017, from http://www.helioscsp.com/noticia.php?id_not=1796

World Nuclear Association. (2017). Nuclear Power in Saudi Arabia. Retrieved February 3, 2017, from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Saudi-Arabia/

World Nuclear Association (WNA). (2016). Nuclear Power in Iran. Retrieved August 3, 2017, from http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/iran.aspx

World Wind Energy Association (WWEA). (2014). *World Wind Resource Assessment Report*. Bonn, Germany.

Yessian, K., DeLaquil, P., Merven, B., Gargiulo, M., & Goldstein, G. (2013). Economic Analysis Of Clean Energy Options For Kuwait. *International Journal of Energy Sector Management*, *7*(1), 29–45. http://doi.org/10.1108/17506221311316461

Zafar, S. (2015). Solid Waste Management In Kuwait. Retrieved October 3, 2017, from http://www.bioenergyconsult.com/solid-waste-management-in-kuwait/

5. Emissions Saving Potential from Transition to Natural Gas

A number of previous studies have highlighted the relationship between fossil fuel consumption and CO_2 emissions in developing regions. Saidi et al. (2015) concluded that the relative increase in CO_2 emissions is closely associated with fossil-based energy consumption in the North African and Middle Eastern regions. Similar results were affirmed by Lotfalipour et al. (2010) who reported that fossil fuel energy consumption and CO_2 emissions were strongly allied in Iran. Also, Niu (2011) found a significant relationship between fossil fuel energy consumption and CO_2 emissions in eight Asian countries. This chapter begins by looking at the relationship between increases in CO_2 emissions and the structure of the energy supply mix across the twelve Middle Eastern countries. Then, an assessment of how individual countries, namely major emitters, could contribute to the region's 450-emissions goal under a "BAU" projections.

5.1 Middle East Emission Distribution and Energy Mix Profile

To understand the main attributes of CO_2 emissions distribution across the Middle East, a country-level correlation analysis is constructed to investigate the long-term relationship between CO_2 emissions (as the dependent variable) and the energy supply mix, gross domestic product (GDP), population, and energy consumption (as independent variables). The energy supply mix from fossil fuel resources is decomposed into shares of oil, coal, and natural gas, to understand their relative impacts on emission increases. Gross Domestic Product (GDP) is also considered here, as previous studies have emphasized its role in driving emission increases in the Middle East (Al-mulali, 2012; Ozcan, 2013). Data collected cover the period from 1990 to 2014 for 12 Middle Eastern countries, namely Bahrain, Iran, Iraq, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, and Yemen. All data were collected from International Energy Agency (IEA) including total primary energy supply (TPES), population, GDP, total final energy consumption (TFEC), and total emissions.

Analysis shows that across the twelve countries, CO_2 emissions were not always correlated with population size and GDP. For example, UAE represents approximately 4% of the region's total population; however, it is one of the major emitters in the region. While Iran represents 35% of the total regional population, it also accounts for 33% of the region's emissions. A stronger trend is observed in cases between: a) CO_2 and GDP, and b) CO_2 and energy supply, especially in countries with high oil dependence like Iraq, Saudi Arabia, and Bahrain, as presented in Table 5.1 below.

Table .5.1: R^2 values from Pearson correlation test for the twelve Middle Eastern countries

CO_2 Emissions	***Bahrain***	***Iran***	***Iraq***	***Jordan***	***Kuwait***	***Lebanon***	***Oman***	***Qatar***	***KSA***	***Syria***	***UAE***	***Yemen***
Population	0.890	0.81	0.501	0.863	0.897	0.790	0.966	0.987	0.974	0.719	0.971	0.950
GDP	0.981	**0.987**	0.342	0.974	0.975	0.834	0.965	**0.995**	0.991	0.718	**0.977**	0.979
TPES	**0.998**	**0.997**	**0.998**	**0.985**	**0.993**	**0.999**	**0.991**	**0.994**	**0.995**	**0.991**	**0.997**	**0.997**
TFEC	**0.985**	0.979	**0.776**	**0.989**	**0.979**	**0.936**	**0.982**	0.990	**0.999**	**0.974**	0.976	**0.994**

From the data set, five clusters of countries are identified according to three categories: 1) countries dependent on both oil and natural gas; 2) countries that are mostly dependent on oil and; 3) countries that are more dependent on natural gas (Figure 5.1).

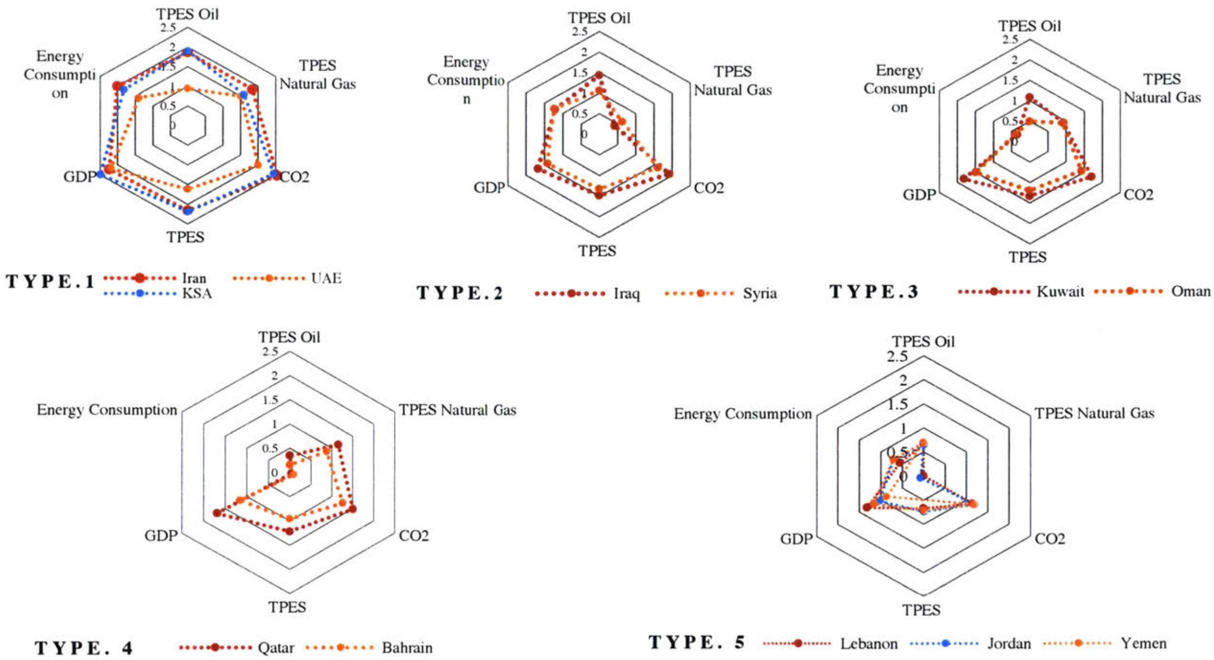


Figure 5.1: Typology classes for the 12 Middle Eastern countries (CO_2 emissions, GDP, TPES from fossil fuel, and energy consumption), (Bayomi & Fernandez, 2017)

In general, the energy supply mix is largely dependent on fossil fuels as previously discussed, with a large portion coming from oil and natural gas. The contribution of coal and renewable resource is very modest. In arriving at these five types, it can be identified that the CO_2 emission volume is clearly affected by the fuel mix profile. In addition, the total primary energy supply size (TPES) is a clear indicator of overall energy consumption and CO_2 emission volume. The five types of countries are described as follows.

Type 1. Countries in this category are key players in the international energy market with strong reliance on both oil and natural gas in their primary energy supply (Figure 5.1). This type is characterized by high levels of CO_2 emissions, energy consumption and GDP. Additionally, they have a large subsidized energy system induced by the large bulk fossil fuel reserves. This category includes: Iran, possessing the second-largest natural gas reserve; Saudi Arabia, with 16% of the world's oil reserves (David Ramin, 2016); and the UAE, which holds 5.8% of global proved oil reserves (IEA, 2015a).

Type 2. Countries in this group are significantly reliant on oil with small contribution from natural gas. This category includes: Iraq, as the third-largest oil exporter with a GDP based on oil export revenue (International Energy Agency, 2012); and Syria, with 2.5 billion barrels of proved oil reserves and 25% of its GDP coming from oil export revenues (US Energy Information Administration, 2013).

Type 3. This group is similar to Type 2, with a different TPES mix. Countries under this group are more reliant on natural gas than oil in their energy supply mix. This category includes: Kuwait, among the top oil producers in the region; and Oman, with 5.5 billion barrels of proved oil reserves (IEA, 2015a). Although countries in this group are considered oil-rich countries, the share of oil in their energy mixes is not as large as natural gas. This is mostly because their GDPs are strongly dependent on oil export revenues, except for Kuwait that uses more oil.

Type 4. This group includes countries that are more reliant on natural gas with a small share from oil. This category includes: Qatar, among the top-ten natural gas producers globally, with a GDP based on natural gas export revenues; and Bahrain, whose economy is based more on oil exports (IEA, 2015a).

Type 5. This group represents countries with large dependence on fossil fuel imports for their energy supply. These countries are characterized by relatively smaller CO_2 emission volume, GDP, and TPES size. This category includes resource-poor countries such as Jordan, Lebanon, and Yemen.

These results present a preliminary indication of the causal link between fossil fuel reserve size, and the structure of energy supply. This is also reflected in the emissions distribution across the region, as generally resource rich countries are also the ones who emit more. Thus, it can be concluded that CO_2 emissions in the Middle East are represented by two main trends. Resource-rich countries with large reserves and high CO_2 emissions levels, and resource-poor countries with strong reliance on fossil fuel imports, small economies and relatively smaller emission volume. Among the resource-rich countries, Iran and Saudi Arabia have the most energy-intensive consumption profile; nearly three times higher than that of the UAE. Although Qatar is considered among the resource-rich countries, its total emissions are low compared to Iran, Saudi Arabia and Kuwait. Yet, it has the highest rate of emissions per capita among the twelve countries, followed by Kuwait. Understanding these findings is relevant to identifying where emission-savings potentials are greatest and which countries will contribute the most to regional emissions goals.

5.2 Methods

As previously discussed, primary energy supply plays a key role in driving CO_2 emissions growth across the twelve Middle Eastern countries. The approach here is to step beyond the effect of population increase and GDP growth, and estimate the impact of the total primary energy supply mix on projected emissions. The focus here is limited to the structure of primary energy supply, to identify the main emissions growth attributes that are associated with mounting fossil fuel shares in the primary energy mix. Such measures are not often included in emissions reduction-focused studies that mainly look at energy consumption, GDP, and population impacts on emissions stabilization. After projecting CO_2 emissions and the future primary energy supply mix, a forecast model for energy demand is conducted to identify the biggest challenges from both the supply and demand sides.

Here, emissions are projected with a modified model of the Kaya identity, drawing on the work of Ehrlich (1971) and Raupach (2007). CO_2 emissions (C) are decomposed based on proportional growth rates of the total primary energy supply (TPES) from fossil fuels, presented in Equation (1) as follows:

$$r(C) = r\left(\frac{C}{TPES}\right) + r(TPES) \qquad (1)$$

Business as Usual "BAU" emissions are projected up to 2040, starting with the base year 1990. The base year selected here is the same year that the Kyoto Protocol has set as a baseline for developing countries' emissions. Growth rates are calculated on the right side of equation (1) and results are validated with reference year 2010.

Results show that under a "BAU" scenario, CO_2 emissions are expected to reach 2.5 gigatonnes p.a. by 2030 and around 3.0 gigatonnes p.a. by 2040. In view of BAU projection and the three IEA projection scenarios presented in figure 5.2, there is a large deviation required from the "BAU" scenario to achieve the emission rates stipulated by planned policies and additional policy scenarios to reach the 450 goal. Results show that oil and natural gas will continue to dominate the energy supply mix, while the contribution of coal will continue to be relatively negligible.

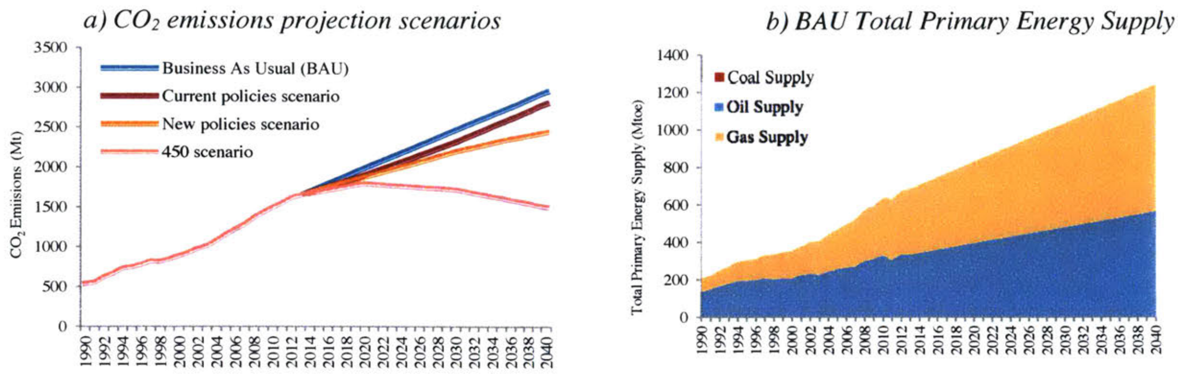


Figure 5.2: a) CO_2 emissions projection scenarios: BAU scenario is compared to the three IEA scenarios, b) Total primary energy supply projection under a "BAU" scenario with a breakdown of the share of different fossil fuels (Bayomi & Fernandez, 2017)

Based on historical trends analysis, natural gas started to take over the energy mix in 2010 (Figure 5.3); however, under a "BAU" scenario, oil will still contribute a large share of the main mix. Projection results show that by 2020, oil will represent 47% of the total energy supply, while natural gas will contribute 52%. This trend will continue until 2040, when oil's share will be approximately 45% and natural gas 54%. The share of coal in the fossil fuel mix will continue to be relatively modest, with an average of 0.4% by the year 2040.

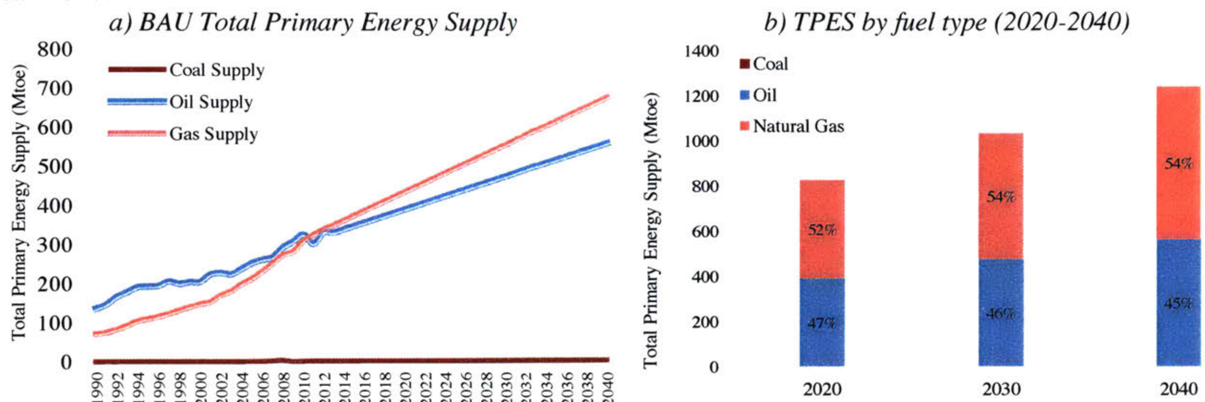


Figure 5.3: Energy supply mix projection under a "BAU" scenario. a) Energy supply growth trends with a relative transition from oil to natural gas in 2010 that is forecast to continue until 2040, b) energy supply mix from coal, oil and natural gas in 2020, 2030 and 2040, where oil still contributes with an average 45% (Bayomi & Fernandez, 2017).

5.3 Projection Scenario: A Country-Level Analysis

To reflect this projection on a country level, a "BAU" projection is constructed for each country to understand the implications of their energy supply on the total region's CO_2 emissions increase. Projection is assuming that historical trends will continue without taking into-account planned policies. Projections from individual countries corroborate with the total region's "BAU" scenario. Results indicate that on a country level, CO_2 emissions will rise rapidly in resource-rich countries and in countries that are highly dependent on oil. As previously noted, there are five main key players considered "major emitters". These countries are significantly driving the increase of CO_2 emissions across the region, and account for 79% of total emission increases by 2040. As presented in figure 5.4 below, these countries are Iran (31% share), Saudi Arabia (28%), UAE (10%), Iraq (8%) and Kuwait (6%). Examining their relative contribution in the region's emission increase is essential to pinpoint which countries have the highest impact on emission reduction, and to what extent a shift to low carbon resources is applicable.

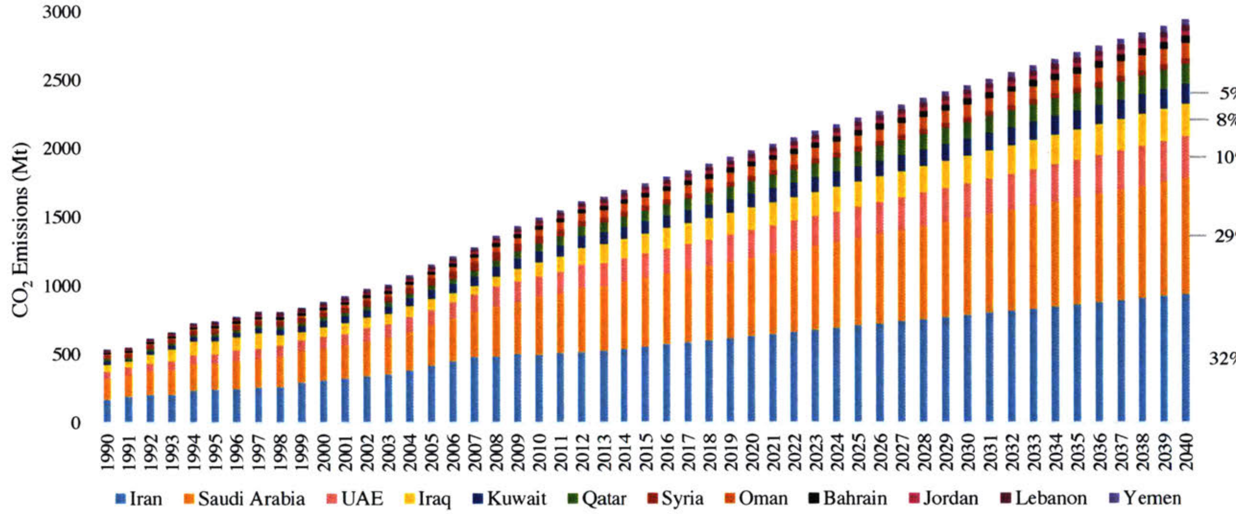


Figure 5.4: Middle Eastern CO_2 emissions projections by country. Percentages refer to share of the five major emitters in total region's emission by 2040 (Bayomi & Fernandez, 2017).

Figure 5.5 disaggregates the primary energy supply of the "major emitters" into oil, natural gas and coal. Challenges are biggest in these countries due to their heavy reliance on fossil fuels and their significant contribution in the region's total emissions increase. The share of oil in the primary energy supply is projected to continue until 2040, with Saudi Arabia and Iraq topping the list.

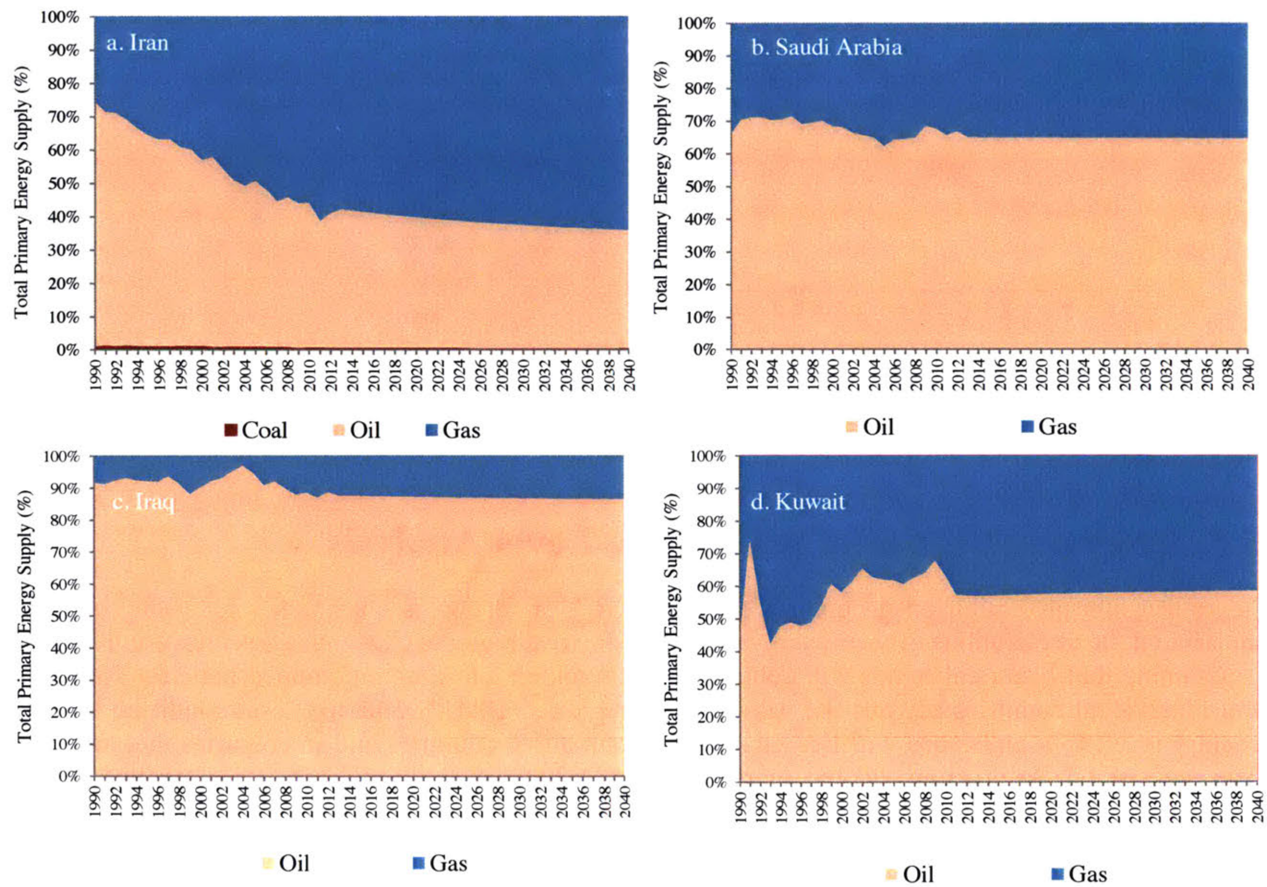


Figure 5.5: Projected energy supply mix for the top-four major emitters in the Middle East (Bayomi & Fernandez, 2017).

It can be identified that energy supply from oil in countries like Iraq, Saudi Arabia, and Kuwait will exceed 50% by 2040. Iraq is considered the most challenging in terms of fuel mix adjustment, as by 2040, oil will account for around 87% of its total energy supply while natural gas will only represent 13%. Although such reliance on oil will continue in the majority of the Middle Eastern countries, "major emitters" countries are the most challenging, as their energy supply and CO_2 emissions will vastly increase by 2040 as presented in figure 5.6. For instance, Iran's energy supply from fossil fuels is expected to reach 410 Million tons of oil equivalent (Mtoe), with emissions reaching 942 Million metric tons (Mt) by 2040. This will account for almost 32% of the total Middle East projected emissions. Such growth in the energy supply raises questions over the future of fossil fuel exports within these countries.

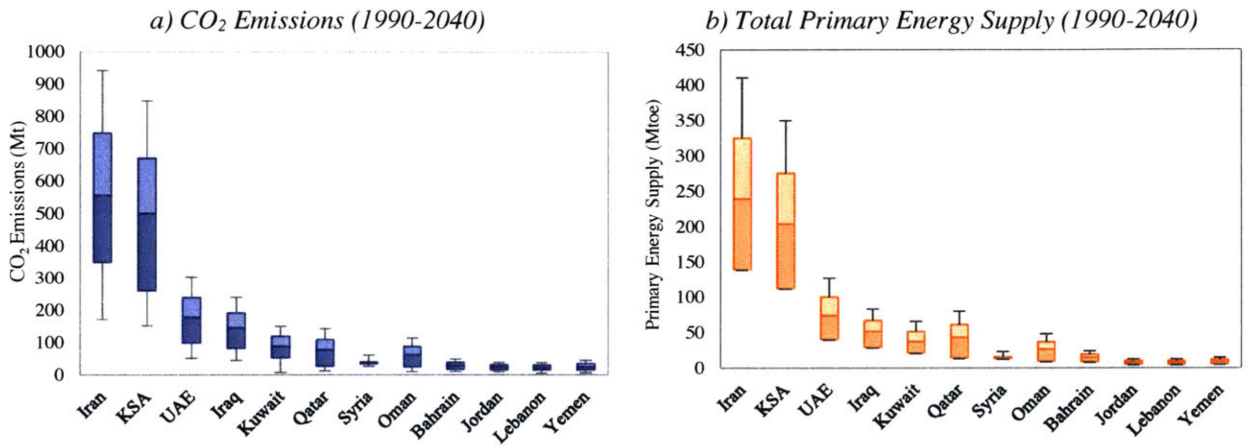


Figure 5.6: Whisker Plot for CO_2 emissions and total primary energy supply from 1990-2040. a) Iran and KSA CO_2 emissions will reach 942 and 850 Mt, respectively, representing 60% of the Middle East's projected emissions in 2040, b) resource-poor countries such as Yemen, Jordan and Lebanon will witness small increases in their primary energy supplies, contributing to 3% of the projected increases in 2040 (Bayomi & Fernandez, 2017).

Across resource-poor countries, or countries that are largely reliant on fossil fuel imports, CO_2 emissions will increase slightly. Countries like Bahrain, Jordan, Lebanon, and Yemen will account for only 6% by 2040. On the other hand, "major emitters" such as Iran, Saudi Arabia, Iraq, Kuwait and UAE will represent 84% of the projected CO_2 emissions by 2040. Iran and Saudi Arabia will have the largest share (61%) of the total projected emissions. These findings are vital to establish that equitable emission reduction is not suitable to reach regional target. The contribution of individual countries in emission savings should be based on their relative share in emission increase. Given this projection, it is clear that fossil fuel resources will continue to play a huge role in the future of the energy supply mix across the Middle East. This underlines the potential for reducing emissions through the sustainable development of the region's energy systems. One of the possible options as a potential pathway towards emissions reduction is switching to low carbon resources such as natural gas. Therefore, the following section will examine the impact of transitioning to natural gas usage on emission savings.

5.4 Emission Saving Potentials: The Wedge Approach

Results from the aggregate projections mentioned above point to the potential for reducing CO_2 emissions through the contribution of individual countries on a regional level. This raises the question: what is the potential extent of CO_2 emission savings by 2040 from transitioning to natural gas usage, especially in "major emitters"? Looking at historical trends, between 2005 and 2010, oil represented 52% of the Middle East's energy supply mix, while the share of natural gas was 47%. According to "BAU" projection, by 2040, oil will account for approximately 45% share of energy supply, and the share of natural gas will reach 54%. While this projection omits potential increases in renewable energy deployment, energy efficiency and energy policies, the analysis here focuses only on estimating the cumulative commitment of individual countries from energy supply adjustment. This is to underline to what extent these countries could potentially reduce emissions by 2040. Here, emissions savings are estimated by switching to more natural gas by 2040, assuming no intervention from renewable energy technologies. In the view of such a projection in isolation from energy policies and renewable energy technologies, a potential CO_2 emissions saving is estimated to be around 980 Mt by 2040 (Figure 5.7).

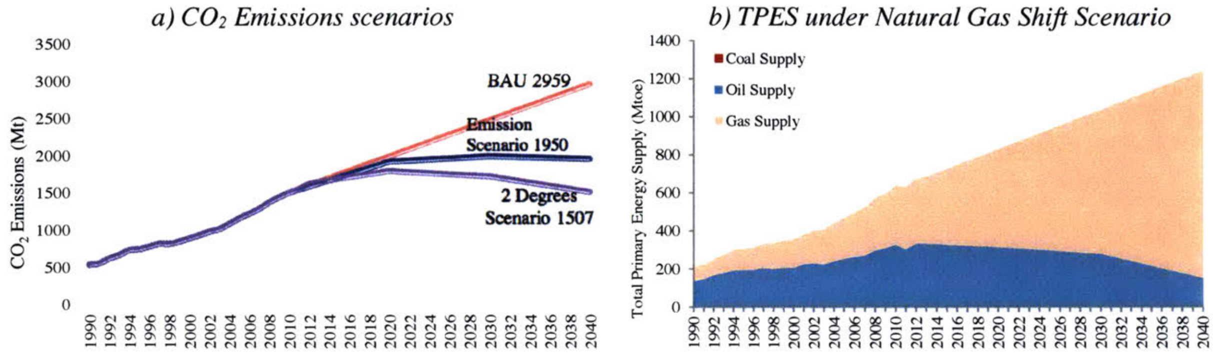


Figure 5.7: a) Emission reduction scenario from Energy supply, b) Energy mix profile from fossil fuel by 2040 (Bayomi & Fernandez, 2017).

The fuel mix adjustments required to reach this goal vary across the twelve Middle Eastern countries. Countries that are heavily dependent on oil in their energy supply mix would need to gradually transition to natural gas to reach an average share of 75% by 2040. In addition, some countries are required to shift to more natural gas usage earlier than others. For example, "major emitters" such as Iran, KSA, Kuwait and Iraq, will need to switch to natural gas earlier than countries like Jordan, Syria, and Yemen. For instance, Iran, KSA and Kuwait, the average annual growth rate of natural gas will be around 5% over the period of 2012-2040. On the contrary, Qatar and UAE will have a smaller average annual rate of 3%. This proposed reduction is calculated primarily for two goals: first underlining the potential savings from transitioning to natural gas (Figure 5.8). Second, examining what would be the theoretical reduction from a total transition to natural gas and its distribution across the twelve countries.

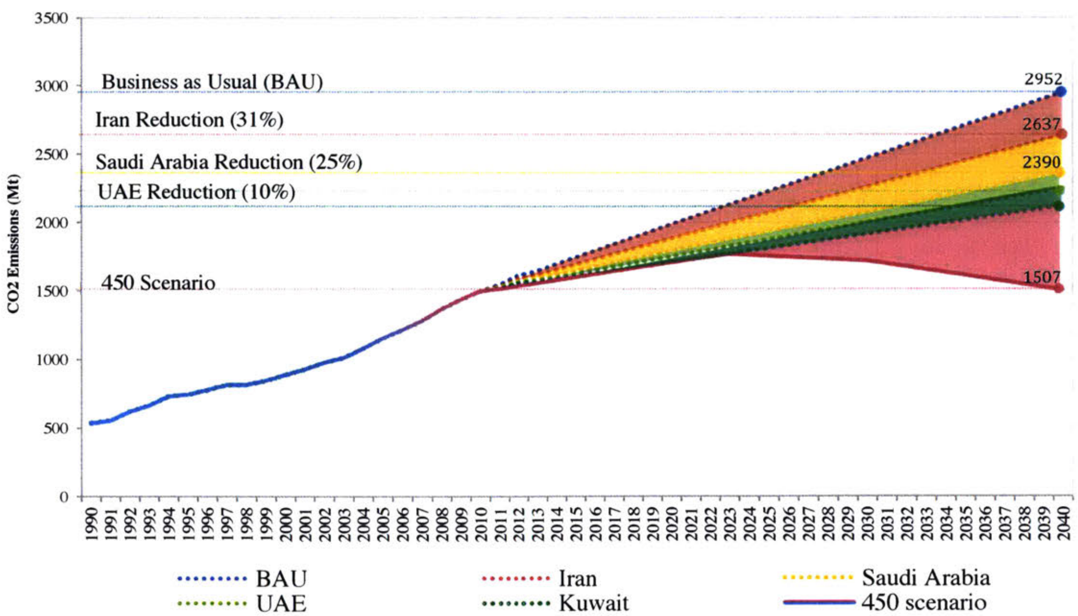


Figure 5.8: Emission reduction potentials by 2040. Iran and Saudi Arabia could save around 562 Mt by 2040 by switching to natural gas (Bayomi & Fernandez, 2017).

The level of uncertainty in the proposed scenario is considerable; however, the main purpose is to pinpoint which countries will contribute the most to the region's emission reductions scenarios. Changes in the underlying assumptions and levels of uncertainty would still influence the magnitude of the potential savings from these countries. Therefore, the main caveat from this analysis is to highlight that estimating emission-savings distribution equally, without taking into account the impact of individual countries' roles, would lead to impractical results. Thus, greater attention should be given to the implications of individual countries' contributions towards achieving regional targets.

Although the results from the transition to natural gas scenario seem a plausible way to save emissions, there are other variables to be considered to achieve this goal. First, it will place a far greater demand on natural gas and available reserves. Second, implications from the demand side in countries with large reliance on oil, such as Iraq, KSA and Kuwait. For these reasons, the following section examines how much of the total saving potential is possible under energy demand projections and available reserves in four "major emitters" countries: Iran, Saudi Arabia, UAE, and Kuwait. Iraq was excluded, mainly because of the political complications associated with the ISIS group taking over prime energy locations in the country.

5.5 Transitioning to Natural Gas Usage Scenario

To understand the potentials of switching to natural gas in the region, it is important to identify which countries have the largest natural gas reserves, and to predict their future demands. As previously discussed in chapter three, Iran, Saudi Arabia, Qatar and the UAE account for 91% of the region's total natural gas reserves (Figure 5.9). Iran tops the list with a total of 34 trillion m^3 available gas reserves (19.7% of world's total), followed by Saudi Arabia with 8.3 trillion m^3, and UAE with 6.1 trillion m^3 (British Petroleum, 2016). For Iraq, its total proven reserves are higher than Kuwait's, with 3.1 trillion m^3, while Kuwait has 1.8 trillion m^3.

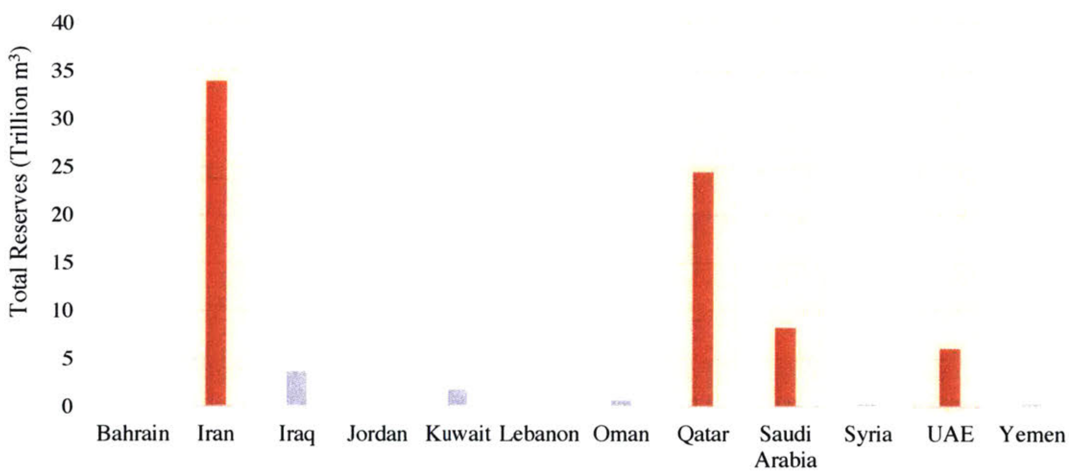


Figure 5.9: Natural gas reserves by country based on 2014 estimates. Iran, Qatar, Saudi Arabia and Iraq represent 82% of the total Middle Eastern available natural gas reserves.

It is observed that there is a large natural gas resource base across the Middle East, specifically within the "major emitters" group. This raises the question of, what are the possible impacts of growing energy demand on available reserves under natural gas-shift scenario. Thus, the following section examine future energy demand in the four "major emitters" countries.

5.5.1 Energy Demand Forecast Model

A regression model was developed to forecast total energy demand in the four "major emitters" mentioned above, with a forecast horizon of 2030. The use of regression models to forecast energy demand has been proven as an effective approach for predicting and analyzing energy requirements. Several studies have used regression models to forecast energy requirements in different contexts. Jannuzzi & Schipper (1991) used regression models to forecast residential sector electricity demand in Brazil. Also, a linear regression model based on population and per capita energy consumption was used to model and project electricity demand in Turkey (Asmaz, 2004; Tunça, Camadli, & Parmaksizoğluc, 2006). A further review of different energy demand forecast models can be found elsewhere (Jebaraj & Iniyan, 2006; Suganthi & Samuel, 2012; Worrell, Ramesohl, & Boyd, 2004).

The regression analysis presented here aims at establishing a relationship between a dependent variable and two or more independent variables (the forecasters). The aim is to forecast energy demand in the simplest way possible using a minimum number of variables. In formulating the projection model, economic indicators are considered, as energy demand is mainly driven by economic and population growth. So, GDP (G) and total population (P) are considered as the independent explanatory variables and energy demand as the dependent variable. To decide the suitability of these independent variables for prediction, the relationship between dependent and independent variables was tested with a simple linear regression analysis, using R^2 as the decision criterion. Results are summarized in Table 5.2 below.

Table 5.2: Coefficient of determination (R^2) between dependent and independent variables.

Iran

Variables	Coal	Oil	Ng	Demand	GDP	Pop.
Coal	1	0.42	0.08	**0.61**	0.12	0.14
Oil	0.42	1	0.52	**0.80**	0.62	0.67
Ng	0.08	0.52	1	**0.96**	0.67	0.82
Demand	0.61	0.80	0.96	1	**0.99**	**0.98**
GDP	0.12	0.62	0.67	0.99	1	0.95
Population	0.14	0.67	0.82	0.98	0.95	1

Saudi Arabia

Variables	Oil	Ng	Demand	GDP	Pop.
Oil	1	0.96	**0.99**	0.97	0.86
Ng	0.96	1	**0.97**	0.69	0.91
Demand	0.99	0.97	1	**0.98**	**0.95**
GDP	0.97	0.69	0.98	1	0.91
Population	0.86	0.91	0.95	0.91	1

UAE

	Coal	Oil	Ng	Demand	GDP	Pop.
Coal	1	0.76	0.76	**0.81**	0.56	0.61
Oil	0.76	1	0.75	**0.94**	0.81	0.90
Ng	0.76	0.75	1	**0.95**	0.66	0.88
Demand	0.81	0.94	0.95	1	**0.82**	**0.97**
GDP	0.56	0.81	0.66	0.82	1	0.84
Population	0.61	0.90	0.88	0.97	0.84	1

Kuwait

	Oil	Ng	Demand	GDP	Pop.
Oil	1	0.62	**0.96**	0.85	0.80
Ng	0.62	1	**0.87**	0.72	0.47
Demand	0.96	0.87	1	**0.91**	**0.77**
GDP	0.85	0.72	0.91	1	0.76
Population	0.80	0.47	0.77	0.76	1

From the results presented above, GDP and population were selected as the independent variables in the case of total energy demand forecast. This was also confirmed in the scatter plot matrix of the dependent variable (energy demand) and predictors (GDP and population) where linear regression is appropriate. Figure 5.10 below shows such matrices for the original data sets, where the scatter plot displays the linear relationship between the independent variables and the energy demand.

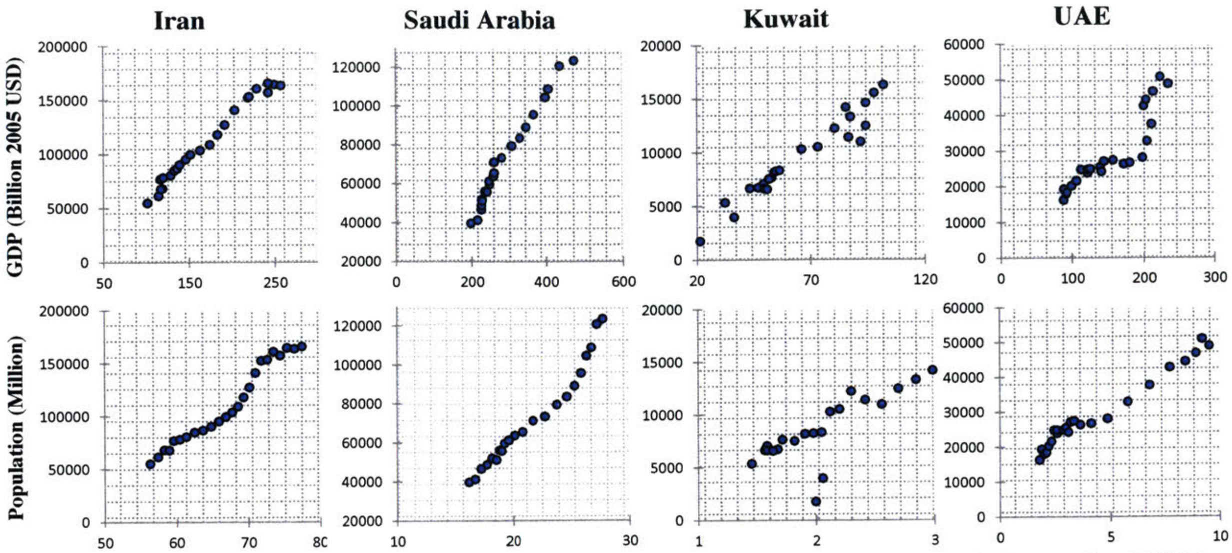


Figure 5.10: Scatter plots of energy demand with GDP and population data (Bayomi & Fernandez, 2017b).

On the other hand, it is observed that the R^2 values are much higher in the case between fuel type and total demand than in the case of GDP and population across the four countries. Thus, a second model is proposed to forecast different fuel demands using total energy demand as the independent variable. For these observations, two regression models are developed. First, a multivariable regression model was used to forecast total energy demand based on economic indicators, and a second simple regression model was used to forecast total demand of different fossil fuels (coal, oil and natural gas) based on total projected demand. Equation (2) presents the suggested multivariable regression model to project total demand:

$$E_t = \alpha + \beta_1 (G)_t + \beta_2 (P)_t + \varepsilon_t \qquad (2)$$

Where E is energy demand, β_0 is the regression model intercept, β_0 and β_1 represent regression coefficients for GDP and population, t represents year, and ε_t is the residual (or fitted error) which is the difference between projected and actual demand. In the second regression model, the demand of different fuels is considered as the dependent variable and total demand is the independent variable. Each fuel demand is projected separately, Equations 3, 4 and 5 represent the suggested linear regression model for coal, oil and natural gas demands, respectively.

$$E_i = \alpha + \beta(D)_t + \varepsilon_t \qquad (3)$$
$$E_j = \alpha + \beta(D)_t + \varepsilon_t \qquad (4)$$
$$E_k = \alpha + \beta(D)_t + \varepsilon_t \qquad (5)$$

Where E is energy demand, α is the regression model intercept, β represents regression coefficient for total demand, t represents year, i, j, and k represent oil, natural and coal demands respectively , and ε_t is the residual (or fitted error). To identify the appropriate model for projection, the ordinary least squares method is used in the two regression models. Data for total energy demand and demand of different fossil fuels are collected from IEA energy balance tables over the period 1990 to 2014.Population and GDP historical data are collected from the United Nation (UN) annual report over the same analysis period (United Nations, 2015). Future data for GDP and population are collected from International Monetary fund (IMF) and the UN 2030 projections (Heerman, 2014; United Nations, 2015).The regression analysis was performed using the software package XLSTAT. Projection here represents a "business-as-usual" scenario, which assumes that the energy sector will follow historical trends with no changes in the efficiency of consumption activities. Results of total demand and different fossil fuels are discussed in the following section.

5.5.2 Demand for Fossil Fuels

In light of the analysis that has been carried out, energy demand under BAU scenario is expected to experience vast growth rates in the next decade. This applies for the four countries of interest (Iran, Saudi Arabia, Kuwait and UAE) with fossil fuels dominating total demand. Based on BAU projection results, there is a strong, growing demand for natural gas that is expected to surge in the next decade. This can be clearly seen in countries that are largely reliant on oil in their primary energy supply, such as Iran and Saudi Arabia. Detailed results for each of the four countries are discussed as follows.

Iran

Energy demand in Iran has been rapidly increasing and this trend is projected to continue. Forecasting results suggest that total energy consumption will grow at an average annual rate of 4% over the period 2014-2030. Demand will grow faster from 2020 to 2030, at an annual rate of 5.0%, and reach almost 300 Mtoe (Figure 5.11-a). In addition, demand for natural gas is forecast to be the highest, growing an annual rate of 4.9% over the period 2014 to 2030. Under these forecasts, the natural gas demand share will grow from 60% in 2014 to 68% in 2030 (Figure 5.11-b). For oil, growth is slower. Over the forecast period, it will grow at an annual average rate of 2.8%, with its share dropping from 39% to 34% by 2030.

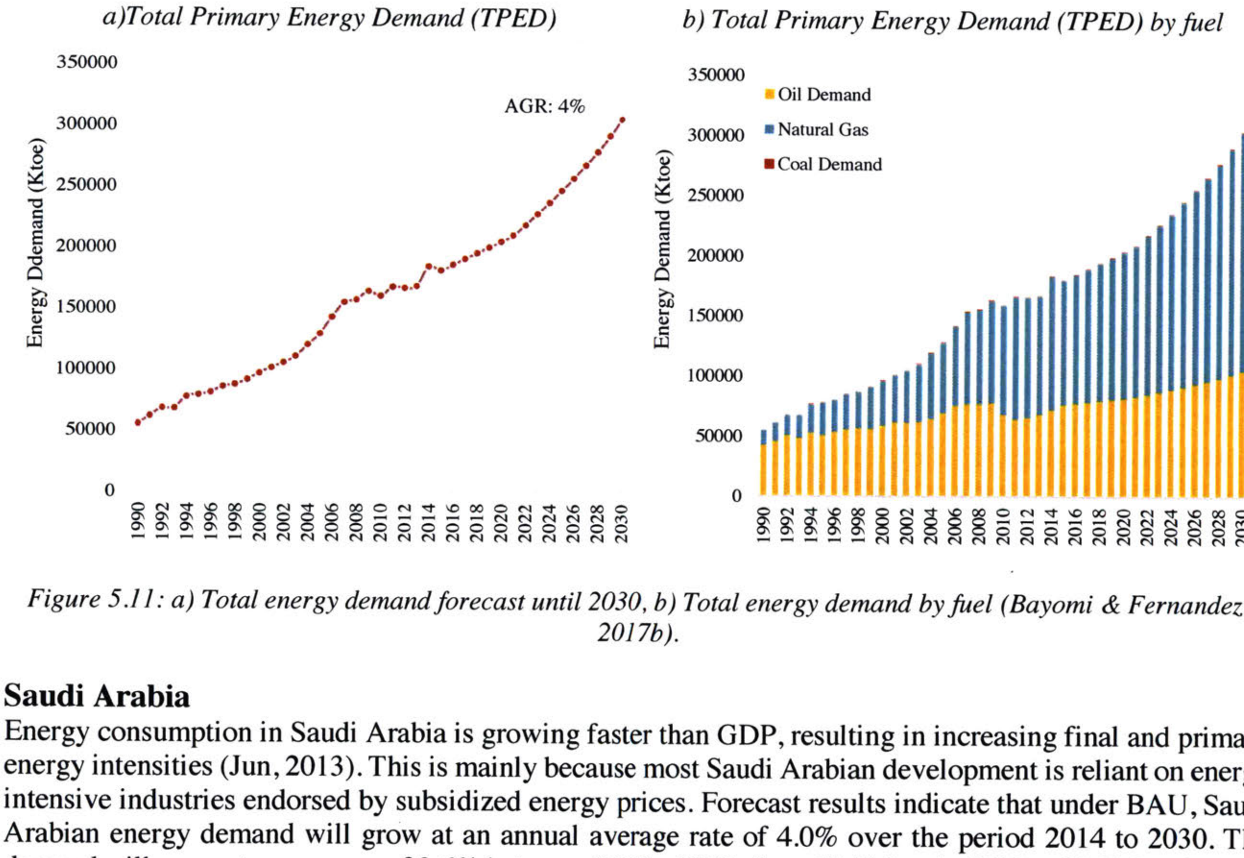


Figure 5.11: a) Total energy demand forecast until 2030, b) Total energy demand by fuel (Bayomi & Fernandez, 2017b).

Saudi Arabia

Energy consumption in Saudi Arabia is growing faster than GDP, resulting in increasing final and primary energy intensities (Jun, 2013). This is mainly because most Saudi Arabian development is reliant on energy intensive industries endorsed by subsidized energy prices. Forecast results indicate that under BAU, Saudi Arabian energy demand will grow at an annual average rate of 4.0% over the period 2014 to 2030. The demand will grow at an average of 3.6% between 2020—2030, from 174 Mtoe in 2020 to 236 Mtoe in 2030 (Figure 5.12-a). Growth in the demand of natural gas is forecast to occur at an annual average rate of 4.6%, while oil is forecast to grow at annual rate of 3.6%. This is mainly tied to the recent shift from oil to natural gas use for electricity generation. Under these forecasts, the share of natural gas in the total energy demand will increase from 29% in 2014 to 31% in 2030 (Figure 5.12-b). On the other hand, oil's share of projected demand will drop from 71% in 2014 to 69% in 2030.

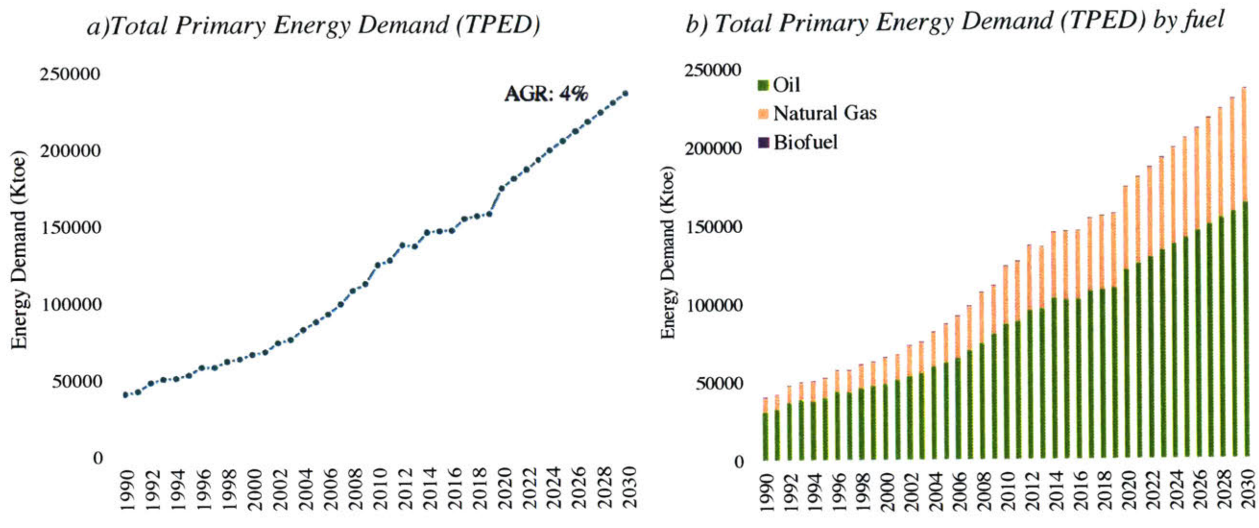


Figure 5.12: a) Total energy demand forecast until 2030, b) Total energy demand by fuel type (Bayomi & Fernandez, 2017b).

The UAE

Energy supply in the UAE is more reliant on natural gas than on oil. In 2014, natural gas accounted for 80% of the energy supply. Such heavy dependence on natural gas is linked to natural gas-fired power plants that dominate the electricity generation sector. Forecast results indicate the under BAU, UAE's energy demand will grow at an annual average rate of 4.2% over the period 2014 to 2030. The demand will grow at an average 3.3% between 2020 to 2030, growing from 59 Mtoe in 2020 to 79 Mtoe (Figure 5.13-a). Demand for natural gas is forecast to grow at an annual average rate of 4.4% over the period 2014 to 2030, while oil is forecast to grow at an annual rate of 2.2%. Under these forecasts, the share of natural gas in total energy demand will increase from 48% in 2014 to 70% in 2030 (Figure 5.13-b). On the other hand, the share of oil will drop from 31% in 2014 to 27% in 2030.

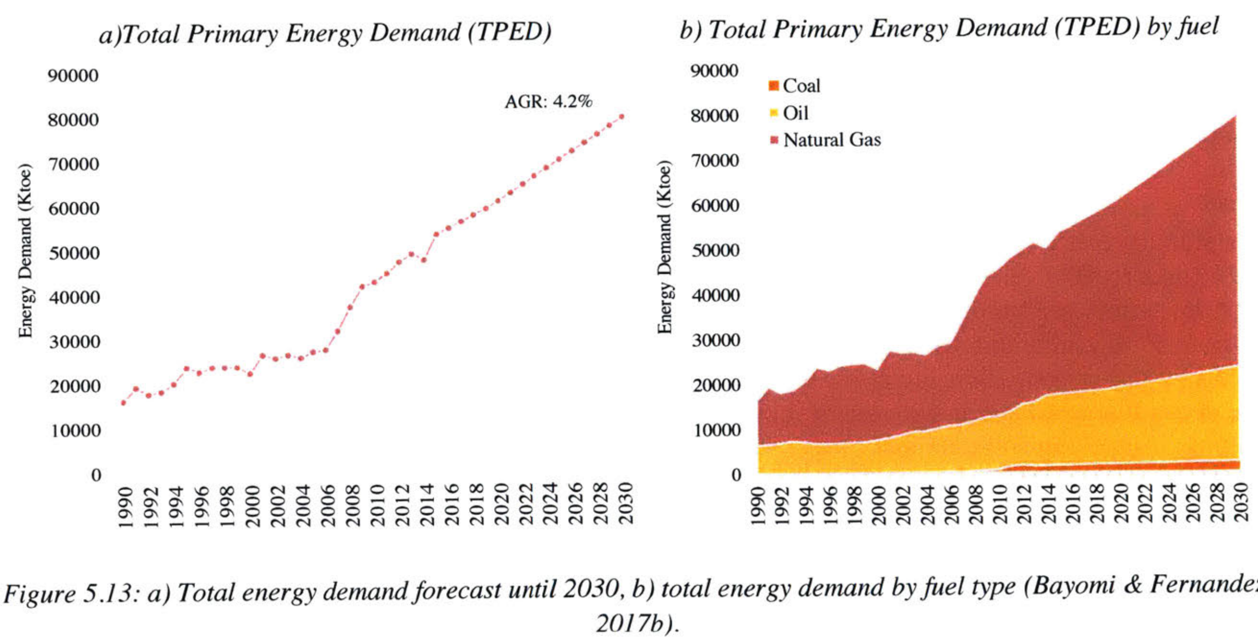


Figure 5.13: a) Total energy demand forecast until 2030, b) total energy demand by fuel type (Bayomi & Fernandez, 2017b).

Kuwait

Kuwait has been experiencing a rapid increase in electricity demand. Its peak load demand reached almost 14 GW in 2014 and is expected to grow to 24 GW in 2030 (Jandal, 2014). Forecast results indicate that under BAU, Kuwait's energy demand will grow at an annual average rate of 3.0% over the period 2014 to 2030. The demand will grow at an average 2.4% between 2020 to 2030, growing from 22 Mtoe in 2020 to 27 Mtoe (Figure 5.14-a). Growth in the demand of natural gas is forecast to grow at an annual average rate of 2.7% over the period 2014 to 2030, while oil is forecast to be the fastest, growing at an annual rate of 4.2%. This is mainly related to the heavy dependence on oil for electricity generation. Under these forecasts, the share of oil in the total energy demand will increase from 64% in 2014 to 67% in 2030 (Figure 5.14-b). The share of natural gas will drop from 36% in 2014 to 33% in 2030.

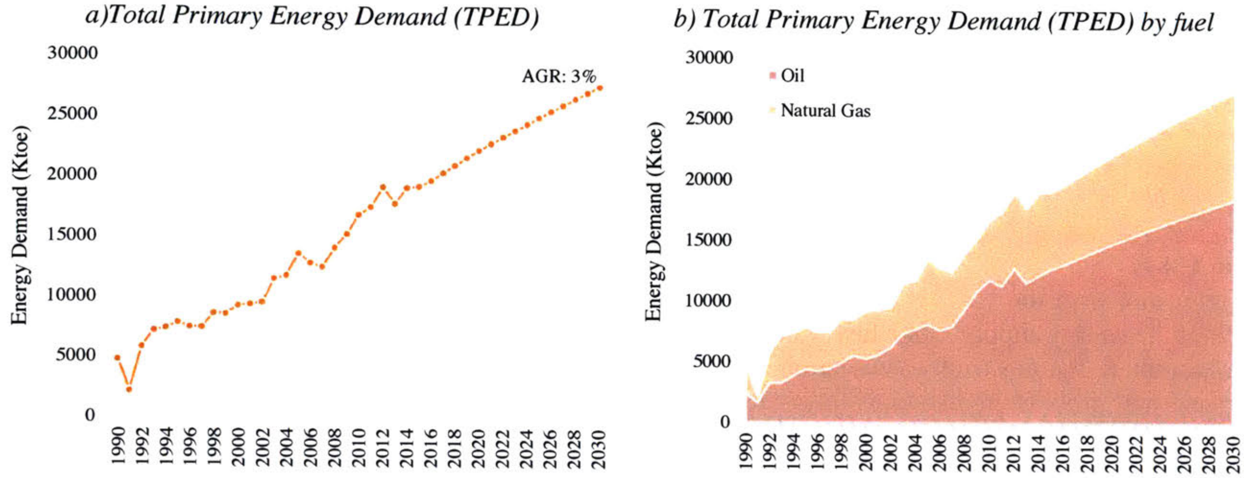


Figure 5.14: a) Total energy demand forecast until 2030, b) total energy demand by fuel type (Bayomi & Fernandez, 2017b).

5.5.3 Barriers to Natural Gas Shift

Results presented above indicate that transition to natural gas scenario will largely influence demand for oil as presented below in figure 5.15, causing supply gaps in Iran, Saudi Arabia and UAE. Discussion on the implications of this scenario for each country is presented in the following section.

Iran

For Iran to reduce its emission share, the country needs to increase the share of natural gas supply from 62% (under a BAU scenario) to 80% by 2030. Oil's share will be reduced from 34% to 20%. This means that the natural gas supply will be expected to grow at an annual average rate of 5% over the period from 2014 to 2030. Under this scenario, Iran will experience an oil supply gap of almost 37 Mtoe in 2030 (Figure 5.15-a). Furthermore, there are also supply-side issues associated with this scenario. Although Iran possess the second-largest natural gas reserve in the world, it only accounts for around 1% of international gas exports. Achieving full potential of its reserve will be a challenge over the near term for several reasons. First, there is the issue of expanding required infrastructure, as the country's gas production is located in the south, yet the bulk of gas demand is in the north (Mohamedi, 2015). Second, recent negative developments in Iran's relations with Arab states in the Persian Gulf may adversely affect Iran's plans for gas trade with those neighbors, and its ability to use their LNG facilities.

Saudi Arabia

Under the proposed emission saving scenario, Saudi Arabia needs to increase the share of natural gas from 35% (under a BAU scenario) to 60% by 2030. Oil's share, in that case, will be reduced from 65% to 40%.

This indicates that natural gas supply will be expected to grow at annual average rate of 12% over the period from 2014 to 2030, which is double the growth rate from 2004 to 2014. Under this scenario, there will be a gap in oil supply of almost 26 Mtoe (Figure 5.15-b). The rapid growth in gas supply will pose major challenges for the development of Saudi Arabia's energy sector. Although Saudi Arabia has the world's 5th-largest natural gas reserves, they only provide about 3% of global natural gas production (British Petroleum, 2016), which is much less than its oil production (13% of global production). In addition, the country consumes all the natural gas that it produces (in 2014, the country produced 69 Mtoe and consumed 67 Mtoe). This is mainly tied to inefficient gas consumption, where a large amount of natural gas is burned and used as feedstock in its petrochemical industry. However, recent gas developments indicate that Saudi Arabia might be on track to boost its gas production capacity. As country has recently initiated new gas exploration projects to reduce its reliance on crude oil for electricity generation (Al Omran, 2016).

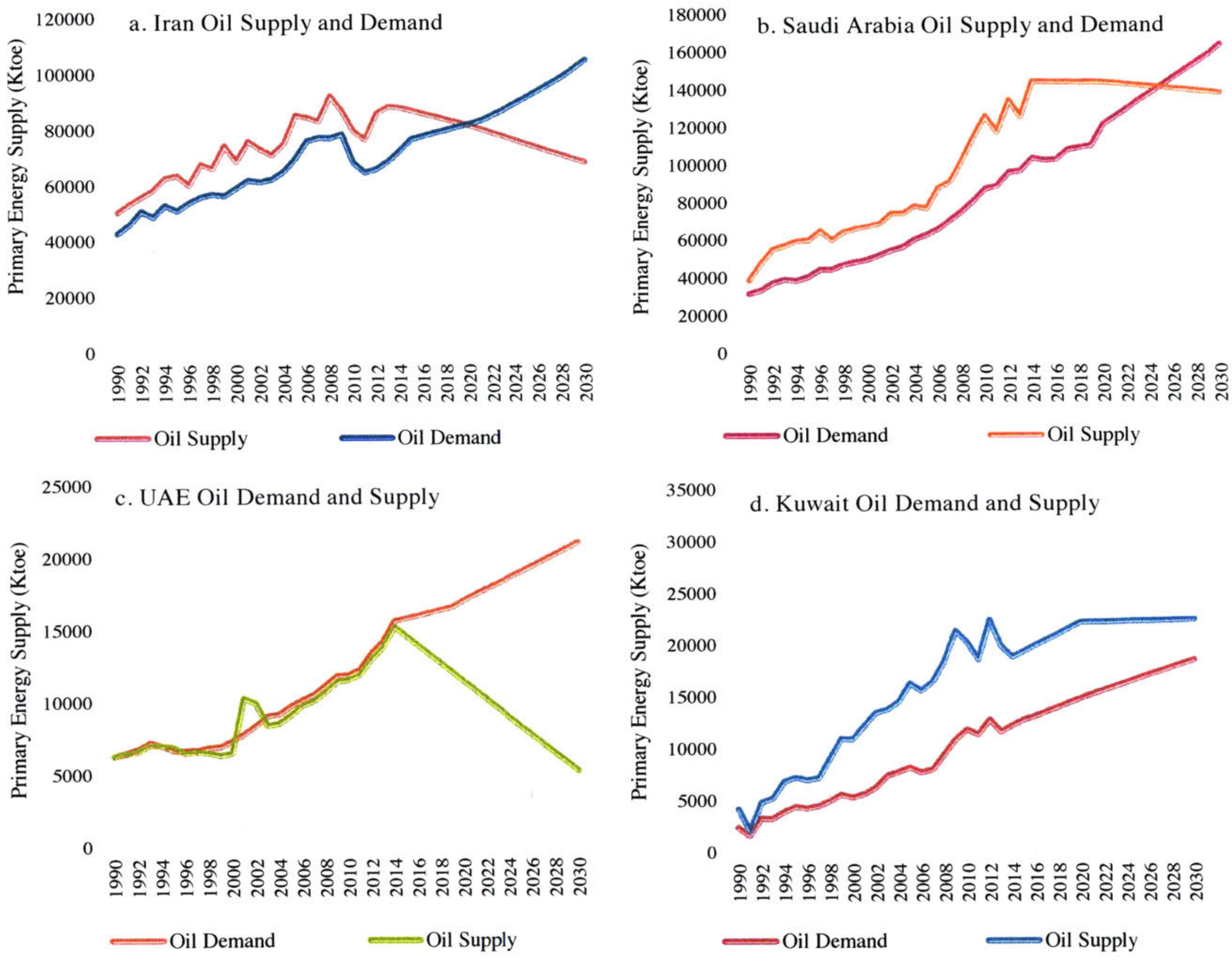


Figure 5.15: Oil supply and demand in four major emitting countries under a natural gas-shift scenario (Bayomi & Fernandez, 2017).

Kuwait

Kuwait has the sixth-most abundant natural gas reserves in the Middle East. However, as previously discussed in chapter three, the country's economy and energy system are heavily based on oil. For Kuwait to reduce its emission share, the country should increase its natural gas supply share from 36% (under a BAU scenario) to 60% by 2030. While the share of oil will be reduced from 64% to 40%. This means that natural gas supply will be expected to grow at annual average rate of 8% over the period from 2014 to 2030, which is four times higher than the growth rate projected under BAU. On the other hand, oil supply will grow at an average rate will be 1% annually instead of 5% under BAU. Although, no supply gap is identified (Figure 5.15-d), there are barriers that will hinder the transition. First, reliance on natural gas rather than oil will allow Kuwait to devote more of its oil production to export markets. Yet, it will largely affect its electricity generation sector that is largely based on oil. This will require huge investments in power generation technologies, especially under expected increase in per capita power consumption to grow from 17,000 kWh in 2011 to 20,000 kWh by 2020 (Raghu, 2016). Second, technical barrier with respect to natural gas production as the country currently extracts less than 1% of its natural gas reserves annually (Ansari, 2013). Finally, the government provides 7.6 billion dinar in subsidies for natural gas prices, equal to 5.8% of GDP, so more natural gas usage will put greater pressure on the national economy (Saleh & Ansari, 2013).

The UAE

For the UAE to reach its emission target, the country needs to increase its natural gas supply from 79% (under a BAU scenario) to 92% by 2030. As a result, the share of oil supply will be reduced from 18% to 5%. Moreover, natural gas supply will be expected to grow at annual average rate of 5.5% over the period from 2014 to 2030. With the projected oil demand, there will be a gap in oil supply of almost 16 Mtoe in 2030 (Figure 5.15-c). Natural gas is used to meet more than 90% of the UAE's power needs. Transitioning to natural gas will be a challenge for several reasons. First, UAE imports around 30% of its natural gas energy requirements from Qatar through the Dolphin pipeline (DiPaola, 2015). Therefore, increasing natural gas supply will put a large burden on natural gas imports. Second, most of the UAE's demand comes from Dubai, which has become more dependent on natural gas to fuel its growing economy, new industries and new power plants (Weems, Midani, & Dubai, 2009). Finally, the country has recently tried to secure gas supplies from Iran; however, due to issues related to pricing and political opposition, these attempts have not yet been fruitful.

5.6 Discussion

This chapter underlines the potential magnitude of individual countries' contribution to emission savings within the Middle Eastern region. Although this region contributes only 5% of global CO_2 emissions (IEA, 2014b), its heavy reliance on fossil fuels in its energy supply mix is a major hindrance to achieving the 2 degrees goal. Analysis presented in this chapter draws attention to the urgency of better understanding countries' roles in emissions increase. A better understanding of how individual countries contribute to emissions within a region is valuable for climate mitigation policies, where a wide range of considerations must come into play. To realize emission saving potentials within a region, different countries require different mitigation and reduction strategies. Analysis presented here estimated the potential emissions savings from transitioning to natural gas as an alternative energy source, given the region's large gas resource base, especially in countries like Iran and Saudi Arabia.

Emission savings from a natural gas-shift look promising based on the analysis presented; however, there are major challenges associated with this transition. After examining both supply and demand, it is clear that demand for natural gas has not been met by adequate exploration and infrastructure. In addition, the overall transition in the Middle East is challenged by a number of factors in the near-to-medium term. Table 5.3 highlights main barrier to natural gas shift facing the four major emitters discussed in this chapter. By looking at both supply and demand sides, it can be concluded that domestic gas supply has lagged behind growing demand. This is evident in cases like Iran and Saudi Arabia that have relatively modest production capacity. In addition, there is a gap between gas demand and sufficient investment in infrastructure, as illustrated in cases like Iran, Saudi Arabia and Kuwait. Inefficient natural gas consumption, spurred by subsidized domestic prices, are hindering the sustainable development of the region's energy systems and meeting of future demands. This requires a major reform in pricing policies alongside with introduction of efficiency measures related to energy-intensive activities.

Table 5.3: Major challenges facing "major emitters" countries in their transitions to natural gas (Bayomi & Fernandez, 2017).

	Iran	Saudi Arabia	UAE	Kuwait
Oil Consumption ***By Sector***	**Transport: 57%** Electricity: 7% Industry: 7% Buildings: 9% Others: 20%	**Transport: 42%** Electricity: 13% Industry: 21% Buildings: 6% Others: 18%	**Transport: 79%** Industry: 8%	**Transport: 36%** Electricity: 32% Industry: 7% Others: 25%
Natural Gas Consumption ***By Sector***	Electricity: 15% Industry: 29% **Household: 35%** Others: 21%	Electricity: 33% **Industry (including Petrochemical): 56%** Non-Energy Use: 11%	Electricity: 29% **Industry: 71%**	Electricity: 28% **Industry: 72%**
Energy Demand ***(2014)***	**Natural Gas: 61%** Oil: 39%	Natural Gas: 29% **Oil: 71%**	**Natural Gas: 48%** Oil: 32%	Natural Gas: 36% **Oil: 64%**
Power Generation	**Natural Gas: 71%** Oil: 22% Hydro: 6% Others: 1%	**Natural gas: 51%** Oil: 49%	**Natural gas: 98%** Oil: 2%	Natural gas: 36% **Oil: 66%**
Total Energy Demand AGR ***(2014-2030)***	**4%**	**4%**	**4.2%**	**3.0%**
Oil Demand AGR ***(2014-2030)***	**2.8%**	**3.6%**	**2.2%**	**4.2%**
Natural Gas Demand AGR ***(2014-2030)***	**4.9%**	**4.6%**	**4.4%**	**2.7%**
Supply Side	• **Iran contributes with only 1% of the total international gas exports.** • Building the necessary infrastructure. • Most gas production is located in the south yet most demand is in the north.	• **Saudi Arabia accounts for about 3% of world natural gas production.** • Much of Saudi Arabia's gas has a high sulfur content that requires an elaborate processing system.	• **UAE is mainly dependent on natural gas imports**, with a large share from Qatar. • Challenges in securing additional gas supplies from countries like Iran.	• **Kuwait extracts less than 1% of its natural gas reserves annually.** • Investments and infrastructure required to develop the country's non-associated natural gas fields is considered a challenge in the near term.
Demand Side	• The majority of power plants have low efficiency rates of 13%. • Using significant amounts of gas in the production of oil. • Subsidized gas prices.	• Natural gas is burned in half the kingdom's power plants and is used as feedstock in its petrochemical industry.	• Growing demand for natural gas, especially in the industry and power sectors.	Growing per capita electricity consumption, with most of the generation coming from oil.
Oil Supply Gap	**36.76 Mtoe in 2030**	**26 Mtoe in 2030**	**16 Mtoe in 2030**	-
Potentials	Iran has started to reform its energy subsidy system to increase the prices of domestic oil and natural gas.	Saudi Arabia has also committed around $10 billion to gas exploration and is focusing on deep-water areas of the Red Sea.	The UAE is aiming to increase building efficiency and water usage, which would affect future energy demand.	The country could secure additional gas imports by increasing its oil exports to the international market

Analysis presented here assumes no major changes in the geopolitical situation in the region, countries that are under political tension, such as Iraq, Syria and Yemen, should be taken into consideration when discussing the future of energy in the region. Another major challenge that should also be taken into account is the reduction in energy subsidies, especially in resource-rich countries. This could thwart attempts to attract renewable energy deployment and lead to delayed emissions reductions. With such delays, it will increase the likelihood of damage from climate change and pose more challenges to the future of energy use in the region. The analysis presented in this chapter will assist in understanding the country-level implications of emission savings efforts in the Middle Eastern region. This is a useful step to identify the basis of how individual countries can contribute to regional emissions goals. Finally, further research may explore renewable energy potential across the presented typologies to underline baseline trends for renewable energy technology deployment, in addition to estimating the energy demands of the water desalination sector, where more national assessment would be required.

References

Abdul-Hamid, O. S., & Bayer, C. (2016). *OPEC Annual Statistical Bulletin.*

Abu Dhabi Government. (2008). *The Abu Dhabi Economic Vision 2030.* Abu Dhabi, UAE.

Al-mulali, U. (2012). Factors Affecting CO2 Emission in The Middle East: A Panel Data Analysis. *Energy*, *44*(1), 564–569. http://doi.org/10.1016/j.energy.2012.05.045

Al Omran, A. (2016). Saudi Arabia Boosts Natural-Gas Output - WSJ. Retrieved August 28, 2016, from http://www.wsj.com/articles/saudi-arabia-boosts-natural-gas-output-1469036809?tesla=y

Ansari, M. (2013). *Kuwait Utilities Sector.* Kuwait, Kuwait.

Asmaz, E. (2004). Electric Energy Demand of Turkey for the Year 2050. *Energy Sources*, *26*(12), 1157–1164. http://doi.org/10.1080/00908310490441520

Bayomi, N., Fernandez, J. E. (2017). Can The Middle East Transition To Natural Gas Usage? A View from Four Major Emitters. *Energy, Under Review.*

Bayomi, N., Fernandez, J. E. (2017b). Trends of Energy Demand in the Middle East: A Sectoral Level Analysis. *International Journal of Energy Research, Under Review.*

British Petroleum. (2016). BP Statistical Review of World Energy, (June).

David Ramin, J. (2016). *Iranian-Saudi tensions: The Energy Dimension. European Policy Center.* Bruxelles, Belgium. Retrieved from http://www.epc.eu/documents/uploads/pub_6296_iranian-saudi_tensions.pdf

DiPaola, A. (2015). U.A.E. Sees Natural Gas Imports Surging on Demand, Minister Says. Retrieved June 8, 2016, from http://www.bloomberg.com/news/articles/2015-06-15/u-a-e-to-need-huge-natgas-imports-on-current-6-demand-growth

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of Population Growth. *Science*, *171*(3977), 1212–1217.

Heerman, K. (2014). USDA ERS - Projected Real Gross Domestic Product (GDP) and Growth Rates of GDP 2010-2030. Retrieved August 5, 2016, from http://www.ers.usda.gov/data-products/international-macroeconomic-data-set/documentation.aspx

IEA. (2014). *World Energy Outlook*. Paris, France. http://doi.org/10.1787/weo-2014-en

IEA. (2015). *Energy Balances of non-OECD Countries*. Paris, France.

International Energy Agency. (2012). *Iraq Energy Outlook*. Paris, France.

International Energy Agency. (2016). *Key World Energy Statistics*. Paris, France.

Jandal, S. Al. (2014). A New Approach for Promoting RE in The Arab Region. In *The 5th International Forum on Energy for Sustainable Development – ESCWA/ANME Workshop*.

Jannuzzi, G. D. M., & Schipper, L. (1991). The Structure of Electricity Demand In The Brazilian Household Sector. *Energy Policy*, *19*(9), 879–891.

Jebaraj, S., & Iniyan, S. (2006). A Review Of Energy Models. *Renewable and Sustainable Energy Reviews*, *10*, 281–311. http://doi.org/10.1016/j.rser.2004.09.004

Jun, H. (2013). Saudi Arabia's Domestic Energy Situation and Policy : Focusing on Its Power Sector. *Kyoto Bulletin of Islamic Area Studies*, *6*(March), 107–135.

Lotfalipour, M. R., Falahi, M. A., & Ashena, M. (2010). Economic Growth, CO2 Emissions, and Fossil Fuels Consumption In Iran. *Energy*, *35*(12), 5115–5120. http://doi.org/10.1016/j.energy.2010.08.004

Mohamedi, F. (2015). The Oil and Gas Industry _ The Iran Primer. Retrieved January 1, 2016, from http://iranprimer.usip.org/resource/oil-and-gas-industry

Niu, S., Ding, Y., Niu, Y., Li, Y., & Luo, G. (2011). Economic Growth, Energy Conservation And Emissions Reduction: A Comparative Analysis Based on Panel Data for 8 Asian-Pacific Countries. *Energy Policy*, *39*(4), 2121–2131. http://doi.org/10.1016/j.enpol.2011.02.003

Ozcan, B. (2013). The Nexus Between Carbon Emissions, Energy Consumption And Economic Growth In Middle East Countries: A Panel Data Analysis. *Energy Policy*, *62*, 1138–1147.

Raghu, M. R. (2016). *Kuwait Power: Altering the Fuel Mix*. Kuwait, Kuwait.

Raupach, M. R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J. G., Klepper, G., & Field, C. B. (2007). Global and Regional Drivers of Accelerating CO2 Emissions. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(24), 10288–10293.

Saidi, K., & Hammami, S. (2015). The Impact Of CO2 Emissions And Economic Growth On Energy Consumption In 58 Countries. *Energy Reports*, *1*, 62–70. http://doi.org/10.1016/j.egyr.2015.01.003

Saleh, M., & Ansari, A. (2013). Natural Gas Potential And Energy Use In The GCC. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, 24–40.

Suganthi, L., & Samuel, A. A. (2012). Energy models for demand forecasting: A review. *Renewable and Sustainable Energy Reviews*, *16*(2), 1223–1240. http://doi.org/10.1016/j.rser.2011.08.014

Tunça, M., Camadli, U., & Parmaksizoğluc, C. (2006). Comparison Of Turkey's Electrical Energy Consumption and Production With Some European Countries and Optimization of Future Electrical Power Supply Investments on Turkey. *Energy Policy*, *34*, 50–59. http://doi.org/10.1016/j.enpol.2004.04.027

United Nations. (2015). *World Population Prospects*. New York, U.S.

US Energy Information Administration. (2013). *Overview Of Oil and Natural Gas In The Eastern Mediterranean Region Geology* (Vol. 2013). Washingston, DC.

Weems, P. R., Midani, F., & Dubai, S. (2009). A Surprising Reality: Middle East Natural Gas Crunch. *The International Who's Who of Oil & Gas Lawyers*, 15–16. Retrieved from http://whoswholegal.com/news/article/12773/a-surprising-reality-middle-east-natural-gas-crunch

Worrell, E., Ramesohl, S., & Boyd, G. (2004). Advances in Energy Forecasting Models based on Engineering Economics. *Annual Review of Environmental Resources*, *29*, 345–381. http://doi.org/10.1146/annurev.energy.29.062403.102042

6. Optimization of Power Generation Mix under the 450-Pathway

This chapter presents the main methodology of portfolio optimization framework and results of the 450-power scenario. Results presented here are meant to describe possible pathways for emission reduction and not to predict the future electricity supply for the four countries of interest. Thus, these results are mainly directed towards analyzing if planned national strategies are sufficient enough to meet the goal of 2 degrees and which technologies will play the major role in the future generation mix to mitigate carbon emissions. Results from the analysis can assist power utilities in the Middle East region in the transition towards low-carbon electricity supply and underline the role of clean generation technologies in meeting emission goals and growing demands.

6.1 Optimal Deployment of Renewable Technologies: Previous Research

In the context of the four countries examined in the thesis, a number of studies have been conducted on the optimization of power generation mixes. In Iran, Aryanpur et al. (2015) modeled Iran's electricity supply system using MESSAGE integrated assessment model to assess the lowest-cost technologies options and investment requirements in case of large renewable deployment in electricity supply. The analysis focused on evaluating the impacts of carbon taxes and fuel prices on the utilization of renewable technologies. Also, Ranjan et al. (2015) developed a mathmatical model to simulate Saudi Arabia's electricity demand on a yearly basis to assess possible power scenario by 2050 based on economic viability of different renewable technologies and associated GHG emissions. Results from the study concluded that complete phase out of fuel subisidy is critical to renewable electricity production. In another study for Saudi Arabia's power sector (AlGarni et al., 2016), a multi-criteria decision making approach was used to assess the economic and environmental performance of different renewable technologies as potential alternatives for electricity generation. Results underlined that Solar (PV) technology and CSP are the most favorable technologies for large renewable deployment.

In Kuwait, Al Jandal et al. (2015) in collaboration with Kuwait Institute for Scientific Research (KISR) have developed a multi-sector power model (TIMES-VEDA Kuwait Power and Water model (KPW)) to investigate different scenario for power production that encompasses the cost effectiveness of fossil fuel switch and deployment of different RETs options. Results showed that renewable generation technologies represent a complimentary alternative for emission reduction and fuel savings, yet, the magnitude of their viability depends significantly on cost reduction projections of RETs. In the UAE, Mondal (2014) examined the UAE's power production sector using the MARKAL model, where he analyzed the impacts of different policies such as emission reduction constraints and subsidy minimization on the development of renewable technologies. Results concluded that diversifying power mix reduced domestic energy consumption, but increased the cumulative system cost. Also, Masdar institute developed a comprehensive mapping of renewable technology penetration to supply energy demand from different economic sectors (Sgouridis et al., 2016). Although the analysis was not restricted to power generation sector, results showed that with 25% of renewable generation, financial benefits are higher than conventional generation scenario. This in addition to 25% reduction in CO_2 emissions from fossil fuel combustions.

Although several studies have been conducted on the optimization of future power systems in the four countries presented here, limited work have been done to examine implications of planned renewable strategies on climate plans. Most of these studies address power optimization under a specified demand and emission target, but no work have been done to examine if current power strategies are adequate to meet emission goals. Thus, the focus is to examine if planned renewable strategies in these four countries are adequate to meet the emission goal of 450-pathway set for the Middle East. The key advantage of this analysis is to highlight the level of renewable deployment required to reach climate goal and understand gaps in current power strategies in accordance with national climate strategies.

6.2 Theoretical Methods

Transition to low-carbon power system will require major changes in energy policies, generation technologies and business strategies. Here, the focus is given to changes in generation technologies under specific climate goals. Four power scenarios are examined: Reference Scenario representing Business as Usual (BAU), National Strategy Scenario portraying renewable targets, 450-Scenario which highlight the optimal generation mix that satisfy climate goals and Deep Decarbonization Scenario that denote complete decarbonization in power generation and transition to clean and low-carbon technologies. The mean variance portfolio (MVP) framework for different assets is implemented with respect to new power generation technologies. Input variables are determined according to current and national power generation strategies. Here, the model captures the structure of both reference and national strategy power mixes to develop a set of generation options that meet emission goals and electricity demand in the year 2020 and 2030.

6.2.1 Power Generation Scenarios

Four scenarios are considered here to represent the likely development of future generation mix: Reference Scenario, National Strategy Scenario, 450-Scenario and Deep Decarbonization Scenario. The contribution of renewable generation in Reference Scenario and National Strategy Scenario are presented in table 6.1 below. The four scenarios are described as follows:

a. Reference Scenario: This scenario considers the base year 2010 as a representative of present and Business as Usual (BAU) mixes in the four countries. The BAU mix implies no changes in RETs' share, deployment of Carbon Capture CC technologies nor implementation of energy efficiency strategies. Examining this scenario is relevant to understand the implications of not pursuing planned power strategies and the continuation of current trends. The share of renewable generation in this mix is represented in table 6.1 below and the distribution of different conventional technologies is provided in section 6.2.2. In addition, data on emission rates and cost of different technologies are provided in section 6.3.

b. National Strategy Scenario: This scenario takes into account current power strategies where generation mixes captured in this scenario are based on established renewable targets for the year 2020 and 2030. The use of carbon capture technology (CC) will be also explored to estimate possible emission savings. For the UAE, the International Renewable Energy Agency (IRENA) REmap scenario is also considered alongside the national power strategy. Analyzing this scenario is important to understand differences between the two strategies and the 450-emission goal. The level of renewable deployment under these two scenarios is provided below in table 6.1.

c. Pathway for 450 Scenario: This scenario portrays portfolio developed using an optimization model for the least-cost and emission constraints that meet both demand and emission goal in 2020 and 2030. Generation mixes presented in this scenario underline possible alternations to push the contribution of power sector towards achieving climate targets. The method and optimization model to achieve this scenario are described in Section 6.2.3.

d. Decarbonization Scenario: This scenario represents a theoretical assumption of total phase out of conventional generation technologies to give an understanding on which technologies will have higher levels of penetration. The objective is to understand conditions of diversification, key technologies and implications for annual generation cost in case of low-carbon and zero-carbon emission power systems.

Technology choices are based on their total technical potentials as previously presented in chapter 4. The integration of nuclear power generation is assumed based on planned National Strategy targets. This scenario includes two pathways that vary across the four countries depending on their planned strategies: a) Decarbonization with nuclear and RETs deployment and b) 100% RETs deployment.

Table 6.1: Share of renewable technologies in Reference Scenario and National Strategy Scenario.

		Iran	Saudi Arabia	Kuwait	The UAE
Reference Scenario		5% RES 1 % Nuclear 94% fossil fuels (IEA, 2016; Iran's Ministry of Power, 2015)	100% Fossil fuels (IEA, 2016)	100% Fossil fuels (IEA, 2016)	100% Fossil fuels 2020: 100% Fossil fuels 2030: 3% RES 18% Nuclear 79% fossil fuels (IEA, 2016; IRENA, 2015c)
National Strategy	*2020*	10% RES 2% Nuclear 88% Fossil fuels (Dodd, 2015; Watson Farley & Williams, 2016)	2.5% RES 5% Nuclear 92.5% Fossil fuels (55% Natural Gas) (Fattouh & Sen, 2016; Kingdom of Saudi Arabia (KSA), 2016; Reuters, 2017)	5% RES 90% Fossil fuels (Oxford Business Group, 2016a; Rezaian, 2010)	24% RES 20% - 25% Nuclear 64% Fossil fuels (Follet, 2016; IRENA, 2015c; Mittal, 2015; World Nuclear Association, 2017b)
					REmap: 15% RES 20% Nuclear 65% Fossil Fuels IRENA REmap Scenario for the UAE (IRENA, 2015c)
	2030	15% RES 4% Nuclear 81% Fossil fuels (Iran-German Cooperation, 2009)	10% RES 10% Nuclear 80% (60% from Natural Gas) (Mahdi, 2016; World Nuclear Association, 2015)	15% RES 85% Fossil fuels *RECREE* (Saurabh, 2016)	30% RES 20% Nuclear 50% fossil Fuels (IRENA, 2015c; McAuley, 2016)
					REmap: 25% RES 20% Nuclear 55% Fossil Fuels IRENA REmap Scenario for the UAE (IRENA, 2015c)

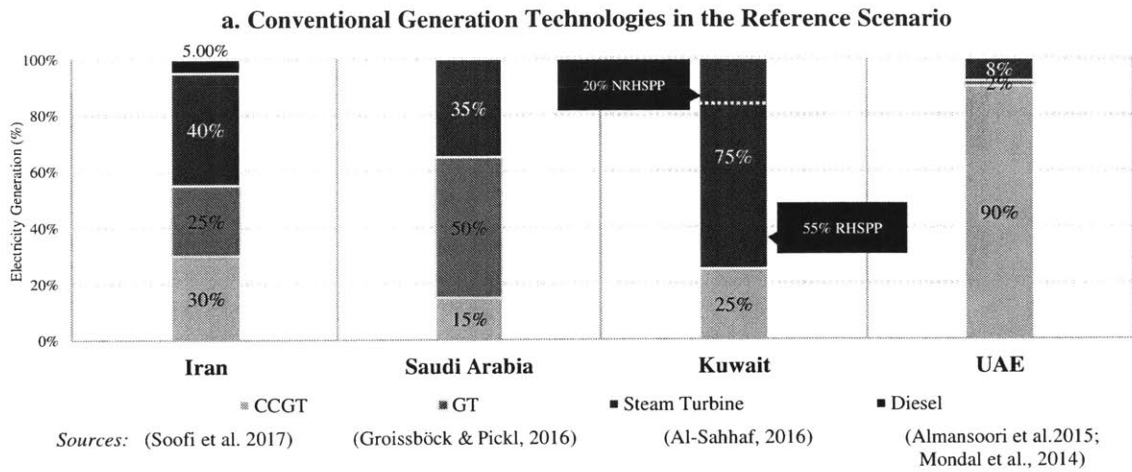
6.2.2 Technology Options

Technology options considered in model formulation vary across the four countries. Structure of different generation technologies is based on current generation mix (in the base year 2010) and national power strategies for 2020 and 2030. The set of technologies considered in the projection scenarios are as follows:

- Fossil fuels: Gas turbine, Combined Cycle Gas Turbine (CCGT), diesel generator and steam turbines[13] are the major representatives of fossil fuel technologies in electricity generation mix.
- Renewable technologies: Solar (Photovoltaic utility (PV) and Concentrated Solar Power (CSP) and Wind (Onshore) are the common technologies across the four countries. Other technologies vary depending on national strategies.
- Nuclear power is determined according to national strategies set by each country for 2020 and 2030.

Figure 6.1 summarizes technology mixes for base year 2010 and the Reference Scenarios and outlines renewable technologies implemented in the model.

[13] Steam turbine in Kuwait includes: Reheat steam power plant (RHSPP) and Non-reheat steam power plant (NRHSPP)



b. Renewable Generation Technologies

Nuclear	**Nuclear**		**Nuclear**
Solar PV	Solar PV	Solar PV	Solar PV
Solar CSP	Solar CSP	Solar CSP	Solar CSP
Wind	Wind	Wind	Wind
Geothermal	Geothermal		
Biomass	Waste to Energy		Waste to Energy
Hydro			

Figure 6.1: a) Share of electricity generation per technology in base year 2010 and in the Reference Scenario, b) Types of renewable technologies used in the four Scenarios.

Information on desalination facilities were challenging to find and sometime unavailable in some countries. Thus, the model is considered only with the development of power generation sector based on demand from different economic sectors. Possible impacts from electricity imports and exports are assumed to unlikely witness any development and so not taken into account.

6.2.3 Portfolio Optimization Model

The main scope of this thesis is to develop a low-carbon electricity generation mix that meets the goal of 2 degrees in 2020 and 2030. The emissions constraint is based on the share of power generation sector in total national emissions goals. The process of computing optimal portfolio mix will examine different generation scenarios where inputs are determined according to current and planned power strategies. Then, an optimization model is used to compute a new generation scenario portraying emissions target and lowest cost in 2020 and 2030. The aim of the optimization process is to determine the least-cost generation mix that satisfies electricity demand and meet emission targets of 2020 and 2030. Optimization process starts by examining current and planned power strategies with respect to the share of different generation technologies and their technical characteristics. The optimization model[14] used to quantify the optimal generation portfolio is computed as follows:

$$\underset{x_{it}\,\forall i,t}{\text{Minimize}}\ C_{pt} = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \sum_{i=1}^{N} c_{pt} \qquad (eq.1)$$

[14] Optimal portfolios are computed using an Excel tool provided by Trancik Lab, Institute for Data, Systems and Society (IDSS), Massachusetts Institute of Technology (Excel Optimization Tool). This tool was created to identify optimal portfolios interactively and understand their implications and impacts

Subject to

$x_{it} \leq z_{it}$, for all i and t – Technology resource constraint (1)

$\sum_{i=1}^{N} x_{it} = d_t$, for $t = 1, \dots, T$ – Energy demand constraint (2)

$\sum_{i=1}^{N} e_i x_{it} \leq E_t$, for $t = 1, \dots, T$ – Emissions constraint (3)

$x_{it} \geq 0$ for all i and t – non-negative consumption constraint (4)

Here, c_{pt} denotes the risk adjusted cost of portfolio p in year t, z_{it} represents maximum renewable resource availability in year t, x_{it} is the power quantity produced by technology i, d_t total demand in year t, e_i is the emission intensity of technology i, E_t is the emission constraint for year t and r is the discount rate. The risk-adjusted cost of portfolio p in year t is calculated using Markowitz's Mean-Variance Portfolio Theory as:

$$c_{pt} = E(c_{pt}) + \gamma\sigma_{pt}^2 \qquad (eq. 2)$$

Where $E(c_{pt})$ denotes the mean cost of the portfolio in year t, σ_{pt}^2 is the portfolio cost variance in year t and γ is the risk aversion parameter of the decision maker, where a risk aversion of a value of 1 is used. The annual cost of electricity generation is calculated as:

$$c_{pt} = \sum_{i=1}^{N} C_{it} x_{it} \qquad (eq. 3)$$

Where, c_{pt} is the total portfolio cost, N refers to technologies used in year t, C_{it} is the generation cost, x_{it} represents total electricity production from technology i.

The optimization procedure used to generate optimal portfolio is conducted on a two-stage sequential process. This is computed with respect to two main constraints: a) emission target set and b) electricity demand in target year. At the first stage, the model examines the capability of the portfolio generation mix to meet emission target. In this stage, low-carbon technologies substitute high- carbon intensive ones until emission target is met. The selection is based on a hierarchal process from lowest to highest emissions and it is repeated across all technologies until annual demand set is achieved.

The second stage optimizes the mix of technologies required to meet demand and emission constraints with lower cost. Here, the model first selects the cheapest technology until demand is met before moving to the second cheapest technology. If both demand and emission constraints are met, the process ends, otherwise optimization process keeps replacing technologies until the emission and demand are satisfied. By the end of the optimization process, the model generates a graphical representation of the share of individual technologies in annual electricity generation mix (MWh) that satisfy demand set. In addition, the annual cost electricity ($), expected capacity and emission achieved ($MtCO_2$ eq) in target year. The workflow of the optimization model is presented in figure 6.2 below.

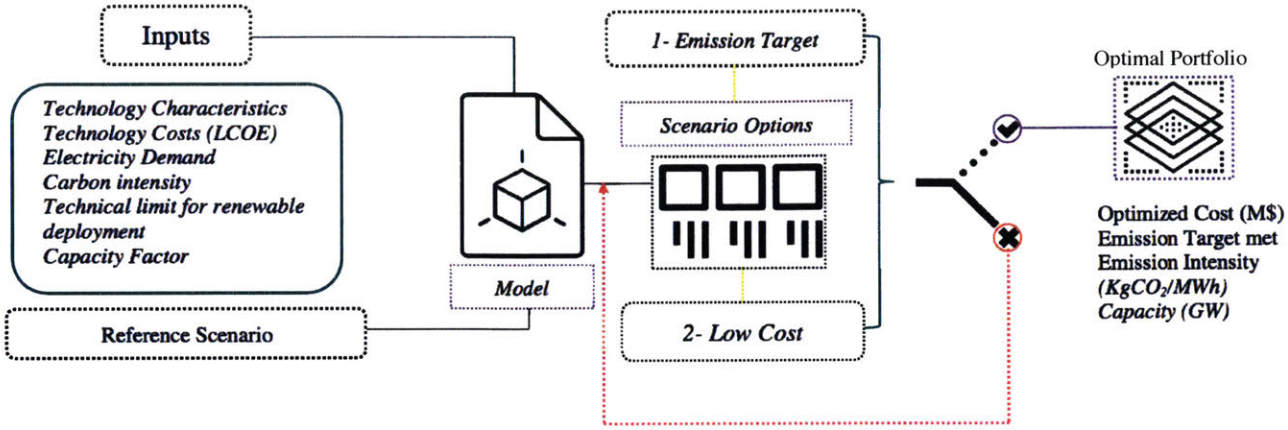


Figure 6.2: Workflow of the portfolio optimization model.

6.2.3.1 Mean Variance Portfolio Theory (MVP)

The Mean Variance Portfolio theory (MVP) is used to calculate the risk –adjusted cost presented in the model above. This section starts with a brief overview on the Mean Variance Portfolio theory, portfolio risk and its application in power planning. The theory of Mean Variance portfolio (MVP) is a financial framework, commonly applied by investors to maximize the portfolio assets under a set of uncertainties. The theory was first developed back in 1952 by economist Harry Markowitz to manage risks from financial portfolio assets through diversification. Where the total risk resulting from individual assets can be reduced. In this sense, efficient portfolios are those who have the largest return at a specified level of risk, or the ones with minimum achievable risk for a given return. (Markowitz, 1952). Where the expected return of portfolio $E(r_i)$ with N assets equals to the sum weighted average return (x_i) of asset (i) in the portfolio and expressed as follows:

$$E(r_i) = \sum_{i=1}^{N} X_i E(r_i)$$

As discussed by (Damodaran, 2001), determining an efficient portfolio of different assets should not only be based on the characteristics of individual components but also on the correlation between them that affects overall risk. Here the overall portfolio risk (σ_P) does not only include the standard deviation of different technologies but also the correlation coefficient between different technologies' costs. The overall portfolio risk used in equation 2 above is calculated as:

$$\sigma_P = \sqrt{\sum_{i=1}^{N} x_i^2 \sigma_i^2 + \sum_{i=1}^{N} \sum_{\substack{j=1 \\ i \neq j}}^{N} x_i x_j \rho_{ij} \sigma_i \sigma_j} \qquad (eq.4)$$

Here, the overall portfolio risk is determined by two key variables, the correlation (ρ_{ij}) and the covariance (σij) of individual technologies. The share of technology i and j is denoted as x_i and x_j with $i \neq j$, σ_i and σ_j are the standard deviation of the two technologies and ρ_{ij} is the correlation coefficient calculated by dividing the covariance by the standard deviation of i and j. Data on the correlation between different technologies and their covariance are provided in section 6.3.

The following section provides an overview on the application of mean variance theory in the field of power generation planning. Studies discussed below vary in their level of application from country level to cooperate level. Yet, they demonstrate the potentials of adapting a financial approach in solving power-planning problems.

6.2.3.2 Mean Variance Portfolio and Power Planning

Several works (Arnesano et al. 2012; Awerbuch & Berger, 2003; Escribano et al. 2013; Marreiro et al. 2013) have examined the application of mean variance portfolio (MVP) in the selection electricity generation portfolio. One of the pioneer applications was conducted by Bar-Lev and Katz (1976) to examine fossil fuel based technologies within the US electricity sector. The researchers found that electric utilities in the US are efficiently diversified yet they were characterized by a relatively high risk and return. In the context of renewable energy technologies, Awerbuch (2006) presented a comprehensive overview on the application of MVA in evaluating different renewable generation scenarios in Mexico, Europe and the US. His review concluded that expanding the share renewable technologies could improve overall portfolios in terms of risk and/or cost. Awerbuch also emphasized in another study that, although renewable technologies may entail higher levelized cost of electricity (LCOE) but they do not necessarily result in more expensive portfolios (Awerbuch 2006). Similar results were also reported in (Arnesano et al., 2012), where researchers concluded that increasing the investments in renewable technologies can lead to a reduction in total generation cost for the same level of risk. Furthermore, Zhu & Fan (2010) have analyzed China's 2020 planned generation portfolio, where they found that overall risk could be reduced by diversifying generation technologies. Further review on MVP application to energy planning can be found in (Bazilian et al. 2008).

6.2.4 Model Assumptions

The model discussed above uses current generation mixes as the Reference scenario. To understand emission implications of the four scenario discussed above, electricity demand is projected for 2020 and 2030 and provided in section in 6.3.3. Emission targets for the four countries are estimated based on their relative contribution in the 450-goal of the Middle East. Changes in generation mix reflected in the final optimal portfolio are defined by a number of assumptions include the following:

a. Base year is 2010 and quantified according to IEA (2016) and national annual reports.
b. Target year is 2020 and 2030.
c. Electricity demand is examined in 2010 and forecasted in 2020 and 2030.
d. Financial interest rate of 10% a year. This rate was found commonly used for governmental investments in UAE and Saudi Arabia (AlGarni et al., 2016; Mondal et al.,2014)
e. Technology costs and emission intensity are computed per unit of electricity generated (MWh).
f. The ratio between oil and natural gas in the fossil fuel share mix is assumed to be the same as 2010 except in Saudi Arabia, the 2030 energy vision is taken into account (KSA, 2016).
g. Emission target is based on the relative share of individual countries in the region's total 450-emission goal (IEA, 2016). Power-related emission goals are based on the average share of power sector in total emissions. Emission targets are summarized in table 6.2 below.

Table 6.2: Emission target for electricity generation sector by 2030.

	Emission Share	*Power-related emissions*	*Power emissions in 2010*	*Power emissions in 2020*	*Power emissions in 2030*
Iran	32%	31%	162	103	107
Saudi Arabia	29%	48%	230	142	147
Kuwait	5%	72%	55	37	38
The UAE	10%	42%	60	42	44

6.2.5 Uncertainties Considered

The focus of the thesis is given to the analysis and development of low-carbon power generation mix; this ultimately means comparison of different electricity generating technologies. The range of assumptions implemented in the optimization model are intended to develop the least-cost and lowest-emission technology portfolio that satisfies the target of 2020 and 2030. However, the construction of the future possible scenarios presented here are fraught with uncertainty with respect to renewable resources constraints, fluctuation of fossil fuel prices, dynamics of climate related policies, changes in energy efficiency and technology improvement. The scope of the thesis is directed towards the parameters of emission intensity where technologies differ and technology capabilities to meet power demands under specific emission constraints. Here, two sensitivity analysis are considered: a) a sensitivity analysis to changes in RETs costs, and b) sensitivity analysis to different discount rates. As the variation of these two parameters can potentially affect the level of renewable penetration portrayed in the 450-Scenario. Other sensitivity analyses will be implemented in future work but not within the scope of this thesis.

6.2.5.1 Sensitivity Analysis to RETs Costs

To understand the effect of changes in renewable technology costs, optimization procedures are recalculated to the 450-scenario mix under RETs cost projection. This analysis will be useful to understand how the share of different generation technologies and overall generation cost would change compared to National Strategy and Reference Scenario. Data on future costs of RETs are based on global average estimations and collected from International Energy Agency (IEA) (Khatib, 2016) and International Renewable Energy Agency (IRENA) (IRENA, 2014a).

6.2.5.2 Sensitivity Analysis to Discount Rates

The impact of different discount rates on total generation cost is examined, where sensitivity analysis is performed for three scenarios, Reference Scenario, National Strategy and the 450-scenario. The discount rate considered in the optimization model is equal to 10%, so here rates ranging from 5% to 15% are analyzed. In addition, a break-even analysis is performed for the three scenario at different discount rates.

6.3 Data Used

Across the scenarios presented above, a number of datasets is needed to model technologies inputs. These dataset reflects electricity demand, technology cost, emission intensity, technical potentials of different RETs. The following section presents data implemented in the formulation of the optimization model.

6.3.1 Electricity Demand

Forecasting electricity demand is a complex process that includes several factors such as economic expansion and population growth, technological improvement and changes in climatic conditions. Thus, here electricity demand is estimated based on annual growth rates projected in national energy strategies in accordance with expected installed capacity. Since electricity demand is a key determinant to establish power-generation scenarios, choosing to use growth rates that are consistent with governmental policies will provide a solid foundation to establish reasonable generation mixes.

6.3.1.1 Iran

Between 1980 and 2005, Iran's electricity demand has increased by almost 8.7 folds (Pourhossein et al., 2014). The average growth rate was reported to be around 5% annually that is almost 3.5% faster than GDP growth (Chandhoke & Kaur, 2015). Under this rapid demand, power capacity has increased by five folds, expanding from 13 GW in 1986 to 65 GW in 2011, growing at annual average of 6.7% (TAVANIR, 2014). The vast expansion in Iran's power capacity is directly resulting from the large deployment of combined cycle technology that has high capacity factor (Iran's Ministry of Power, 2016). According to Iran's sixth development plan, the country is planning to achieve an economic growth of 8% by 2021 at average annual rate of 2.5% (Khajehpour, 2016). The plan also includes an increased efficiency across all economic sectors including power demand. According to Iran Power Generation and Transmission Company (TAVANIR), long-term electricity demand is expected to increase by around 2.5% annually between 2016 and 2021(TAVANIR, 2014), with an expansion in power capacity to over 100 GW by 2030 (Chitchian, 2014). Accordingly, an average annual growth rate of 2.5% is used to project annual electricity demand by 2020 assuming this rate will also continue up to 2030. Under these assumptions, Iran's electricity demand is forecasted to increase from 260 TWh in 2014 to 290 TWh by 2020 and 346 TWh by 2030.

6.3.1.2 Saudi Arabia

Over the past ten years, electricity demand in Saudi Arabia has been growing at an average rate between 7% to 8% annually (ECRA, 2014). Rapid population growth and low electricity tariffs have greatly induced the rapid increase in electricity demand. Among the country's economic sectors, residential sector alone consumes about 50% of total electricity production (Jeddah Chamber, 2015), largely due to high air-conditioning requirements. Between 2004 and 2013, summer's peak demand in Saudi Arabia increased by almost 93%, growing from 28 GW to 54 GW, representing twice winter's demand (ECRA, 2014). According to King Abdullah City for Atomic and Renewable Energy (KA-CARE), electricity demand in Saudi Arabia is expected to grow at an average rate of 6% annually till 2032 with a capacity expanding from 62 GW in 2016 to 70 GW by 2020 and to over 120 GW by 2030-2032 (KA-CARE, 2015). By looking at the past 15 years, electricity demand in Saudi Arabia has almost doubled (McAuley, 2017), which implies that historical trends will be highly expected to continue within the next 15 years. Under these projections, an annual growth rate of 6% is used to forecast electricity demand in Saudi Arabia. Thus, annual electricity demand is projected to increase from 290 TWh in 2014 to 380 TWh by 2020 and 493 TWh by 2030.

6.3.1.3 Kuwait

Energy consumption per capita in Kuwait is considered among the highest worldwide (IEA, 2015e). Between 2000 and 2009, annual electricity demand per capita in Kuwait has increased at annual average rate of 6.8% outstripping population growth rate of 3.9% annually (Ramadhan & Naseeb, 2011). The large increase in electricity demand is strongly linked to increasing water desalination needs. As the country power sector consists of co-generation power-desalination plants (CPDP) that generate both electricity and drinking water, and 93% of water needs are supplied through seawater desalination (Alotaibi, 2011a). According to Kuwait's Electricity and Water minister, national electricity demand is expected to triple within the next 15 years, growing from 11.6 GW in 2008 to reach over 30 GW by 2030 (KISR, 2016). Projections of Kuwait's Ministry of Electricity and Water (MEW) indicate that electricity demand would increase from 55 TWh in 2012 to reach around 146 TWh in 2030 (Yessian et al., 2013). Accordingly, projections from MEW are used as an estimation for Kuwait's annual demand. Same projections were also reported in the study of Kuwait Institute for Scientific Research (KISR) (Jandal & Sayegh, 2015). Under these projections, annual electricity demand in Kuwait is estimated to reach 106 TWh in 2020 and 146 TWh in 2030.

6.3.1.4 UAE

Over the past decade, electricity demand in the UAE increased by around 8.8% annually, growing from 79.5 TWh in 2000 to 90.6 TWh in 2009 (Mokri, Aal Ali, & Emziane, 2013b). Escalation in power needs is significantly driven by population growth and vast economic expansion that are projected to continue over the next twenty years. Projections indicate that the UAE's GDP is expected to triple with a population increase of 40% by 2030 (Malek, 2016). Under these projections, the government predicts a larger expansion in economic infrastructure and energy needs especially in the power sector. Currently, the UAE's installed capacity is 26 GW and the government expects an annual increase of 9% to exceed 40 GW by 2020 and reach over 60 GW in 2030 (Gulf Business, 2015; John, 2017). Through the literature, no governmental scenario is yet established to describe expected power demands. So, here the recent study of Masdar Institute is used to represent expected power needs in 2020 and 2030. The reason for that is the study provides a comprehensive analysis of expected energy requirements in addition to a sectoral projection of power demand in 2030 (Sgouridis et al., 2016c). Electricity demand in 2020 is projected accordingly and validated with the study of (Mondal, et al., 2014). Under these assumptions, electricity demand in the UAE is expected to grow from 100 TWh in 2013 to 196 TWh by 2020 and 234 TWh by 2030.

The section outlined the estimated values of electricity demand and the rationale behind their assumptions. Projections from other studies within the four countries are collected to underline how estimated projections differs from other studies. Table 6.3 presents electricity demand forecasts from different literature sources and the thesis's estimated values to be used in the optimization model.

Table 6.3: Reported electricity demand forecasts from different literature and estimated demand values.

	2020 Demand	*2030 Demand*	*Literature reference*
Iran	274	359	(Ataei et al., 2015)
	280	378	(Aryanpur et al., 2015)
	400	520	(Al-Saleh et al., 2008)
	260	**364**	***Estimation***
Saudi Arabia	320	383 by 2025	(Mansouri et al., 2013)
	360	500	(Parajuli et al., 2015)
	380	**493**	***Estimation***
Kuwait		146	(Yessian et al., 2013)
	106	146	(Jandal & Sayegh, 2015)
	106	**146**	***Estimation***
The UAE	196	334	(Mondal et al., 2014a)
	170	250	(Sgouridis, Griffiths, Kennedy, Khalid, & Zurita, 2013b)
	196	**234**	(Sgouridis et al., 2016c)

6.3.2 Levelized cost of Electricity

According to the International Energy Agency (IEA), the levelized cost of electricity (LCOE) is the average price that is paid back to investor for the cost of operation and maintenance, capital investment and fuel prices with a rate of return equal to the discount rate (IEA, 2015c). The LCOE considers the costs and lifetime of generated energy to determine the unit cost per electricity generated ($/MWh). This method has been widely used to assess the cost-effectiveness of electricity generation technologies (Short et al.1995). For any given technology, the assessment of the LCOE is based on a set of techno-economic variables that includes: construction time, plant life, capital cost, operation and maintenance cost, discount rate and load factor (Gross et al. 2010).

In order to estimate the LCOE of different technologies, techno-economic characteristics are collected from different sources: the International Energy Agency Report (2015c), International Renewable Energy Agency (IRENA), National Renewable Energy Laboratory (NREL) (Tidball et al. 2010) and U.S. Energy Information Administration (EIA) (EIA, 2011). Middle East's specific data on nuclear are unavailable, therefore data from IRENA's Rethinking Energy publication are used in this context (IRENA, 2014b, 2015c). Additional variables like intermittent generation costs and emission costs are not included in the analysis. Fossil fuel prices are based on the global average price of large gas producing countries like Canada and the US. Here, the LCOE is estimated by the following formula:

$$LCOE = \frac{\sum_{n}^{nf} (VarCost_n + FixedCost_n) \times CRF}{\sum_{n}^{nf} Output_n \times CRF}$$

Where the variable costs at year n include: capital cost, fixed operation, maintenance cost (O&M) and variable (O&M) cost in dollars per kWh at year (n). CRF refers to the capital recovery factor using an interest rate of (i) in year (n) and expressed as follows:

$$CRF = \frac{i \times (1+i)^{n}}{(1+i)^{n-1}}$$

Electricity output is calculated based on available capacity in year n (capacity*load factor*8760). Where, load factor represents the ratio of electricity generated by a plant and the annual theoretical production (8760 hours). Electricity production from RETs is estimated according to their conversion efficiency factors. Yet, it must be noted that capacity factors largely depend on geographical location and technical capacity. For wind, a capacity factor of 30% that is close to values reported in Jordan and Morocco is used as reported by (Boccard, 2009). Solar (PV) is assumed at 19% that was found commonly used by (Jandal et al., 2015; Sgouridis et al., 2016) in the Middle East context. Capacity factor for solar (CSP) is found ranging from 8% to 25% (Hang, Jun, Xiao, & Junkui, 2008) , so here a capacity factor of 20% is assumed as reported in (Jandal et al., 2015). Capacity factors for conventional generation technologies vary across the four countries. For Saudi Arabia, capacity factors are based on values described in Electricity & Cogeneration regulatory Authority (ECRA) annual report (ECRA, 2004; ECRA, 2006). Likewise, values for Kuwait are obtained from (Jandal et al., 2015), the UAE (Sgouridis et al., 2016; Sgouridis et al., 2013) and Iran (TAVANIR, 2014). Technical and economic parameters used to estimate LCOE for different technologies are specified in table 6.4 below.

Table 6.4: Techno-economic characteristics of electricity technologies and calculated LCOE. Data are collected from (median case in IEA, 2010, 2015; Tidball[a] et al., 2010).

	Technology	Capital Cost ($/kW)	Fixed O&M ($/kW)	Variable O&M ($/MWh)	Heat Rate[a] (BTU/kWh)	Plant factor (%)	Lifetime (Years)	Construction time (Years)	Unit size (MW)
Fossil Fuel Technology	Steam power plant	1100	9.4	0.48	9000	32-35	30	5	325
	Gas Turbine (GT)	550	4.4	0.64	10450	40	12	2	162
	Combined cycle (CCGT)	760	4.3	0.41	6870	55	30	5	480
	Diesel Generator	550	3.7	0.74	7450	70	10	1	–
	IGCC	3700	148	0	9000	80	40	4	700
Nuclear	*LWR*	4800	92	0.5	10400	80	40	8	1000
	ALWR	5800	69	0.46	10400	80	60	8	1000
Renewables	Solar photovoltaic	5000	50	0	–	19	25	1	–
	Solar CSP	5700	64	0	–	19-22	25	2	–
	Geothermal	5500	84	9.6	–	80	30	6	–
	Small hydropower	2000	14	0	–	50	40	4	–
	Large hydropower	1500	10.8	2.43	–	20-30	50	6	–
	Wind turbine (onshore)	1500	48	0	–	30	20	2	–
	Biomass combustion	2800	60	4	14500	85	25	2	–

Fuel costs for renewable technologies (solar, wind, geothermal and hydro) are zero, while LCOE of fossil fuels and nuclear technologies are sensitive to changes in their fuel costs. Thus, in the analysis, it is assumed fuel prices are stable for the matter of simplicity; however, the sensitivity of prices fluctuation should be noted. Previous studies (Tidball et al., 2010) have shown that changes in fuel costs have a larger impact on LCOE values in fossil fuel technologies. The sensitivity analysis conducted in the study has indicated that an increase of 10% in the cost of natural gas led to an increase of 7% to 8% in technologies' costs. On the contrary, in coal power plants and biomass, there was an increase of about 2% to 4% due to a 10% increase in fuel cost. Thus, sensitivity to fuel prices fluctuation will have a huge impact on future generation mixes, especially when optimizing for lowest-cost technologies. Since the scope is restricted to the electricity generation sector and achieving emission targets, fuel prices are assumed stable following the values of 2010. Table 6.5 presents the costs of fuel implemented in LCOE calculations per MWh.

Table 6.5: Fuel costs in base year 2010 ($/MWh). Based on data from (a-IEA, 2010; b-IEA ETSAP, 2010; c- U.S. Energy Information, 2013).

	Oil [c]	Natural Gas [c]	Coal [c]	Diesel [c]	Nuclear [a] (incl. waste management cost)	Biomass [b] (Lignocellulosic)
Prices	10.04	4.39	3.30	12.4	1.1	3.6

6.3.3 Risk and Correlation

The application of technology risks in mean variance optimization portfolio is derived from the work of (Awerbuch et al. 2008) to determine efficient European electricity generation mix. Technology risk is defined as "the standard deviations of the holding-period returns based on historical data for each cost component" (Awerbuch et al. 2008), where standard deviation is expressed as percentage. This is useful to highlight the impacts of fuel prices fluctuation on generation costs. Here same approach is used with a focus given to fuel prices to estimate the standard deviation of fossil fuel technologies using International Energy Agency (IEA) database of fossil fuel prices. This will allow calculating annual variability in technologies cost stream, to highlight differences between technologies attributable to different fuels used in non-renewable technologies. On the other hand, renewable technologies will have zero fuel cost. Dataset on renewable technologies in the Middle East is based on (IRENA, 2014b). Due to data limitation on renewable technologies' LCOE in the Middle East, analysis is restricted to the period of 2010 to 2016.

Figure 6.3 below presents the levelized costs and technology risks for twelve electricity generation technologies used across the four countries in cost–risk space. Where, technology cost ($/MWh) is presented on the vertical axis and technology risk is on the horizontal axis (percentage). It can be clearly identified that there are two distinct grouping of renewable technologies that range from 60 to 100 $/MWh, with risk between 5% and 10%. This group includes Nuclear, Biomass, Onshore Wind, Hydropower and Geothermal. The other group is for non-renewable technologies with generation cost ranging from 50 to 100$/MWh, with risk between 30% and 40%. This group includes Steam, Integrated Gasification Combined Cycle (IGCC) and Combined Cycle Gas Turbine (CCGT).

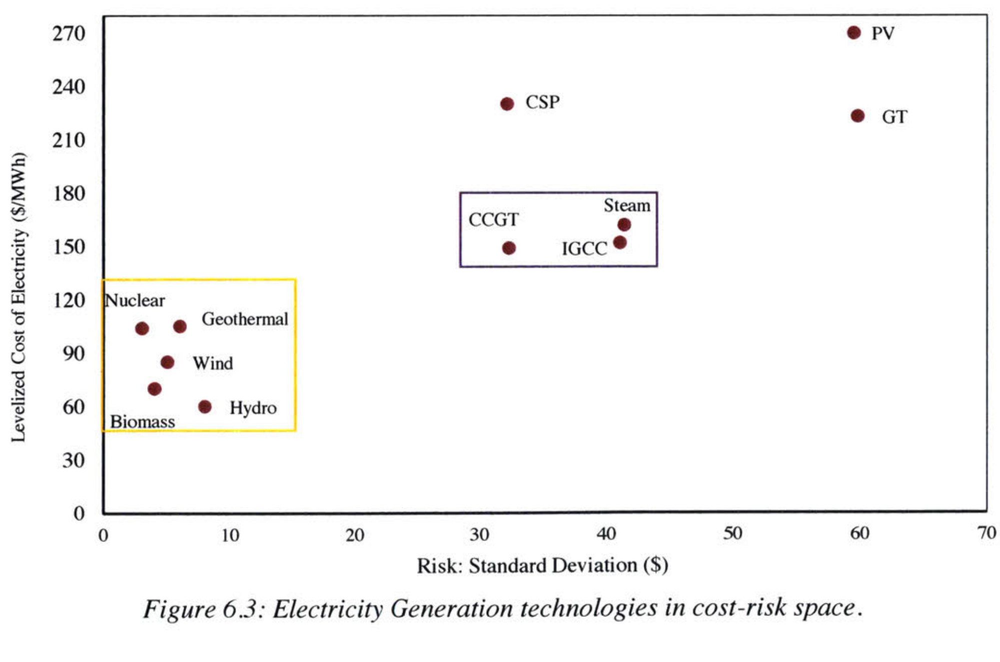


Figure 6.3: Electricity Generation technologies in cost-risk space.

The second step after risk estimation is to determine the correlation between different technologies' cost. Here, levelized cost of electricity (LCOE) is used as a representative of technologies' total cost. Table 6.6 outlines correlation between different generation technologies, where the correlation matrix is symmetric about the diagonal. As shown in table 6.6, correlation coefficient values of (-1) indicate negative correlation relationship and (1) refers to positive correlation. Positive correlation reflects that the two cost values are moving in the same direction, while negative correlation indicate that the two costs are moving in opposite directions. It can be identified that correlation coefficient between non-renewable generation technologies are generally positive due to upward trend in fuel prices between 2010 and 2013. On the other hand, there is a negative correlation mostly between nuclear and renewable power technologies. This is explained by the dropping costs of RETs against the relatively stable cost of nuclear power. The sensitivity of the correlation assumptions here is considered, however it is not taken into account in the scope of the analysis.

Table 6.6: LCOE Correlation between different generation technologies.

	Steam	**GT**	**CCGT**	**Diesel**	**IGCC**	*Nuclear*	*PV*	*CSP*	*Wind*	*Geothermal*	*Bio-mass*
Steam	1	0.88	0.99	0.81	0.52	0.43	0.35	0.35	0.35	0.35	-0.35
GT	0.88	1	0.89	0.99	0.69	0.29	0.59	0.59	0.59	0.59	-0.59
CCGT	0.99	0.89	1	0.82	0.50	0.51	0.31	0.31	0.31	0.31	-0.31
Diesel	0.81	0.99	0.82	1	0.73	0.18	0.68	0.68	0.68	0.68	-0.68
IGCC	0.52	0.69	0.50	0.73	1	-0.09	0.91	0.91	0.91	0.91	-0.91
Nuclear	0.43	0.29	0.51	0.18	-0.09	1	-0.46	-0.46	-0.46	-0.46	0.46
PV	0.35	0.59	0.31	0.68	0.91	-0.46	1	0.98	0.91	0.95	0.92
CSP	0.35	0.59	0.31	0.68	0.91	-0.46	0.98	1	0.98	0.91	0.96
Wind	0.35	0.59	0.31	0.68	0.91	-0.46	0.91	0.98	1	0.96	0.94
Geothermal	0.35	0.59	0.31	0.68	0.91	-0.46	0.95	0.91	0.96	1	0.96
Biomass	-0.35	-0.59	-0.31	-0.68	-0.91	0.46	0.92	0.96	0.94	0.96	1

6.3.4 Technical Potentials of Renewable Technologies

The availability of renewable resources across the four countries has been discussed in detail in chapter 4. Here, the technical potential of RETs is based on the average yielded energy with which national potentials can be exploited. Several studies have discussed renewable resources availability across the four countries, and it has been found that solar and wind energy are the game changers when it comes to large renewable deployment (Alnaser et al., 2011; Griffiths, 2013). On the other hand, smaller and limited potentials are reported for geothermal and biomass energy alongside with technical and economic barriers for large geothermal deployment (Taleb, 2009). Table 6.7 summarizes RETs' energy potentials based on resources availability in the four countries of interest.

Table 6.7: Renewable technologies resources availability based on their technical potentials. Technical potential represents the average yielded energy with which the national potential can be exploited.

Potential (kWh/m²/year)	**Iran**	**Saudi Arabia**	**Kuwait**	**UAE**
Solar PV	2010 [a]	2130 [a]	1900 [b]	2360 [a]
Solar CSP	2200 [d]	2200 [a]	2100 [b]	2200 [a]
Wind	781 [c]	570 [b,c]	225 [a]	120 [c]
Geothermal	113 TWh [b]	70.9 TWh [b,c]	–	–
Biomass	194 TWh [b]	3.0 Mtoe [b,c]	–	$7.5*10^6$ GJ [b]
Area (Km^2) (Alnaser et al. 2011)	1,648,000	2,240,000	17,818	77,700
Land Area (Trading Economics, 2017; World Bank, 2016)	Uninhabited flat area: 35% Arable land: 11% Urbanized: 7%	Uninhabited flat area: > 50% of total land area Arable land: 80.6%	Uninhabited area: around 50% Arable Land: 0.6%	Uninhabited area: 66% Arable Land: 0.61%
Data Sources	(**a.** Atabi, 2004; **b.** Moshiri, 2015; **c.**Mostafaeipour 2014; **d.**Samimi, 1994)	(**a.** Alawaji, 2001;**b.** Alnaser et al. 2011; **c.** Said et al. 2004)	(**a.** Al-Nassar, et al. 2005; **b.** DLR, 2005)	(**a.** Alnaser et al. 2011; **b.** DLR, 2005; **c.** Janajreh et al. 2013)

6.3.5 CO_2 Emissions Module

There are two main factors governing CO_2 emission intensity (emission rate per electricity generated) of different generation technologies. First, the amount of emissions depends on the type of fuel consumed to generate electricity (MWh/year) and second, the corresponding emission factors in g CO_2/MWh. Here, data for different fuel emission factors are obtained from the Intergovernmental Panel on Climate Change (IPCC) (Gómez et al., 2006). Typically, thermal coal, oil and diesel are considered the most carbon-intensive compared to natural gas. Biomass combustion is considered a carbon-neutral and therefore emission factor is assumed zero (IEA ETSAP, 2010). Table 6.8 below presents emission factors given for different fuel types.

Table 6.8: CO_2 emission factors (g CO_2/MJ). Based on data from (Gómez et al., 2006).

Emission Factor	**Oil**	**Natural Gas**	**Coal**	**Diesel**	**Biomass (Lignocellulosic)**
	77.6	**56.2**	**95.6**	**74.4**	**0.0**

In addition, conversion efficiency is another determinant of the overall CO_2 emission per electricity generated (Gómez et al., 2006). Whenever available, data on carbon emissions per MWh in the four countries were used. Otherwise, standard electric conversion factors are used to calculate the amount of emissions from different generation technologies. Emission rates for RETs are based on international values since no fuel consumption is involved (Edenhofer et al., 2012; Müller et al., 2011). Electricity conversion factor and total carbon intensity of different technologies are provided in table 6.9.

Table 6.9: Conversion efficiency, fuel types and emission rates for different generation technologies. Data are collected from (Edenhofer et al. 2012; Iran's Ministry of Power, 2015; Müller et al. 2011).

	Technology	Conversion Efficiency (%)	Fuel Type	Emission rate[15] (kg CO_2/MWh)
Fossil Fuel Technology	Steam power plant	41.2	Fuel oil – Natural Gas	628
	Gas Turbine (GT)	34.3–38.9	Diesel – Natural Gas	782
	Combined cycle (CCGT)	50–58	Diesel – Natural Gas	487
	Diesel Generator	33	Diesel	743
	IGCC	35.3	Coal	790
Nuclear	*LWR*	31	Uranium	16
	ALWR	33	Uranium	16
Renewables	Solar photovoltaic	12-15[16]	–	70
	Solar CSP	21[17]	–	22
	Geothermal	15-16	–	122
	Large hydropower	90[18]	–	18
	Wind turbine (onshore)	26	–	40
	Biomass combustion	30	Biomass (Lignocellulosic)	67

6.4 Results

This section begins by presenting associated emissions of individual countries generation profile under both Reference and National Strategy scenarios and then outlines results from portfolio optimization model. The total carbon emissions (Mt of CO_2/year) are compared to the 450-goal to highlight required reductions in 2020 and 2030. From figure 6.4 below, it can be observed that the characteristics of generations mix in the four countries embrace the use of non-renewable technologies, which have resulted in an emission gap even under the National Strategy scenario. In Iran, National Strategy mix deviates from emission target by around 60 Mt in 2020 and around 70 Mt in 2030. Although the UAE has the most ambitious target among the four, the country need to save around 15 Mt and 20 Mt of power-related emissions in 2020 and 2030 respectively. Saudi Arabia that is more dependent on oil-based generation technologies will need to save about 60 Mt in 2020 and 70 Mt in 2030 to meet the goal of 450. The estimation of emission gaps presented above highlights how far planned policies from reaching the 450-emission goal. The following section, presents results for low-carbon driven scenario that could balance mitigation needs while ensuring security of electricity supply.

---

[15] *Emission rate* represent the base case, country-specific rates are estimated based on fuel inputs.

[16] *Efficiency* is based on commercial available modules

[17] *Conversion efficiency* is reported based on a standard solar conditions of 1,000 W/m^2 (EIA, 2011)

[18] *Conversion efficiency* is based on large-scale Hydroelectric plant (US department of the Interior Bureau of Reclamation Power Resources office, 2005).

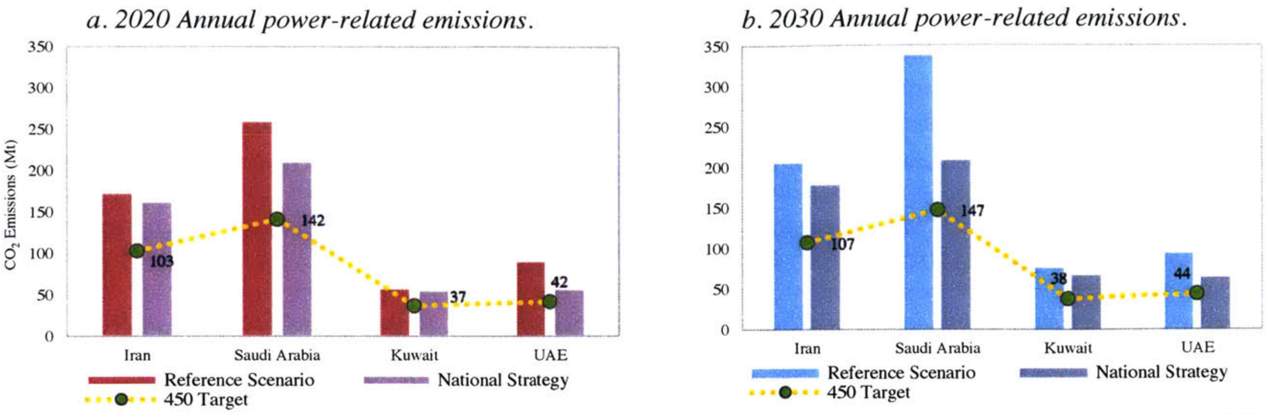


Figure 6.4: Emission profile of electricity generation mix under Reference Scenario, National Strategy and the 450-goal.

6.4.1 Iran

The Iranian government has set a target of 5 GW of renewable installed capacity that would roughly account for 10% of total electricity generation by 2020 and additional 2.5 GW by 2030 (Lindner, 2017; Farley & Williams, 2016). Figure 6.5 illustrates renewable technology deployment in 2020 and 2030 according to National Strategy Scenario. Hydropower and wind technology account for almost 95% of the renewable build-up in 2020 and 2030 with most of renewable generation coming from hydropower (figure 6.5-a).

National Strategy Scenario

Under National Strategy Scenario, total electricity-related emissions are higher than 450-emission goal by about 58% in 2020 and 66% in 2030 (figure 6.5-b). However, with the introduction of carbon capture technology (CC), power-related emissions decreased significantly even further below the 450-emission goal. On the other hand, annual generation cost almost doubled in both 2020 and 2030 relative to without CC deployment. In the view of such possibility, Iran could meet the 450-emission goal with planned national strategy, but with nearly double the annual generation cost.

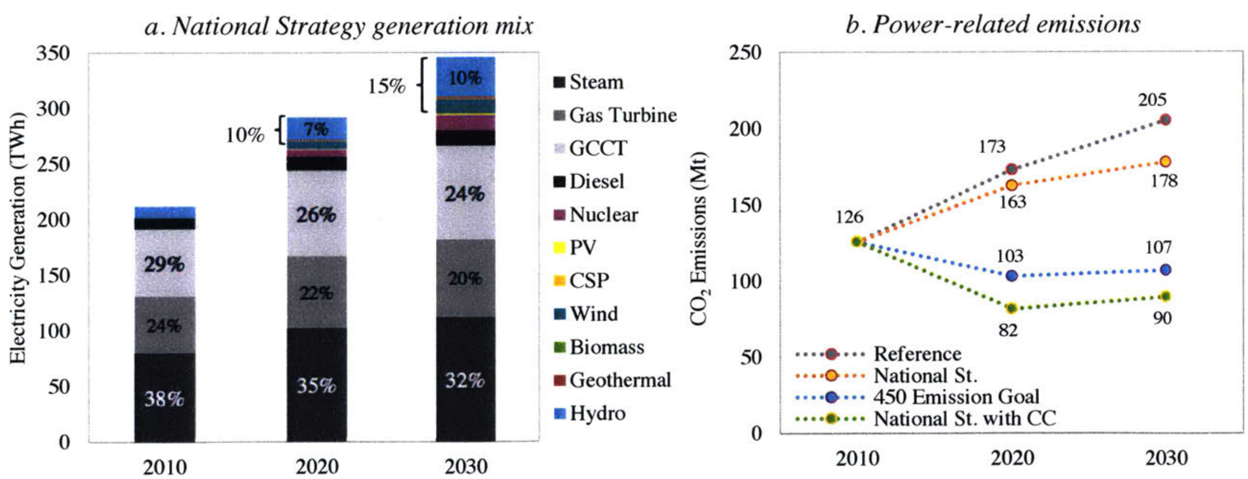


Figure 6.5: a) Electricity generation mix under National Strategy scenario, b) Power-related emissions across different scenarios relative to 450-emission pathway.

450-Scenario

The 450-Scenario model was solved under the constraints of projected installed renewable capacities, with an assumption of 20% relaxed constraints for wind and solar technologies based on deployment potentials reported in (Najafi et al., 2015; REVE, 2016). The breakdown of RETs, in particular wind power, solar photovoltaic (PV), concentrated solar power (CSP) and biomass is based on their resource availability as presented in chapter 4. It was concluded from literature review that wind deployment in Iran has a great potential for larger penetration (Hosseini et al., 2013; Mohammadnejad et al., 2011). Also, that maximum range of installed wind capacity acceptable in the model is assumed based on potential investment 30 GW (Rostami, 2015). Capacity factors and conversion efficiency of conventional and hydropower technologies is based on value reported by Iran's Ministry of Power annual report (TAVANIR, 2014) and the study of (Mazandarani et al., 2011). The deployment scale of renewable technologies in National scenarios and the 450-Scenario is contrasted in figure 6.6-a.

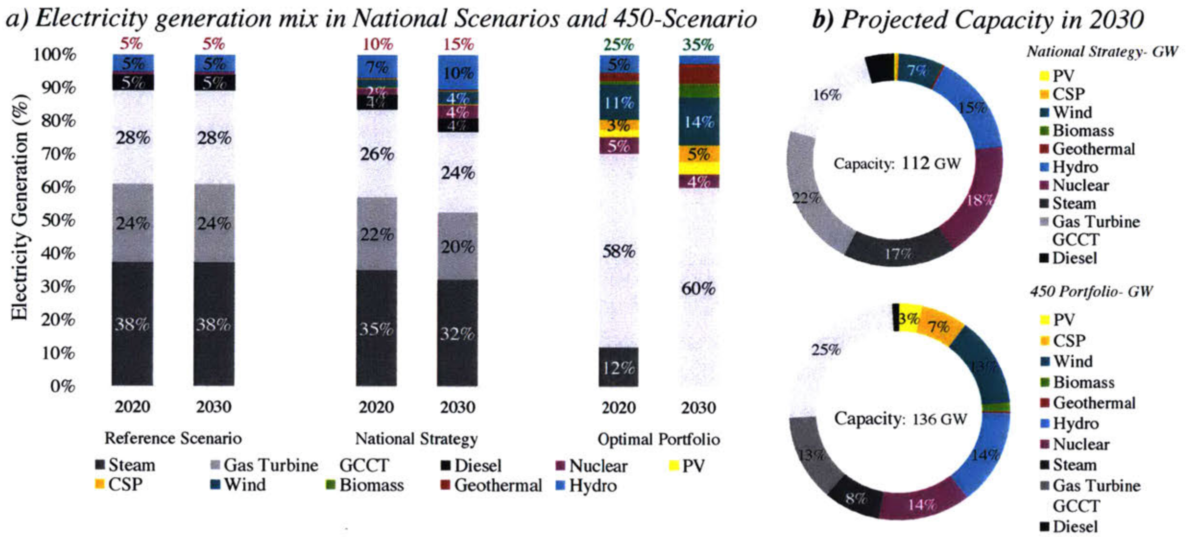


Figure 6.6: a) Generation mix across National scenarios and 450-Portfolio, b) 450- Portfolio power capacity in 2030 relative to National Scenario.

While in the Reference Scenario almost 5% of total generation is coming from RETs, mainly hydropower and small share from wind, in the 450-Scenario, the share of renewable generation increases to 25% in 2020 and to 35% in 2030. Wind and hydropower collectively are making up 74% and 70% of total renewable generation in 2020 and 2030 respectively. Figure 6.6-b additionally illustrates the implications for generation capacity compared to National Strategy Scenario in 2030. Notably, solar PV increase from 0.5 GW to 8.0 GW and CSP jumps from 1 GW to 14 GW. In addition, 20% of natural gas-fired turbines are offset entirely by dispatchable CSP. Hydropower capacity decrease from 17 GW to 14 GW in 2030 and wind expands to 31 GW. Geothermal capacity is consistent with National Strategy Scenario and biomass increases from 0.1 GW to 1 GW.

Deep Decarbonization Scenario

Iran Deep Decarbonization Scenario is divided into two possible pathways: a) 100 % generation from nuclear and RETs, and b) 100% generation from RETs. In the nuclear-RE mix, aggressive transition starts by 2020 with only 20% of CCGT technology and 26% nuclear power (figure 6.7). By 2025 phase out is assumed to start up until 2030 to reach 100% from nuclear and renewable technologies with solar and wind accounting for 39% of total 2030 build-up. In the 100% RETs mix, aggressive transition is assumed by 2020 using CCGT and nuclear power as part of the mix, then full transition to renewable by 2025 (figure 6.7-a). In the Deep Decarbonization scenario, the large share of CSP deployment is linked to its ability to replace gas-fired technologies.

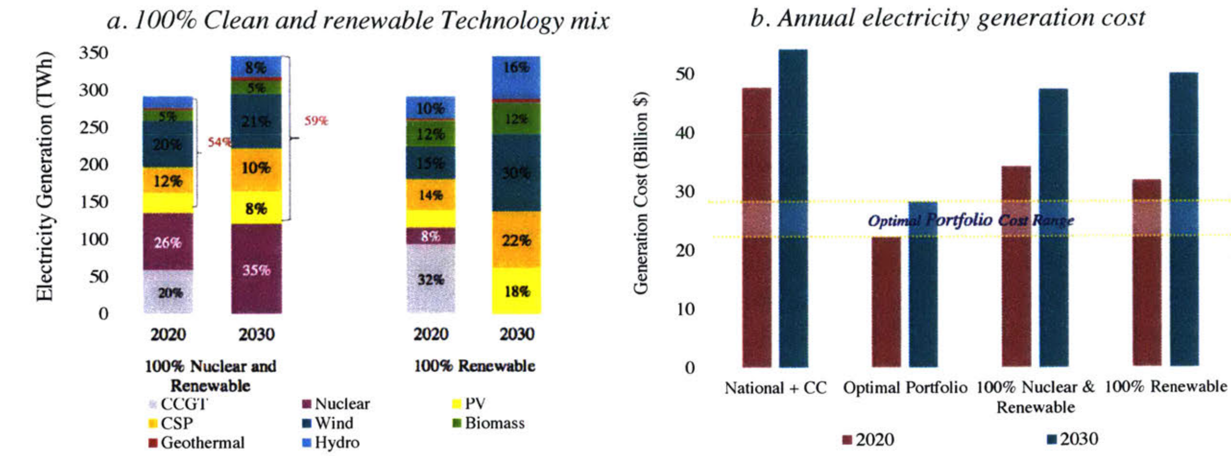


Figure 6.7: a) Electricity mix under Deep Decarbonization scenario, b) Annual electricity generation costs compared to the 450-Scenario.

Results presented above indicate the large contribution of wind and solar power in Iran's energy future. Although 100% renewable power system might seem very ambitious for a growing economy like Iran; however, results from a recent study showed that it could be a real policy option (Aghahosseini et al., 2016). The study underlined that wind and solar power are considered the most economical energy options with a potential of 50% less cost compared to new nuclear power capacity or conventional power technologies with carbon capture deployment.

Sensitivity to RETs Costs

Future costs of renewable technologies could have an impact on optimal share of different RE technologies. The sensitivity analysis shows an increase in the share of CSP and wind, with an increase of cumulative renewable generation to 36% as illustrated in figure 6.8-a below .The magnitude of annual generation costs shows also a variation across different portfolios. Yet, the 450-Scenario could provide an economic alternative compared to Reference and National Strategy scenarios with a further reduction under changes in RETs' costs as depicted in figure 6.8-b.

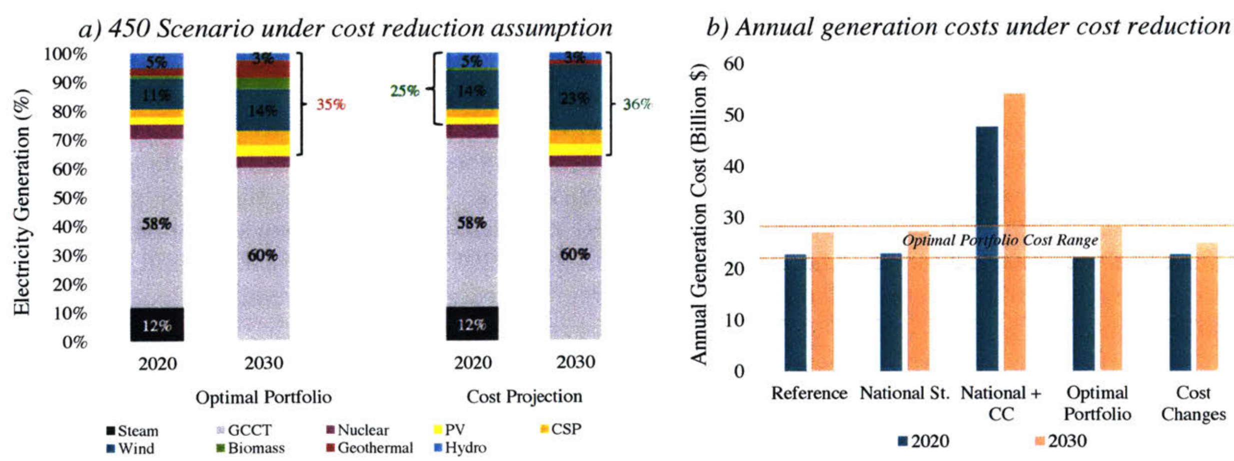


Figure 6.8: a) 450-Scenario in case of future cost reduction compared to base-case cost, b) Annual electricity generation cost across national scenarios and 450- optimal portfolio under future RETs' cost.

Sensitivity to Discount Rates

Results from sensitivity analysis showed that, in 2020, at discount rates of 5% through 10%, the 450-Scenario is more economical than Reference Scenario and National Strategy. This trend continue until discount rate of 12% where the three scenarios break even. Thereafter, at discount rate of 12%, reference scenario (fossil-based) becomes again more economical. Conversely, in 2030, the 450-Scenario is more economical at discount rate of 5% and the three scenarios breakeven at discount rate of 7.5% as shown in figure 6.9-b. Interestingly, the 2030-cost of National Strategy mix stays below reference scenario until a breakeven point at 10% discount rate and becomes more expensive. Such results underline that generation mixes with higher penetration of renewable and nuclear technologies are more sensitive to different discount rates than fossil fuel-based mixes.

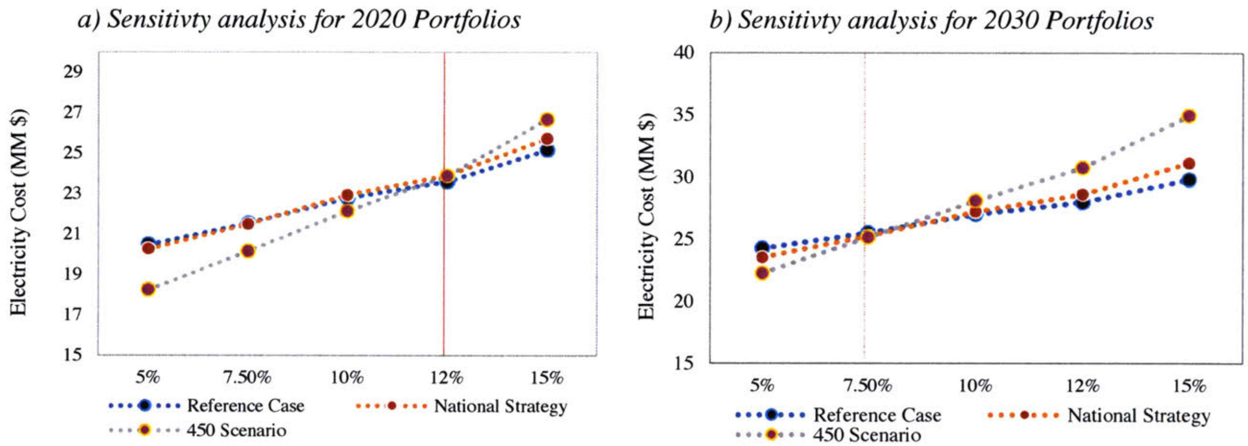


Figure 6.9. Break-even points and generation cost comparison at different discount rates in 2020 and 2030.

Analysis presented above highlights that Iran large dependence on fossil fuels to supply power will be a major challenge in the face of growing power demand infused by inefficient energy use. Although existing wind and solar capacity are relatively modest compared to conventional technologies, but potentials for these two technologies are huge. As explained earlier in chapter 4, solar potential in Iran is among the largest across the Middle East, and wind has even higher potential for larger penetration. According to SUNA (Renewable Energy Organization of Iran), there is only 15 wind farm that currently deployed in Iran but there is an economic potential of having 100 GW of wind alone across Iran (Bayar, 2017). Thus, wind technology will play the key role in case of higher renewable capacity; however, the issue of transmission is a major challenge that cannot be overlooked. Typically, wind project could take between 2 to 3 years for planning and construction, yet, remotely located wind farms cannot be financed until transmission access is provided (Fischlein et al., 2013). In the United States, Texas has overcome this problem through establishing a Competitive Renewable Energy Zone (CREZ) where it allows transmission line to be built in advance of the construction of wind farm (J. C. Smith et al., 2013). This could be a useful to catalyze wind deployment in Iran, where flat land available for larger wind deployment are remotely located outside demand locations.

Results for Iran indicate a large level of renewable deployment required in the future that far exceed announced targets. Yet, it is important to underline that new announced feed-in tariff policy and sanction removal will largely boost the level of renewable deployment in Iran and provide a more attractive environment for financial investments in RETs (Dodd, 2015). Iran's transition to a more diverse power mix will not only assist in emission reduction, the country will also experience a couple of major benefits. For instance, reduced demand for fossil fuels will yield an increase in Iran's exports of oil and natural gas. In addition, diversifying power mix will allow the government to ease power subsidies while meeting growing demand with low-carbon and cost effective technologies.

6.4.2 Saudi Arabia

Saudi Arabia has set an initial target of 3.5 GW by 2020 and later announced 9.5 GW of renewables by 2023 as part of the national 2030 vision (KSA, 2016). The kingdom's vision to reduce dependence on fossil fuel generation technologies (KA-CARE, 2012) represents the foundation of Saudi Arabia's model that has been taken into consideration in delineating devised 450-Scenario. Furthermore, the distribution of RETs, specifically, solar (PV), solar (CSP) and wind is defined according to their resources availability. In addition, deployment constraints for solar PV is assumed at 32% and CSP at 50% that are based on KA-CARE study (2012). The maximum deployment range for wind is assumed between 18% and 20% and waste-to-energy at 2% by 2030 based on the reports of (KA-CARE, 2012; McDermott, 2012). Geothermal is assumed at a maximum deployment range of 1% by 2030, as it has been reported in the literature that its technical and economic viability in Saudi Arabia is questionable (Rehman, 2005). The kingdom has announced a target of 17 GW of nuclear power by 2030, until recently it has been announced that this target was pushed back to 2040 (Reuters, 2016). Accordingly, the range of nuclear power deployment is based on linear interpolation of 2040 target.

National Strategy Scenario

Under the National Strategy Scenario of Saudi Arabia, there is a large reduction required to meet the 450-emission goal in both 2020 and 2030 as shown in figure 6.10 below. As previously discussed, the country will need to save almost 70 Mt of power- related emission in 2020 and around 60 Mt by 2030. The deployment of Carbon Capture technology (CC) to Saudi Arabia's mix is based on the study of (Mansouri at al., 2013). The study estimated that under CC deployment to existing and new power fleet, attained emission savings ranged between 45% and 75% below Business as Usual (BAU). Here, the introduction of carbon capture technology, annual generation emission decreased below the 450-emission goal by 57% in 2020 and 51% in 2030. However, annual generation costs increased from 36 to 52 Billion USD in 2020 and from 43 to 57 Billion USD in 2030.

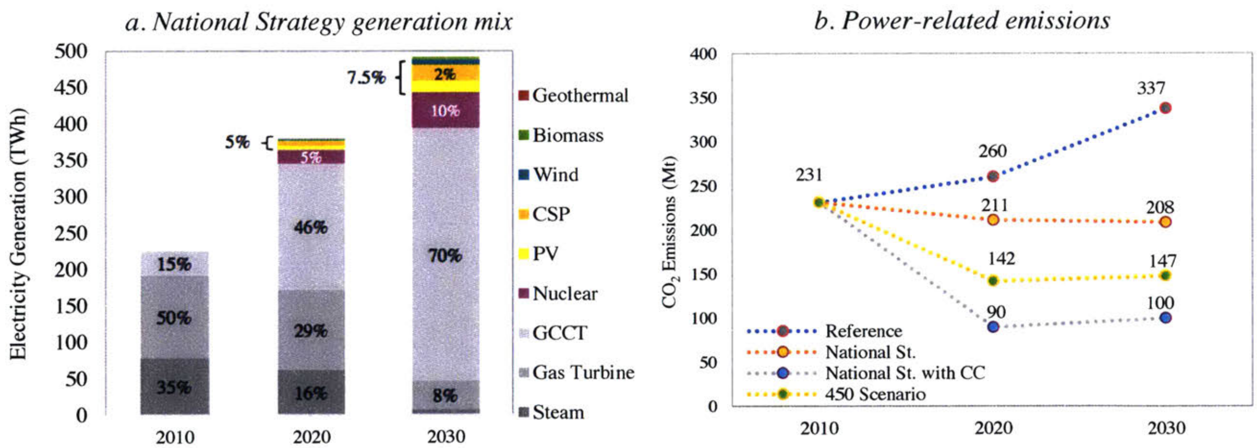


Figure 6.10: a) Electricity generation mix under National Strategy scenario, b) Power-related emissions across different scenarios relative to 450-emission pathway.

450-Scenario

As discussed above, Saudi Arabia's projected demand is expected to reach 380 TWh in 2020 and 493 TWh by 2030. In the 450-Scenario, nuclear power will cover around 6% of total generation mix with a cumulative capacity of 3.4 GW in 2020, expanding to 7.0 GW by 2030 to cover 10% of total electricity. Solar (PV) and solar (CSP) will cover 23% of total generation in 2030 with a capacity of 24 GW and 38 GW respectively. Wind power will account for 7% of total generation in 2030 with a cumulative capacity of 10 GW as shown in figure 6.11 below. These results imply that around one third of total generation can be covered by solar and wind technologies. The deployment of RETs and nuclear power facilitates the gradual decrease in the operation of fossil-based generation but taking into account the country's plan of generating 70% of its power generation from natural gas by 2030 (Cunningham, 2017).

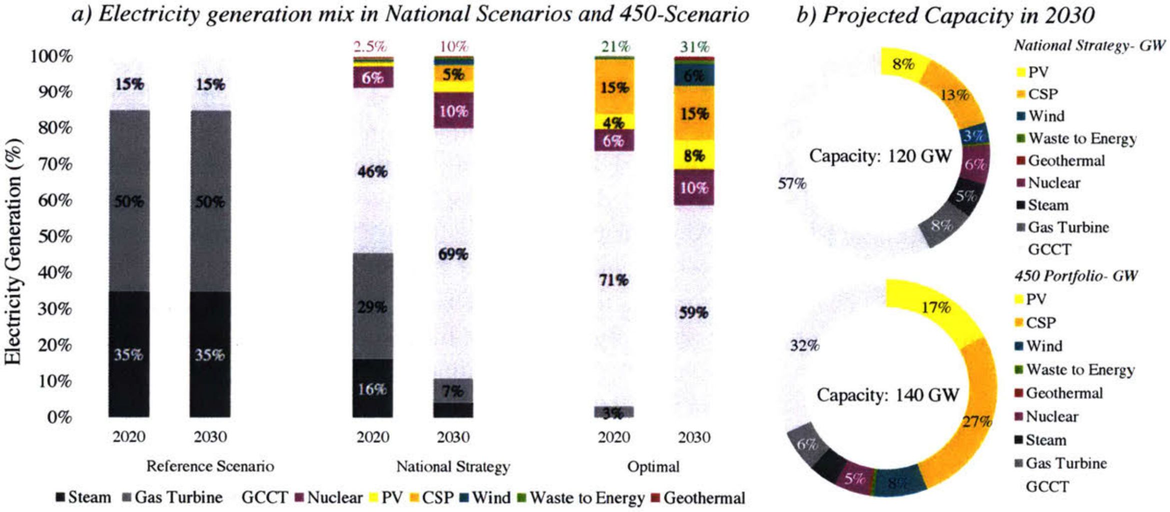


Figure 6.11: a) Generation mix across national scenarios and 450-Portfolio, b) 450- Portfolio power capacity in 2030 relative to National Scenario.

Deep Decarbonization Scenario

The Nuclear-RE pathway for Saudi Arabia constitutes 50% of natural gas based technologies in 2020 and 49% RETs in 2020. Under an assumption of full deployment of nuclear power, aggressive transition starts by 2025 until full dependence on nuclear and RETs by 2030. Solar (CSP) and (PV) are considered the key technologies, with a total share of 39% of total renewable generation in 2020 and 54% in 2030 (figure 6.12-a). For the 100% RE pathway, solar (CSP) and (PV) represent 60% and 79% in 2020 and 2030 respectively while wind and waste-to-energy account for 16%. The annual generation cost of 100% RETs is almost double the cost of the 450-optimal portfolio in 2030 explained by high renewable penetration.

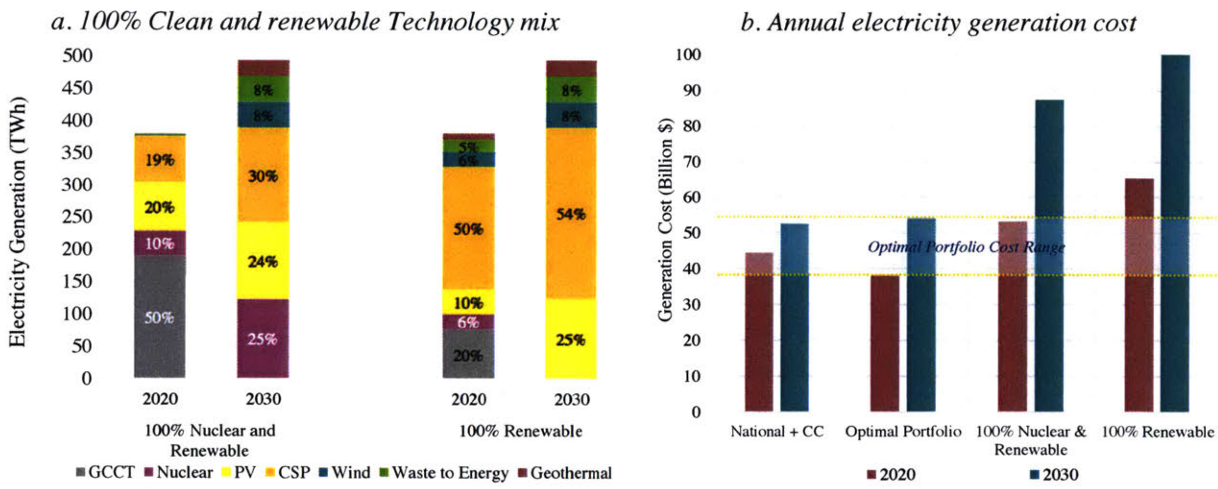


Figure 6.12: a) Electricity mix under Deep Decarbonization scenario, b) Annual electricity generation costs compared to the 450-Scenario.

Results for Saudi Arabia's Deep Decarbonization Scenario indicate that solar technologies are relevant in case of large renewable expansion. Although such scenario is significantly ambitious compared to current power structure. Yet the extent of their applicability on the long term is largely linked to reformations of electricity subsidy allocation and provision of sufficient incentives to upscale RETs.

Sensitivity to RETs Costs

Under the cost projection scenario, the share of renewable technologies has not changed significantly except in the share of solar (CSP) as presented in figure 6.13 below. This is because when optimizing for cost, the optimal portfolio is largely based gas-based combined cycle technology that would still have a cost advantage against RETs generation. Annual cost of electricity generation shows that there is a large difference between 450-Scenario and cost projection mix especially in 2030. Yet, cost reduction in RETs could be more economical relative to National Strategy Scenario mix with generation cost saving by around 2.0 Billion USD in 2020 but still higher in 2030 by 2.5 Billion USD.

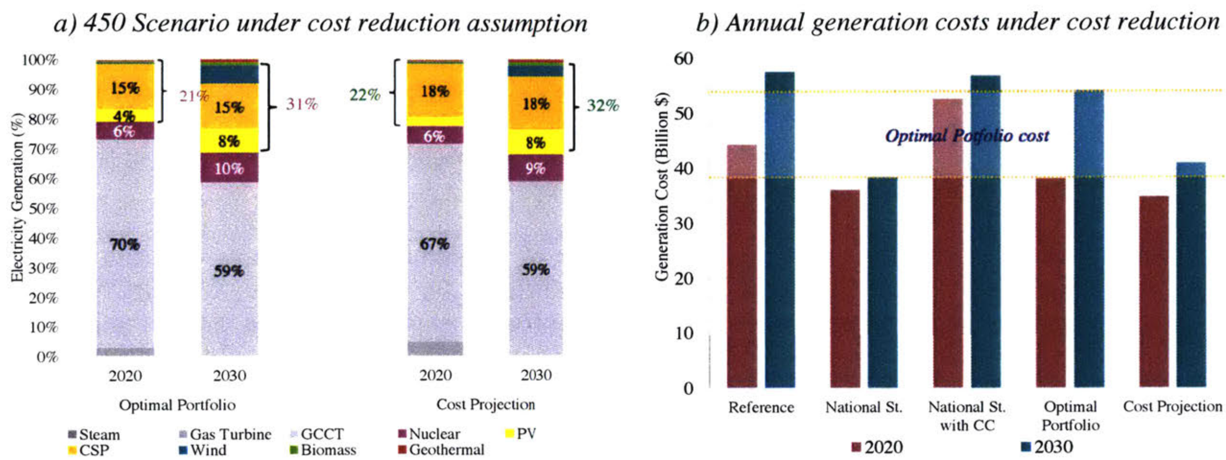


Figure 6.13: a) 450-Scenario in case of future cost reduction compared to base-case cost, b) Annual electricity generation cost across national scenarios and 450- optimal portfolio under future RETs' cost.

Sensitivity to Discount Rates

Results for Saudi Arabia indicate that, in 2020, the cost of 450-Scenario stays below National Strategy and Reference scenario until 7.5% where the two scenarios break even. Notably, the breakeven point between 450-Scenario and Reference scenario occurs at discount rate of 15% in 2020 and at 12% in 2030 as shown in figure 6.14. In addition, it can be observed that in both 2020 and 2030, reference scenario is generally stable at different discount rates. This is because the power mix of the Reference scenario is significantly based on fossil technologies that are almost insensitive to changes in discount rates. Such results highlight that with higher penetration of nuclear and renewable technologies the overall system cost becomes significantly sensitive to discount rate decisions. Thus, addressing such variations in power planning is essential, as it will largely influence diversification decisions.

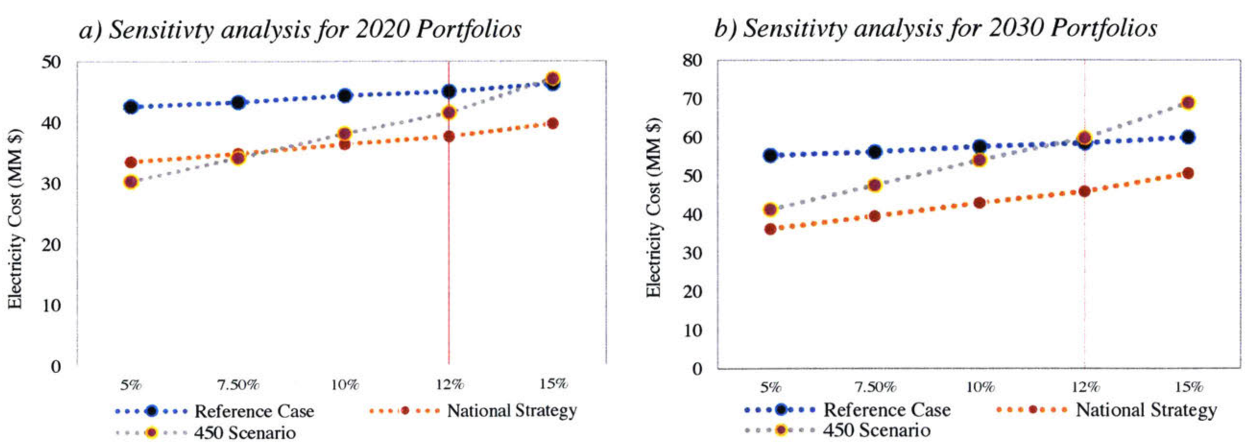


Figure 6.14. Break-even points and generation cost comparison at different discount rates in 2020 and 2030.

In the light of the results presented above, solar (PV), (CSP) and wind will play the main role in the case of large renewable deployment. The large share of solar (CSP) depicted in the results can be justified by a number of supporting indications of its viability for Saudi Arabia. First, solar (PV) and wind are quicker to deploy under the growing needs for peak-load generation, yet (CSP) with storage could offer a considerable capacity value for Saudi Arabia. The country is hugely blessed with adequate solar resources and vast land area available, thus PV and CSP technologies could complement each other. Solar (PV) can serve peak demand during daytime, CSP plants can dispatch power stored through the evening as found in the study of (Alyahya & Irfan, 2016). Second, solar (CSP) could be utilized in the form an Integrated Solar Combined Cycle power plants (ISCCs) that are already being carried out in Saudi Arabia (PRWEB, 2014). In addition, Saudi Electricity Company (SEC) managed to achieve lowest installed cost for CSP at less than 1.6$/MW in Waad Al Shamal and Duba 1 (ISCC), which could further push CSP deployments (Hashem, 2017). Finally, Saudi Aramco projects a large cost drop in CSP with six hours storage within the next 10 years, dropping from 5.32$/W in 2016 to 3.80$/W by 2026 (MENASol, 2016). Beyond electricity, CSP can offer a great fit for solar thermal desalination in Saudi Arabia with a capacity of factor up to 75% in the north-west regions of Saudi Arabia like Tabuk (Agboola, 2015).

Diversifying power generation mix will yield a number of economic (fuel savings and employment opportunities) and environmental benefits (emission reduction) for Saudi Arabia to help balancing environmental goals against economic needs. Government officials have realized that in order to maintain the country's revenues from petroleum-based exports, alternative means of energy should be identified and utilized (McAuley, 2017). Still, highly subsidized fuel prices represent significant economic barriers to RETs deployment that have greatly minimized their competitiveness in the country's power market. However, if current reduction in electricity and fuel subsides continue, there will be a larger potential for solar deployment in Saudi Arabia. Other technical barriers for large solar deployment include high temperature and dust. However, these can be overcome with adequate solutions. A good example can be found in Princess Noura bint Abdul Al Rahman University in Riyadh, the world largest operating solar plant, providing heat and water needs (IEA, 2014a).. Finally, dropping costs of PV has discouraged developer to push for CSP with energy storage advantage, but wide CSP deployment happening in China will be a key to cost reduction.

6.4.3 Kuwait

According to Kuwait's vision for 2030, the country plans to secure 5% of power generation from RETs by 2020 and 15% by 2030 (Alhajraf, 2017). The plan is focusing on three main technologies: solar (PV), solar (CSP) and wind, with larger focus on solar (PV) and (CSP) (figure 6.15-a). The recent study by Kuwait Institute for Scientific Research (KISR) was used to guide the investigation of larger RETs penetration in Kuwait's power mix (Jandal & Sayegh, 2015). Capacity factors and conversion efficiency for renewable and conventional technologies are also based on reported values in KISR study (Jandal & Sayegh, 2015). The breakdown of RETs in the model is framed in accordance with their share in Al-Shagaya Solar Park project to generate 2 GW by 2025 and 4.5 GW by 2030 that was recently announced by the electricity and water authorities in Kuwait (Oxford Business Group, 2016b). The 450-model was solved under the constraints of projected installed renewable capacities for wind. Lower constraint is utilized for solar technologies attributable to their high resource availability as discussed in chapter 4.

National Strategy Scenario

As discussed above, the country will need to save about 20 Mt in 2020 of CO_2 emission in 2020 and around and 30 Mt in 2030 below National Strategy Scenario (figure 6.15-b). The deployment CC technology to fossil fuel fleet has greatly curbed power-related emissions. As a result, annual emissions savings reached almost 9 Mt in 2020 and 4.5 Mt in 2030 below 450-emission goal but still doubling total annual generation cost. In 2020, generation cost with CC deployment increased by almost 43% compared to without CC and by nearly 32% in 2030.

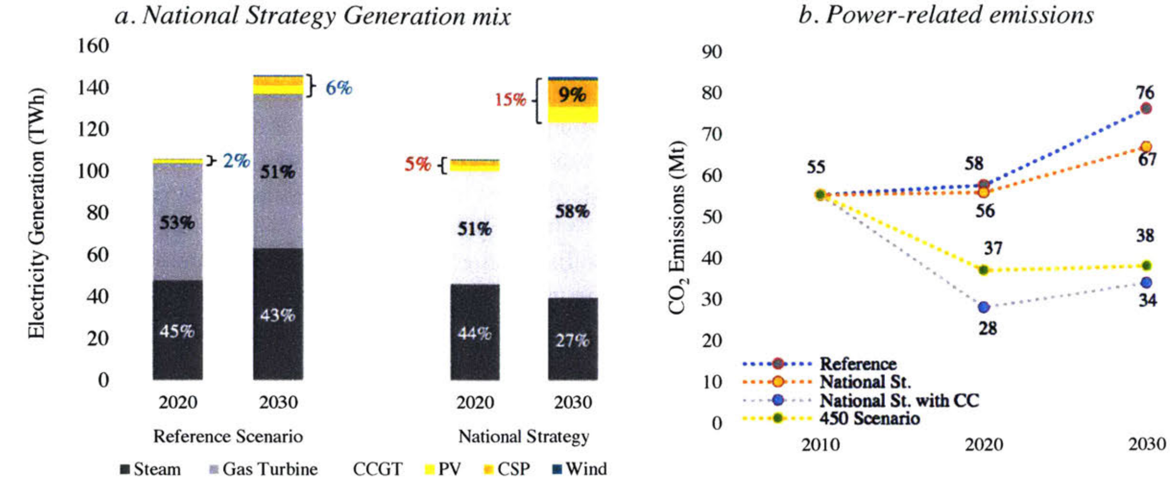


Figure 6.15: a) Electricity generation mix under National Strategy scenario, b) Power-related emissions across different scenarios relative to 450-emission pathway.

450-Scenario

Results for 450-Scenario indicate a large RETs deployment compared to National Strategy Scenario as depicted in figure 6.16. The share of RETs expands from 15% to 48% in 2030 with solar (PV) and solar (CSP) accounting for 36% and 40% of total generation mix in 2020 and 2030 respectively. Implications on total capacity underline that RETs would contribute around 71% of required capacity in 2030. Notably, solar (PV) would jump to 16 GW (32%), solar (CSP) expands from 2.5 GW to 15 GW (30%) and wind grow to 4.5 GW by 2030 (figure 6.16-b). Consequently, expected capacity to meet peak demand would jump from project 32 GW to 50 GW in 2030. Combined Cycle Gas Turbine technology (CCGT) would still dominate the share of fossil fuel based-generation and solar (PV) and (CSP) will take over the largest segment of total installed capacity in 2030. Undoubtedly, such large renewable deployment would entail large investment costs alongside with an increase in annual generation costs. The 450-Scenario has pushed annual generation costs by around 5 and 7 billion USD in 2020 and 2030 respectively, compared to National Strategy Scenario. However, associated fossil fuel savings would have an enormous advantage in return. Plummeting costs of RETs and the widespread availability of solar and wind resources would significantly reinforce the economic and environmental plausibility of larger RETs deployment in Kuwait.

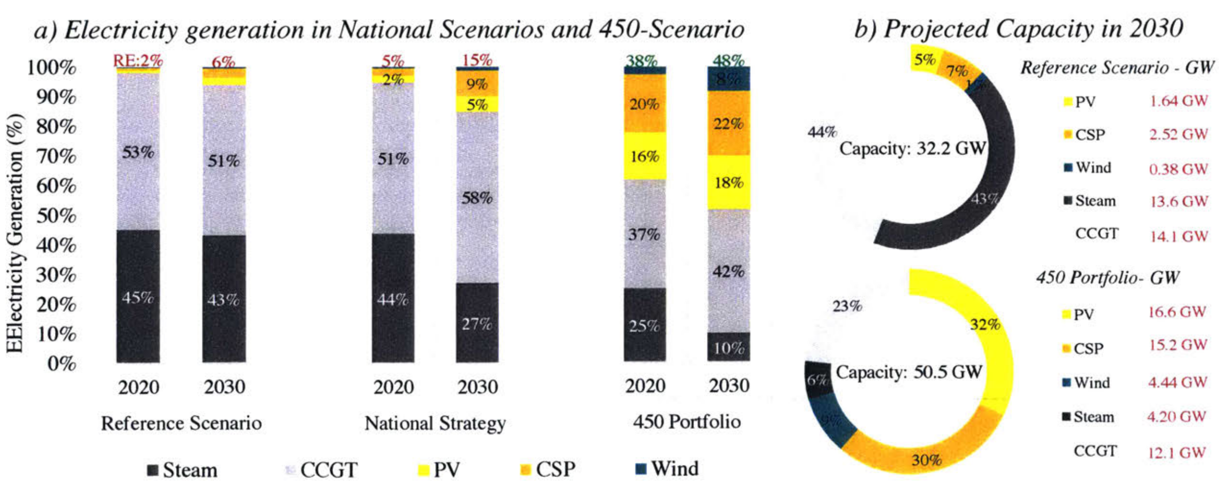


Figure 6.16: a) Generation mix across national scenarios and 450-Portfolio, b) 450- Portfolio power capacity in 2030 relative to National Scenario.

Deep Decarbonization Scenario

The Deep Decarbonization Scenario for Kuwait disregards nuclear power generation as part of the mix. Here, solar (PV) and (CSP) account for 69% electricity generation in 2020. Aggressive transition is assumed to start by 2025 with CSP replacing CCGT capacity and significant solar (PV) is attained. By 2030, PV and CSP would constitute around 85% of total generation while wind would account for 17%, as presented in figure 6.17 below. Annual electricity generation cost of the Deep Decarbonization Scenario is not as economical as the 450- Scenario and National Strategy with CC. This is a result of the large deployment of solar technologies that increased total generation cost by around 11 billion USD compared to the 450-Scenario. Results from Deep Decarbonization are far from the actual position of Kuwait's power system. Yet, the theoretical possibilities of 100% clean power system in Kuwait implies that solar (PV) and (CSP) would notably have the greater role.

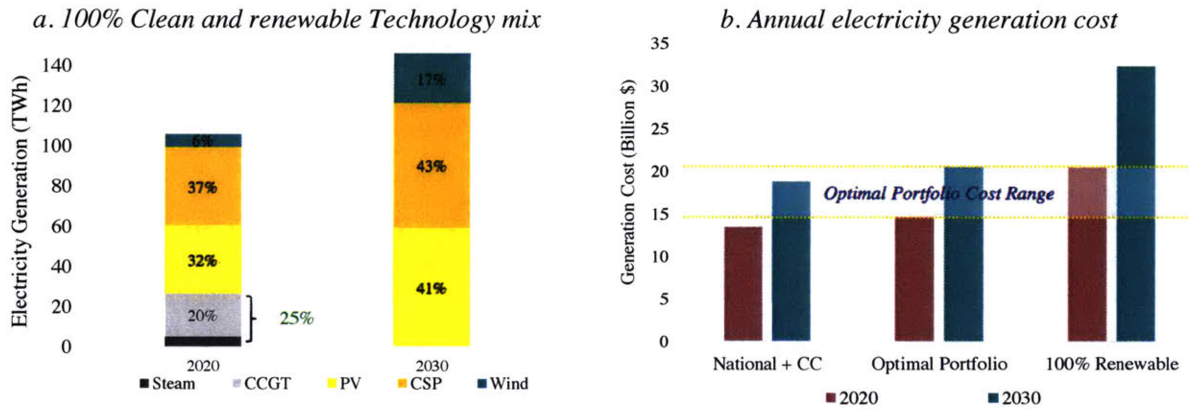


Figure 6.17: a) Electricity mix under Deep Decarbonization scenario, b) Annual electricity generation costs compared to the 450-Scenario.

Sensitivity to RETs Costs

Under cost projection, the share of renewable have increased to 42% and 57% in 2020 and 2030 respectively. As presented below in figure 6.18-a, the share of PV has increased from 18% to 20% in 2030 as a result of projected decrease in the unit cost of solar (PV). In addition, annual generation cost of the 450-Scenario has become more economical compared to National Strategy Scenario with CC (figure 6.18-b). As the cost is dominated by solar (PV) and solar (CSP) that currently have cost disadvantage against conventional technologies, National Strategy mix remains more economical than 450-Scenario in both 2020 and 2030.

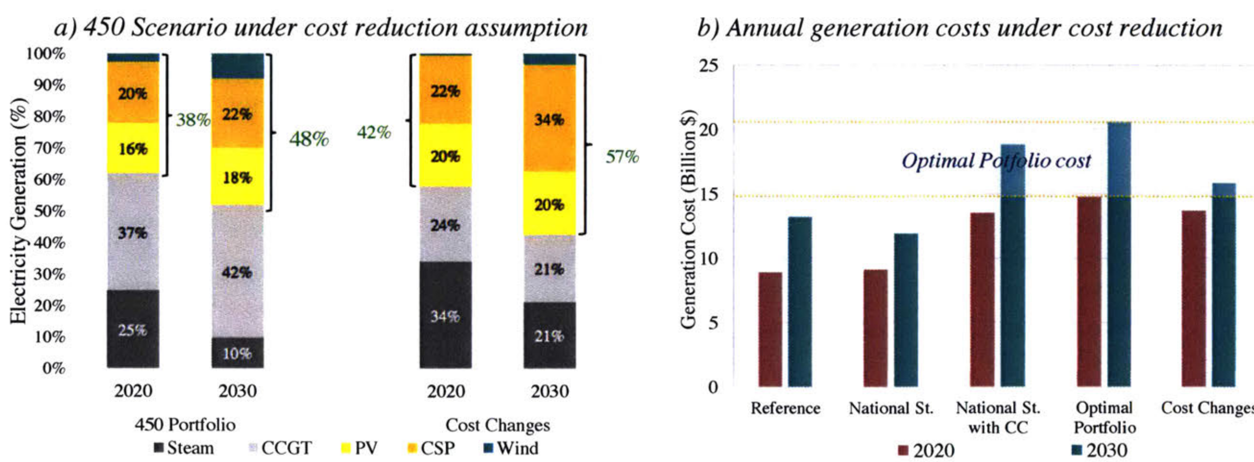


Figure 6.18: a) 450-Scenario in case of future cost reduction compared to base-case cost, b) Annual electricity generation cost across national scenarios and 450- optimal portfolio under future RETs' cost.

Sensitivity to Discount Rates

Results of sensitivity analysis for Kuwait show that across different discount rates for both 2020 and 2030, the cost of 450-scenario is higher than National Strategy and Reference Scenario. The cost gap between the three scenario starts narrow at discount rate of 5% and then it becomes wider with higher discount rates as shown in figure 6.19. This is tied to the higher percentage of RETs in the 450-Scenario mix, where its cumulative share exceeds 30% in both 2020 and 2030. In addition, economic viability differences between Reference scenario and National Strategy is not significant for both 2020 and 2030. Compared to Iran and Saudi Arabia results, the profitability of portfolios with higher level of renewable deployment is less significant at small discount rates.

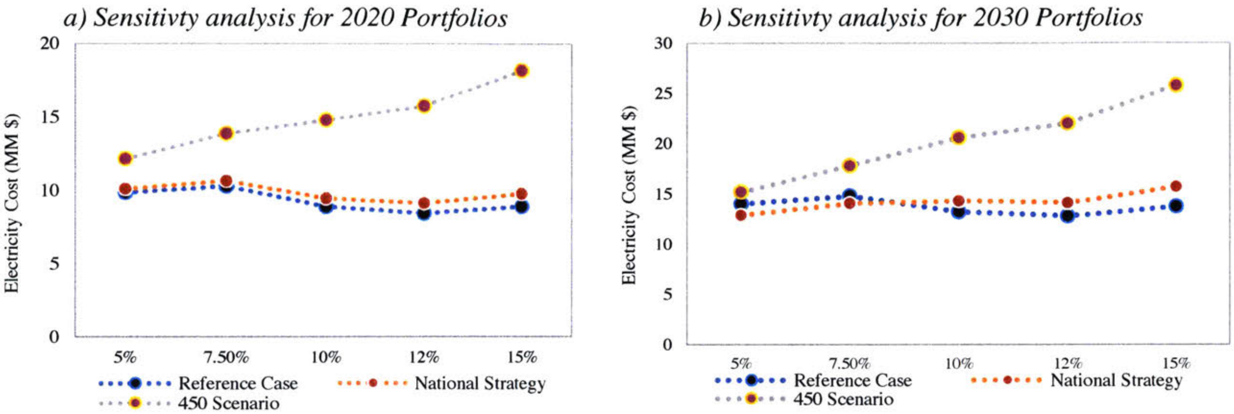


Figure 6.19. Break-even points and generation cost comparison at different discount rates in 2020 and 2030.

From the results, it can be noted that diversifying power mix in Kuwait, who is among the highest carbon footprints worldwide (IEA, 2015e), would considerably assist in establishing a sustainable pathway for its energy system. In theory, Kuwait could provide domestic power generation depending solely on its own hydrocarbon resources. However, in 2009, the country has become a net natural gas importer due to the mounting gap between power demands and available gas production capacity (Stanton, 2009). Thus, in order to meet growing power demands, Kuwait would either depend on imported natural gas or use its own heavy fuel oil for power generation. Both scenarios would result in significant drawbacks for the national economy. This is either from increased imports costs or decreased fuel exports volume. Burning oil for domestic power generation is not only economically inefficient, but also, it emits more carbon emission than natural gas.

Results presented above highlight the major role of solar (PV) and solar (CSP) in case of large renewable deployment. Shifting towards solar (PV) and (CSP) can be justified through a number of aspects. First, solar (PV) can provide an efficient and less expensive alternative for air-conditioning demands within the building sector. A number of studies have proven that utilizing solar (PV) under maximum incident of solar radiation matches peak load demand during summer months (Al-Sahhaf, 2016; Ramadhan at al., 2013). Similarly, solar (CSP) can be efficiently integrated with CCGT power plants to meet desalination requirements similar to its neighbor, Saudi Arabia. Second, solar research activities of Kuwait Institute for Scientific Research (KISR) positioned the country among the pioneers in solar energy applications for desalination, air-conditioning and power generation across the Gulf region. Thus, such research experience should be applied to push solar RETs utilization in power generation. Finally, Kuwait's government plans to increase natural gas usage in future electricity generation and water desalination (EIA, 2016). Yet limitations from production capacity and imports costs could hinder the dependence on CCGT technology in the future, especially that the government covers the largest share of generation costs through utilities subsidies programs (IBP, 2015). Finally, the advent of renewable deployment will significantly add efficiency and back-up capabilities to Kuwait's power network alongside with possible export outlets for excess power.

6.4.4 The UAE

The National Strategy Scenario of the UAE is considered the most ambitious among the four countries in terms of RETs deployment. The country has set a target 24% of total electricity generation in 2020 and 30% in 2030 (IRENA, 2015c). The integration of RETs and nuclear power in the UAE's power sector is based on the analysis conducted by Masdar institute and International Renewable Energy (IRENA). The study is used as the main foundation to delineate the breakdown of RETs and outline the potentials of additional renewable capacity (Sgouridis et al., 2016b). All conventional technologies are reflected in the total installed capacity as natural gas since it constitute 98% of total conventional generation in the UAE. The REmap Scenario for 2030 is also examined to understand possible emission implications relative to the 450-emission target. The distribution of RETs in 2020 under RE-map scenario is linearly interpolated in accordance with 2030 planned capacities. Deployment constraints for RETs is based on the announced capacities and resources availability in the UAE. The maximum range for renewable deployment is mainly guided by the study of Masdar institute on the ability of RETs to supply demand at higher levels of penetration (Sgouridis et al., 2013). Limitations on the level of deployment for solar (PV) and solar (CSP) are consistent with planned strategy in 2030 and the national energy plan for 2050 (44% RETs, 38% natural gas, 12% clean fossil fuel and 6% nuclear) (Al-Maktoum, 2017).

National Strategy Scenario

Although the RE-map and the National Strategy scenarios encompass a significant level of renewable deployment, the two scenarios do not meet the 450-emission target in 2020 and 2030. As depicted in figure 6.20, the UAE will need to reduce around 15 Mt in 2020 and 20 Mt in 2030 below the National Strategy scenario. The deployment of CC technology has significantly curbed power-related emission below the 450-target by around 13Mt and 10 Mt in 2020 and 2030 respectively (figure 6.20-b), yet increased total annual generation costs by almost 20% in 2020 and 15% in 2030.

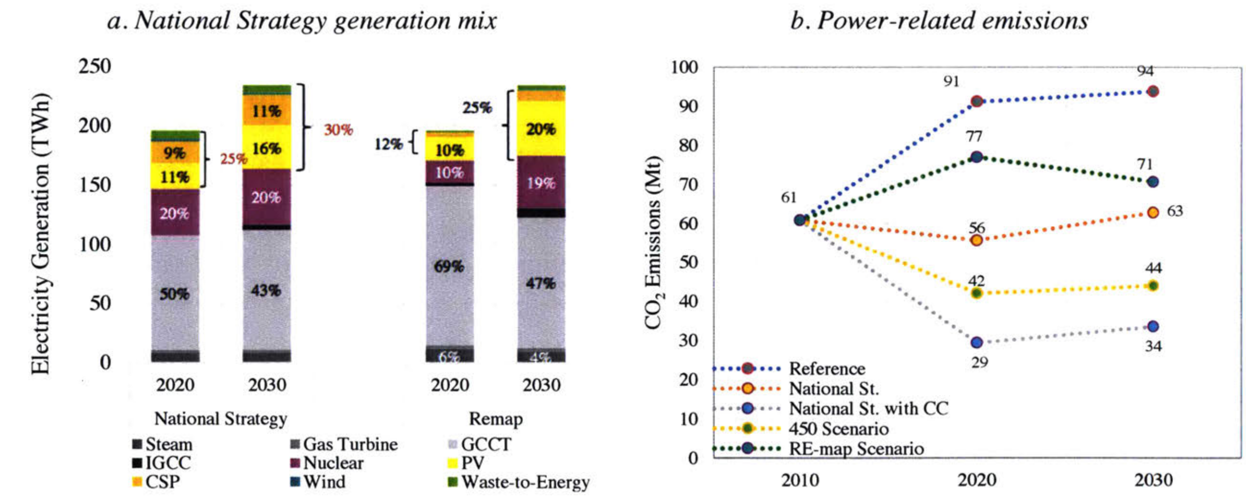


Figure 6.20: a) Electricity generation mix under National Strategy and RE-map scenarios, b) Power-related emissions across different scenarios relative to 450-emission pathway.

450-Scenario

The 450-Scenario entails a 10% increase in total renewables share in 2020 and 12% in 2030. The relative percentage of RETs deployment required against conventional generation is demonstrated in figure 6.21 below. Solar power would still represent the largest source of renewable generation collectively accounting for 75% of total renewable generation in 2020 and 86% in 2030. Solar (PV) is making up 52% of renewable generation followed by solar (CSP) with over 35% in 2030. The remaining 13% is provided through wind (7%) and waste to energy (6%). On the contrary, the share of conventional generation is substantially reduced from 48% in the National Strategy scenario to 30% in 2030.

The key benefit from large RETs portrayed in the 450-Scenario is the attained reduction in conventional generation capacity as depicted in figure 6.21-b.The compatibility of combining solar (PV) and (CSP) could efficiently replace conventional power supply in the UAE. Studies have proven that solar (PV) could reliably supply peak demand during afternoon hours under both high and low DNI conditions and (CSP) could supply evening demand with storage up to 12 hours (Griffiths, 2013; Sgouridis et al., 2013a). While the added renewable capacity is significant, yet it is economically justified by saving of fossil fuels' costs and increasing exports volume. Accordingly, the bulk of renewable capacity would be a split between solar (PV) and solar (CSP) constituting both 53% of total installed capacity in 2030. Under this level of deployment, RETs' total capacity increased by over 32% in 2030 compared to the 40% share in the RE-map scenario.

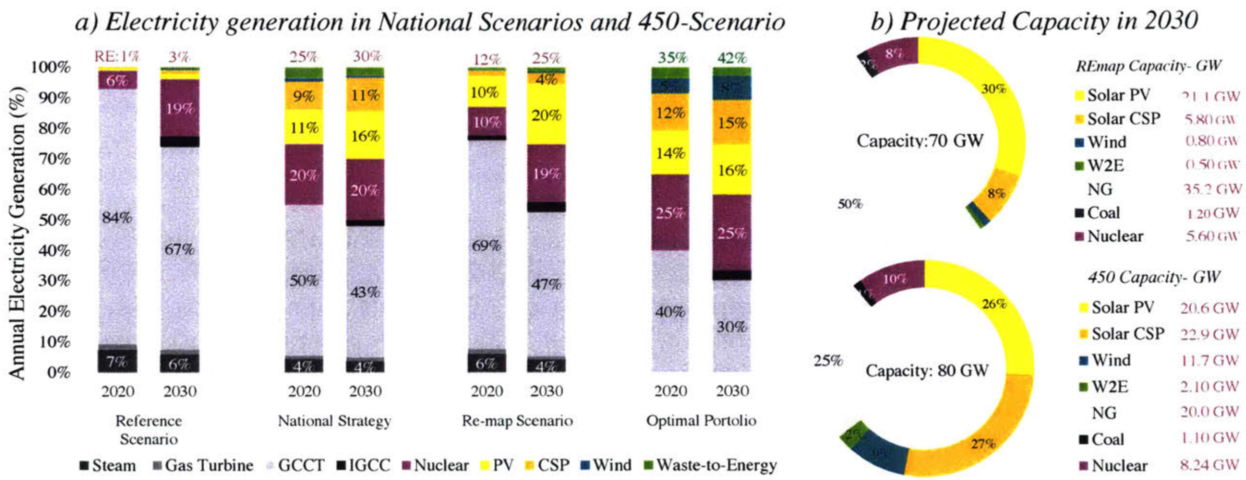


Figure 6.21: a) Generation mix across national scenarios and 450-Portfolio, b) 450- Portfolio power capacity in 2030 relative to RE-map Scenario.

Deep Decarbonization Scenario

Nuclear power generation will play a key role in case of Deep Decarbonization. Under the 100% nuclear and RETs pathway, nuclear power will account for 25% of total generation in 2020 and 30% in 2030. Solar technologies (PV and CSP) will cumulatively account for more than 50% of total generation mix in 2030 followed by wind with a share of 10% (figure 6.22-a). In the 100% RETs pathway, solar (PV) and (CSP) will account for 70% of total generation in 2030. The annual generation cost for the two pathways are not considered as economical as the 450-Scenario and National Strategy with CC (figure 6.22-b).

Results presented here draw out an aggressive transition to larger renewable deployment over a short timeframe. Yet, the aggressive deployment of nuclear power on the long-term alongside solar technologies will play a major role in the UAE. Other studies have shown that larger deployment of nuclear power could result in a feasible low-carbon power alternative that is able to replace conventional technologies and supply demand by almost 60% in 2050 (AlFarra & Abu-Hijleh, 2012).

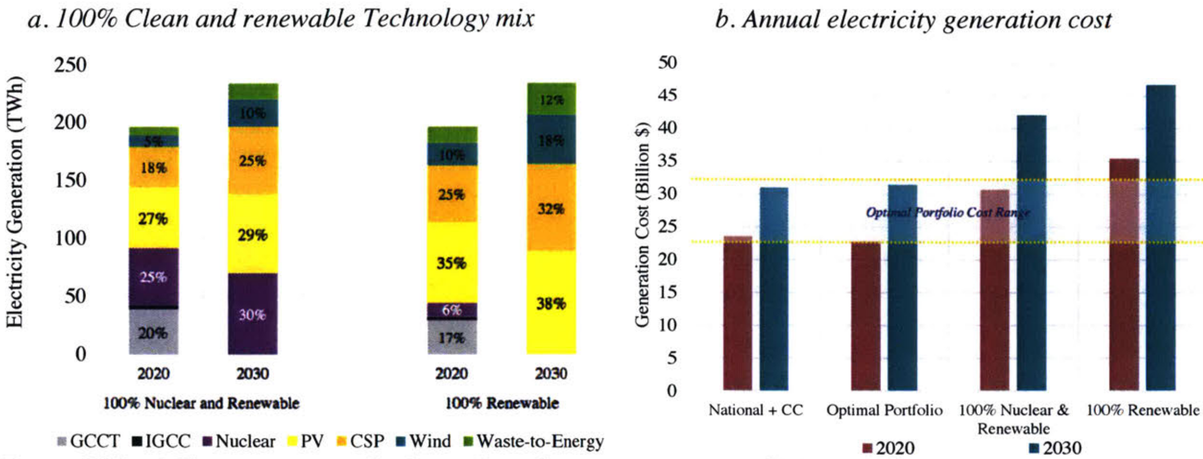


Figure 6.22: a) Electricity mix under Deep Decarbonization scenario, b) Annual electricity generation costs compared to the 450-Scenario.

Sensitivity to RETs Costs

Future cost reduction of renewable technologies has led to an increase in total RETs under the 450-Scenario. The share of renewable have increased from 35% to 37% in 2020 and from 42% to 50% in 2030 (figure 6.23-a). This is because of the projected drop in solar (PV) and (CSP) costs that made them more favorable in the generation mix against conventional technology. The annual generation cost have dropped significantly under costs projection, remarkably achieving an economical option over the National Strategy with CC. The 450-Scenario under cost reduction is still not as economical as the National Strategy Scenario; yet, the economic advantage of fuel cost savings significantly justifies the large RETs penetration.

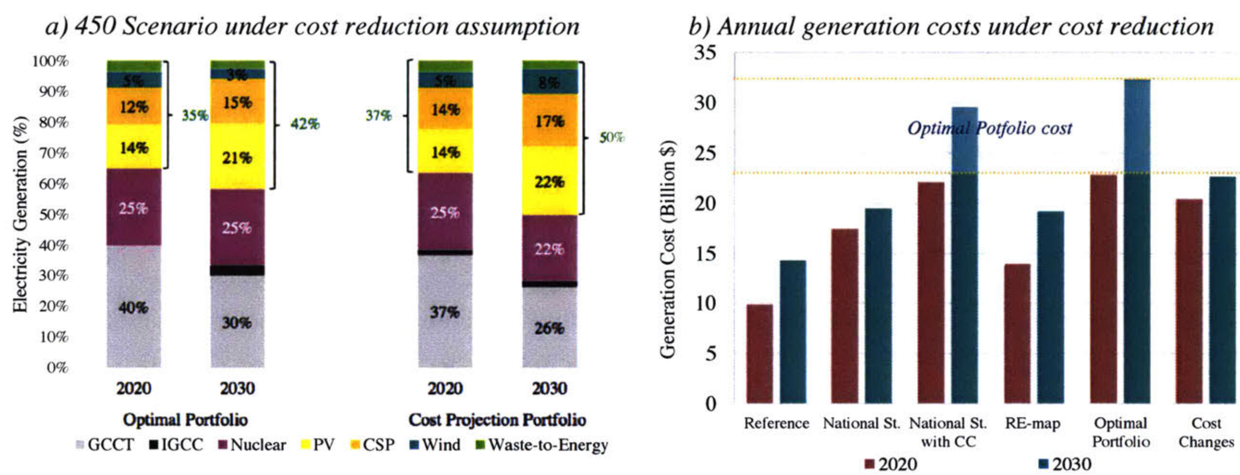


Figure 6.23. a) 450-Scenario in case of future cost reduction compared to base-case cost, b) Annual electricity generation cost across national scenarios and 450- optimal portfolio under future RETs' cost.

Sensitivity to Discount Rates

From the results, it can be observed that in portfolios with high nuclear penetration, annual generation cost increases significantly at higher discount rates. In 2020, annual cost of the 450-Scenario is steadily higher than Reference scenario and National Strategy Scenario across with no overlap between the three scenarios. In addition, generation costs increased significantly almost doubled, at discount rate of 15% in both 2020 and 2030 as depicted in figure 6.24. This could be linked to some extent to higher deployment of nuclear power in the UAE's portfolio, since the construction time of nuclear power plants is longer than any other power technologies including RETs. The presented sensitivity of the portfolio costs to different discount rates indicates that the economic viability of RETs scenarios is greatly affected by discount rate values.

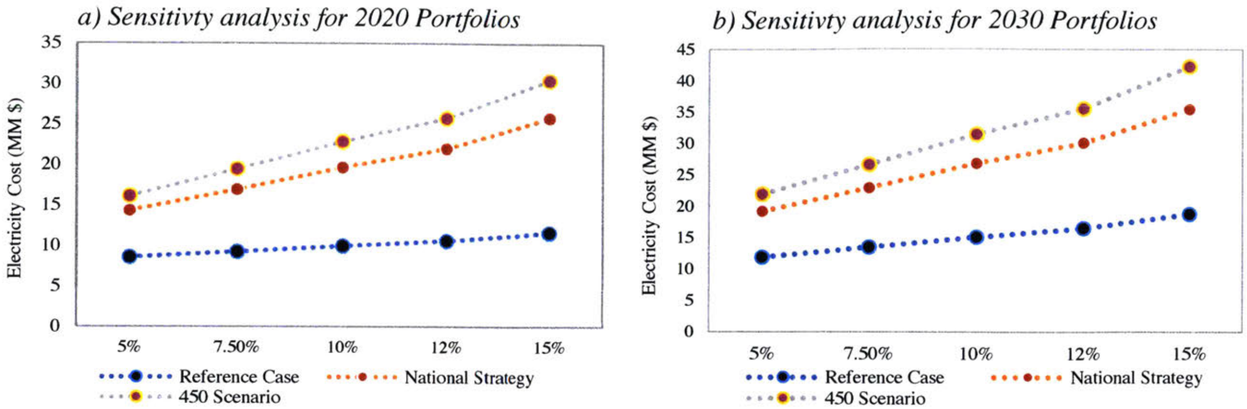


Figure 6.24. Break-even points and generation cost comparison at different discount rates in 2020 and 2030.

The UAE is taking steady steps towards diversifying its energy mix with nuclear power and large-scale RETs. However, it is clear from the analysis presented above that, the country will continue to depend significantly on hydrocarbon for power supply even under National Strategy Scenario. Yet, the plummeting costs of RETs supported by large resource availability, especially solar, makes more sense for larger deployment economically and environmentally for a country like the UAE. Higher renewable deployment will greatly support in curbing power-related emissions for country that is among largest CO_2 emission per capita worldwide (IEA, 2015e). Expanding renewable capacity will also pave the way for depleting resources to tail off from the energy system in the long term alongside to investments and employment opportunities through nuclear and solar industries.

Results from the 450-scenario notably favor solar technologies, specifically (PV) over (CSP), this is justified by PV's advantage to match peak demand as proven in the study of (Griffiths, 2013). The large renewable penetration in the UAE's 450-Scenario is justified by a number of factors. First, existing generation fleet in the UAE is mainly composed of Combined Cycle Gas turbine (CCGT) and Open Cycle Gas Turbine (OCGT) (Almansoori & Betancourt-Torcat, 2015), who both offer a flexible support for large renewable penetration. In addition, large-scale CSP deployment with storage have proven to be economically viable as noted earlier, and a number of studies have shown that solar (CSP) system could achieve efficiency of 22% across the UAE (Mokri et al.2013). The study also pointed that the system can be largely affected during days with low direct normal irradiance (DNI) that would require technical solutions (such as solar collectors and concentrating optics). Beyond the possibilities of large renewable deployment presented through the results, the UAE is significantly challenged to materialize RETs' advantages. Demand-side management is a key hurdle to moderate the viability of renewable penetration. Moderating energy demand in the UAE is greatly challenged by subsidized tariffs that needs to be revisited aggressively. This is alongside reframing energy policy to push private-sector participation and open the market for renewable deployment.

6.5 Discussion

The main motivation behind the analysis presented in this chapter is to draw attention towards the relative importance of renewable penetration on the long-term to mitigate CO_2 emissions and underline the possible transitions under growing power demands. There is still a level of uncertainty whether projected capacities can be delivered in accordance with a suitable economic and regulatory support. In addition, changes in the underlying assumptions, emission constraints and the extent of RETs penetration would largely affect the results. However, the main contribution stems from underlining the feasibility and sustainable advantages of increasing RETs penetration to meet emission goals across the four countries of interest. The Mean Variance Portfolio theory (MVP) has been employed to analyze and delineate possible generation mixes that satisfy 450-emission goals in 2020 and 2030. The CO_2 emission target constraint significantly influences the alteration of technology decisions. The penetration of Carbon Capture technology (CC) to planned generation mixes has resulted in a system with negative-emission characteristics that are far below emission goals. However, retrofitting CC technology on conventional generation mix has significantly increased the overall annual cost in 2020 and 2030. In addition, CC deployment would still be considerably challenging due to its economic and technical uncertainty. The technology is still at an early development stage to be implemented for full chain deployment even in developed countries in Europe (Page, 2016).

Results of the 450-Scenario across the four countries underline that switching to more efficient, low-carbon technologies and increasing the level of renewable deployment could provide several benefits. The attained environmental gains associated with renewable deployment come along side with major economic benefits as been pointed out earlier. Reducing demand for fossil fuels at the domestic level will greatly increase exports volume and secure an important source of national revenues, especially for Kuwait and Saudi Arabia. Figure 6.25 below illustrates the estimated fossil fuel savings across the four countries from 450-Scenario and associated emission savings. On the oil side, a total estimated reduction of 0.5 Mtoe in 2020 and 1 Mtoe in 2030 can be achieved for Iran under 450-Scenario. This is also relevant for Saudi Arabia, where associated oil-savings reached 6 Mtoe in 2020 and 15 Mtoe in 2030. Such reductions would significantly enable these countries to meet sustainable energy targets together with expanding exports volume. On the gas side, the 450-Scenario in Iran and the UAE has resulted in fuel savings of 19.5 Mtoe and 50 Mtoe in 2030 respectively. Under these savings, the future role of Iran among the major natural gas exporters in the Middle East can be positively affected. It will also come with greater advantage for the UAE to reduce dependence on natural gas imports. Accounting for this, the renewable installed capacity would significantly save required expansion in conventional capacity yet would requires larger investments needs. However, the 450-scenario will entail higher investments costs, yet it can be paid back by fuel savings and increased exports volume in the long term, potentially reinforcing the financial viability of these portfolios.

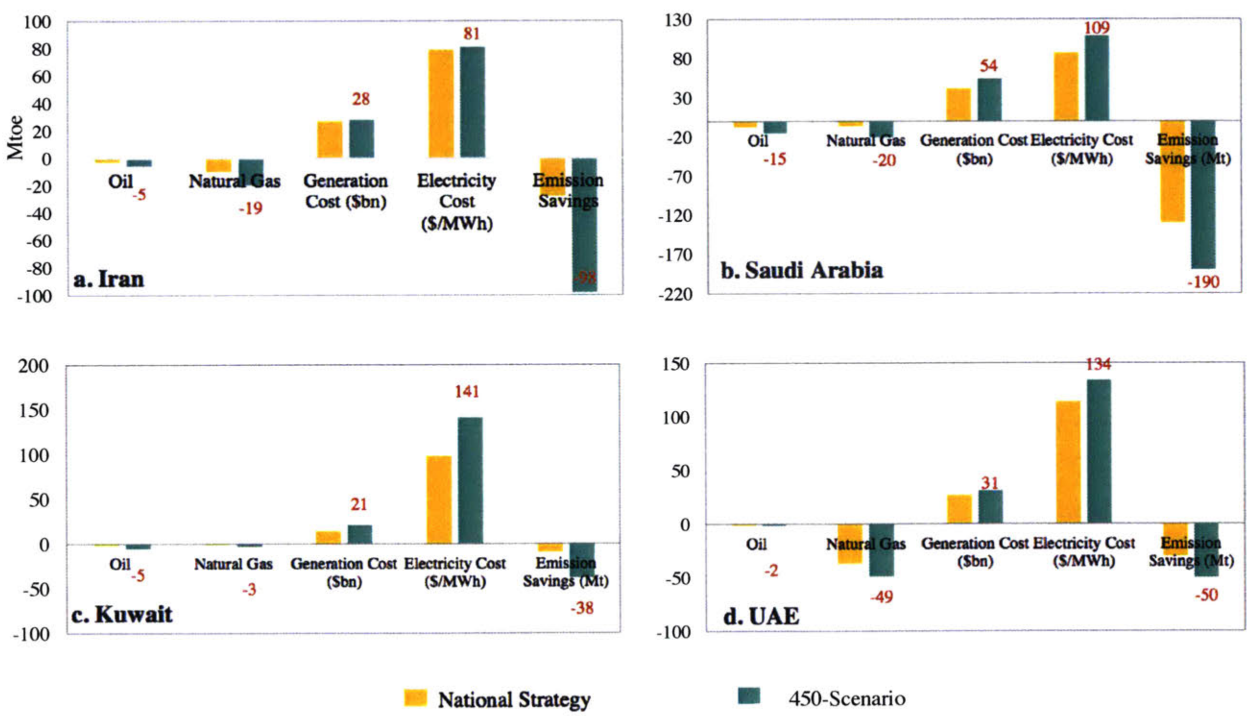


Figure 6.25: Fossil fuel saving and emission reduction from the 450-Scenario compared to National Strategy in 2030.

Certainly each country of the four addressed in this thesis has its own energy characteristics, yet results highlight that there is a level of technological similarity found alongside such variations. Analysis showed that solar (PV) and (CSP) stand as a great alternative in case of high RETs penetration. As discussed previously, solar (PV) can contribute significantly to power supply in both Kuwait and the UAE. The research expertise in these two countries greatly qualifies them to proceed with higher PV penetration in their power supply mix, where collaboration could be greatly beneficial to achieve least-cost. Results from Saudi Arabia and Kuwait, indicate a similar tendency to diversify away from conventional technologies towards larger use of solar (CSP). As it has been pointed out, solar (CSP) can be efficiently utilized for power supply and water desalination needs in the two countries. Morocco offers a role model in CSP deployment within the MENA region, yet undoubtedly, Saudi Arabia, Kuwait and the UAE are adopting concrete plans to increase CSP deployment and take advantage of its storage potentials (MESIA, 2017). As it has been pointed out, solar (PV) and (CSP) represent a low hanging fruit for countries addressed in the analysis. The potentials of these technologies are immense either in a form of hybrid PV-CSP system or integrated combined solar cycle (ISCC) with existing fleet.

The geographical proximity between Saudi Arabia, Kuwait and the UAE comes with great advantage for a potential partnership in renewable development and market investments. Similarity in climatic conditions and the structure of their regulatory frameworks can allow to these countries to work together to advance RETs penetration supported by similarity in technological diversification. Nuclear power will also play a crucial role in achieving emission goals from 2020 and 2030, with large relevance for Iran (under political conditions) and the UAE. Finally, it important to point out that proposed methodology does not take into account a number of important factors. For example, potentials for energy efficiency and regulatory framework, RETs supporting mechanisms and condition of grid access are vital for RETs investment decisions.

Finally, through the four countries presented in the analysis, a consistent policy is imperative to layout the foundation for RETs penetration and make planned targets reality. The UAE provides a good example with the ongoing efforts to achieve globally competitive tariffs for solar (PV) and (CSP), as the country currently aiming to achieve around 80$/MWh for solar (CSP) (Al-Maktoum, 2017). Yet the regulatory framework is still important to provide effective mechanisms and to maintain the leadership of these countries in the global energy market.

References

Agboola, O. P. (2015). The Potentials of Concentrating Solar Thermal Power (CSTP) in Meeting Saudi Future Energy Gap. *Proceedings of the World Congress on Engineering*, 2, 1–5.

Aghahosseini, A., Bogdanov, D., & Breyer, C. (2016). The Role of a 100 % Renewable Energy System for the Future of Iran : Integrating Solar PV , Wind Energy , Hydropower and Storage. In *11th International Energy Conference*. Tehran, Islamic Republic of Iran.

Al-Maktoum, M. bin R. (2017). UAE to invest $163bn in renewable-energy projects.

Al-Nassar, W., Alhajraf, S., Al-Enizi, A., & Al-Awadhi, L. (2005). Potential Wind Power Generation In The State of Kuwait. *Renewable Energy*, *30*(14), 2149–2161. http://doi.org/10.1016/j.renene.2005.01.002

Al-Sahhaf, T. (2016). Sustainable Energy Research and Development. In *International Conference on New Trends for Sustainable Energy (ICNTSE)* (pp. 1–17). Alexandria, Egypt.

Al-Saleh, Y., Upham, P., & Malik, K. (2008). *Renewable Energy Scenarios for the Kingdom of Saudi Arabia*.

Alawaji, S. H. (2001). Evaluation Of Solar Energy Research And Its Applications In Saudi Arabia: 20 Years Of Experience. *Renewable and Sustainable Energy Reviews*, *5*(1), 59–77. http://doi.org/10.1016/S1364-0321(00)00006-X

AlFarra, H. J., & Abu-Hijleh, B. (2012). The Potential Role Of Nuclear Energy in Mitigating CO2 Emissions in The United Arab Emirates. *Energy Policy*, *42*, 272–285. http://doi.org/10.1016/j.enpol.2011.11.084

AlGarni, H., Kassem, A., Awasthi, A., Komljenovic, D., & Al-Haddad, K. (2016). A Multicriteria Decision Making Approach For Evaluating Renewable Power Generation Sources In Saudi Arabia. *Sustainable Energy Technologies and Assessments*, *16*, 137–150.

Alhajraf, S. (2017). *Role of Renewable Energy in Kuwait Energy Security Vision 2030*. Kuwait, Kuwait.

Almansoori, A., & Betancourt-Torcat, A. (2015). Design Optimization Model For The Integration Of Renewable And Nuclear Energy In The United Arab Emirates' Power System. *Applied Energy*, *148*, 234–251. http://doi.org/10.1016/j.apenergy.2015.03.068

Alnaser, W. E., & Alnaser, N. W. (2011). The Status Of Renewable Energy In The GCC Countries. *Renewable and Sustainable Energy Reviews*, *15*(6), 3074–3098. http://doi.org/10.1016/j.rser.2011.03.021

Alotaibi, S. (2011). Energy Consumption In Kuwait: Prospects and Future Approaches. *Energy Policy*, *39*(2), 637–643. http://doi.org/10.1016/j.enpol.2010.10.036

Alyahya, S., & Irfan, M. A. (2016). The Techno-Economic Potential of Saudi Arabia's Solar Industry. *Renewable and Sustainable Energy Reviews*, *55*, 697–702. http://doi.org/10.1016/j.rser.2015.11.017

Arnesano, M., Carlucci, A. P., & Laforgia, D. (2012). Extension Of Portfolio Theory Application To Energy Planning Problem - The Italian case. *Energy*, *39*(1), 112–124. http://doi.org/10.1016/j.energy.2011.06.053

Aryanpur, V., & Shafiei, E. (2015a). Optimal deployment of renewable electricity technologies in Iran and implications for emissions reductions. *Energy*, *91*, 882–893. http://doi.org/10.1016/j.energy.2015.08.107

Aryanpur, V., & Shafiei, E. (2015b). Optimal Deployment of Renewable Electricity Technologies in Iran And Implications for Emissions Reductions. *Energy*, *91*, 882–893. http://doi.org/10.1016/j.energy.2015.08.107

Atabi, F. (2004). Renewable energy in Iran: Challenges and opportunities for sustainable development. *International Journal of Environmental Science & Technology*, *1*(1), 69–80. http://doi.org/10.1007/BF03325818

Ataei, A., Choi, J., Shamshiri, S., & Torabi, H. (2015). Evaluating of the Energy Consumption in Iran During 1980-2030 Using the Leap Model Evaluating of the Energy Consumption in Iran During 1980-2030 Using the Leap Model. *American Journal of Renewable and Sustainable Energy*, *1*(2), 72–85.

Awerbuch, S. (2006). Portfolio-Based Electricity Generation Planning: Policy Implications For Renewables And Energy Security. *Mitigation and Adaptation Strategies for Global Change*, *11*(3), 693–710. http://doi.org/10.1007/s11027-006-4754-4

Awerbuch, S., & Berger, M. (2003). Applying Portfolio Theory To EU Electricity Planning And Policy Making. *IEA/EET Working Paper*, *3*(February), 69.

Awerbuch, S., & Yang, S. (2008). An Efficient, Sustainable And Secure Supply Of Energy For Europe. In F. M., Roques (Ed.), *Analytical Methods for Energy Diversity and Security* (Vol. 12, pp. 38–61). Amsterdam, Netherlands: Elsevier.

Bar-Lev, D., & Katz, S. (1976). Portfolio Approach To Fossil-Fuel Procurement in Electric Utility Industry. *Journal of Finance*, *31*(3), 933–947. http://doi.org/10.2307/2326437

Bayar, T. (2017). Iran To More Than Double Renewable Capacity In One Year.

Bazilian, M., & Roques, F. (2008). *Analytical Methods for Energy Diversity and Security*. Elsevier Science.

Boccard, N. (2009). Capacity Factor Of Wind Power Realized Values Vs. Estimates. *Energy Policy*, *37*(7), 2679–2688. http://doi.org/10.1016/j.enpol.2009.02.046

Chandhoke, A., & Kaur, R. (2015). Iran is on an Aggressive Growth Path to Develop Renewable Energy to Manage with Capacity Shortages, notes Frost & Sullivan. Retrieved August 25, 2016, from http://ww2.frost.com/news/press-releases/iran-aggressive-growth-path-develop-renewable-energy-manage-capacity-shortages-notes-frost-sullivan/

Chitchian, H. (2014). Iran's Electricity Generation Capacity to Reach 100,000 MW. Retrieved March 23, 2016, from http://www.iran-daily.com/News/56429.html

Cunningham, N. (2017). Saudi Arabia To Spend $50 Billion On Massive Solar Push. Retrieved January 28, 2017, from http://oilprice.com/Energy/Energy-General/Saudi-Arabia-To-Spend-50-Billion-On-Massive-Solar-Push.html

Damodaran, A. (2001). *Corporate Finance: Theory and Practice* (2nd ed.). John Wiley & Son.

DLR. (2005). Concentrating Solar Power for the Mediterranean Region. *MED-CSP Project*, 285.

Dodd, J. (2015). Analysis Iran Takes Action To Enable Renewables Growth.

ECRA. (2004). Electric Energy Production Costing for the Saudi Electricity Sector (Phase-I), (November).

Edenhofer, O., Pichs Madruga, R., & Sokona, Y. (2012). *Renewable Energy Sources and Climate Change Mitigation. Ipcc* (Vol. 6). Geneva, Switzerland.

Electricity & Cogeneration Regulatory Authority (ECRA). (2006). *Updated Generation Planning for the Saudi Electricity Sector Report*. Dhahran, Saudi Arabia.

Electricity & Cogeneration Regulatory Authority (ECRA). (2014). *Electricity Annual Report*. Riyadh, Saudi Arabia.

Escribano Francés, G., Marín-Quemada, J. M., & San Martín González, E. (2013). RES and risk: Renewable Energy's Contribution To Energy Security- A Portfolio-based Approach. *Renewable and Sustainable Energy Reviews*, *26*, 549–559. http://doi.org/10.1016/j.rser.2013.06.015

Excel Optimization Tool provided by Trancik Lab, Institute for Data, Systems and Society (IDSS), Massachusetts Institute of Technology

Fattouh, B., & Sen, A. (2016). *Saudi Arabia's Vision 2030: Oil Policy and the Evolution of the Energy Sector.*

Fischlein, M., Wilson, E. J., Peterson, T. R., & Stephens, J. C. (2013). States Of Transmission: Moving Towards Large-Scale Wind Power. *Energy Policy*, *56*, 101–113. http://doi.org/10.1016/j.enpol.2012.11.028

Follet, A. (2016). Saudi Arabia To Start Building Nuclear Power Plants "Very Soon." Retrieved January 1, 2016, from http://dailycaller.com/2016/10/20/saudi-arabia-to-start-building-nuclear-power-plants-very-soon/

Gómez, D. R., Watterson, J. D., Americanohia, B. B., Ha, C., Marland, G., Matsika, E., … Treanton, K. (2006). *Guidelines for National Greenhouse Gas Inventories- Combustion Stationary. IPCC.* Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

Griffiths, S. (2013). Strategic Considerations for Deployment of Solar Photovoltaics in The Middle East And North Africa. *Energy Strategy Reviews*, *2*(1), 125–131. http://doi.org/10.1016/j.esr.2012.11.001

Groissböck, M., & Pickl, M. J. (2016). An Analysis Of The Power Market In Saudi Arabia: Retrospective Cost And Environmental Optimization. *Applied Energy*, *165*, 548–558. http://doi.org/10.1016/j.apenergy.2015.12.086

Gross, R., Blyth, W., & Heptonstall, P. (2010). Risks, Revenues And Investment In Electricity Generation: Why Policy Needs To Look Beyond Costs. *Energy Economics*, *32*(4), 796–804. http://doi.org/10.1016/j.eneco.2009.09.017

Gulf Business. (2015). UAE's Electricity Demand To Exceed 40,000MW By 2020. Retrieved April 6, 2016, from http://gulfbusiness.com/uaes-energy-demand-to-exceed-40000mw-by-2020/

Hang, Q., Jun, Z., Xiao, Y., & Junkui, C. (2008). Prospect Of Concentrating Solar Power In China-The Sustainable Future. *Renewable and Sustainable Energy Reviews*, *12*(9), 2498–2507. http://doi.org/10.1016/j.rser.2007.06.002

Hashem, H. (2017). Saudi Arabia Tenders Open Up New CSP Power, Desalination Markets. Retrieved from February 18, 2017

Hosseini, S. E., Andwari, A. M., Wahid, M. A., & Bagheri, G. (2013). A Review On Green Energy Potentials In Iran. *Renewable and Sustainable Energy Reviews*, *27*, 533–545. http://doi.org/10.1016/j.rser.2013.07.015

IEA. (2010). *Projected Costs of Generating Electricity. IEA* (Vol. 118 Suppl). Paris, France.

IEA. (2014). *Linking Heat and Electricity Systems. IEA*. Paris, France.

IEA. (2015a). *Projected Costs of Generating Electricity- 2015 Edition.* Paris, France.

IEA. (2015b). *World Energy Outlook.* Paris, France. http://doi.org/10.1787/weo-2014-en

IEA ETSAP. (2010). *Technology Brief: Biomass for Heat and Power*. Paris, France.

International Business Publication (IBP). (2015). *Kuwait Energy Policy, Laws and Regulations Handbook- Volume 1 Strategic Information and Basic Laws*. Washingston, D.C.: IBP.

Iran-German Cooperation. (2009). *Energy Scenarios for Iran*. Tehran, Islamic Republic of Iran.

Iran's Ministry of Power. (2015). *Iran Electricity Statistics*. Tehran, Islamic Republic of Iran.

Iran's Ministry of Power. (2016). *Statistical Report of Iran's Electricity Industry*. Tehran, Islamic Republic of Iran.

IRENA. (2014a). *A Renewable Energy Roadmap*. Abu Dhabi, United Arab Emirates.

IRENA. (2014b). *Rethinking Energy: Towards A New Power System*. Abu Dhabi, United Arab Emirates.

IRENA. (2015). *Renewable Energy Prospects: United Arab Emirates*. Abu Dhabi, United Arab Emirates.

Janajreh, I., Su, L., & Alan, F. (2013). Wind Energy Assessment: Masdar City Case Study. *Renewable Energy*, *52*(December 2014), 8–15. http://doi.org/10.1016/j.renene.2012.09.025

Jandal, S. Al, & Sayegh, O. Al. (2015). Clean Energy Policy Options: Modeling Possible Deployment Scenarios. In *EcoMod Conference*. Boston, MA.

Jeddah Chamber. (2015). *Sectorial Report on Saudi Arabia Electricity*. Jeddah, Kingdom of Saudi Arabia.

John, I. (2017). Power up: UAE needs $35b.

KA-CARE. (2012). Building the Renewable Energy Sector in Saudi Arabia. Retrieved October 8, 2016, from http://irena.org/DocumentDownloads/events/MaltaSeptember2012/5_Ibrahim_Babelli.pdf

KA-CARE. (2015). Saudi Arabia's Nuclear Energy Program for Electricity Generation.

Khajehpour, B. (2016). Will New 5-Year Plan Solve Iran's Economic Problems? Retrieved August 8, 2016, from http://www.al-monitor.com/pulse/originals/2016/06/iran-sixth-five-year-development-plan-rouhani-parliament.html

Khatib, H. (2016). A review of the IEA/NEA Projected Costs of Electricity - 2015 edition. *Energy Policy*, *88*, 229–233. http://doi.org/10.1016/j.enpol.2015.10.030

Kingdom of Saudi Arabia. (2016). *Vision 2030*. Riyadh, Saudi Arabia. Retrieved from http://vision2030.gov.sa/sites/default/files/report/Saudi_Vision2030_EN_0.pdf

KISR. (2016). Kuwait Innovative & Renewable Energy Program. Retrieved August 8, 2016, from http://www.kisr.edu.kw/en/research/energy-and-building/programs/innovative-and-renewable-energy-program

Lindner, J. (2017). Iran Rapid Growth in Renewable Energy.

Mahdi, W. (2016). Saudi Arabia Scales Back Renewable Energy Goal to Favor Gas. Retrieved from http://www.bloomberg.com/news/articles/2016-06-07/saudi-arabia-scales-back-renewable-energy-target-to-favor-gas

Malek, C. (2016). Nuclear Power is the Answer To Growing Energy Demands.

Mansouri, N. Y., Crookes, R. J., & Korakianitis, T. (2013). A Projection Of Energy Consumption And Carbon Dioxide Emissions In The Electricity Sector For Saudi Arabia: The Case For Carbon Capture And Storage And Solar Photovoltaics. *Energy Policy*, *63*, 681–695. http://doi.org/10.1016/j.enpol.2013.06.087

Markowitz, H. (1952). Portfolio Selection. *The Journal of Finance*, *7*(1), 77–91. http://doi.org/10.1111/j.1540-6261.1952.tb01525.x

Marreiro, G. A., Ramos-real, F. J., & Losekann, L. (2013). Efficient Power Generating Portfolio in Brazil: Conciliating Cost, Emissions and Risk. *Energy Policy*, *62*, 301–314. http://doi.org/http://dx.doi.org/10.1016/j.enpol.2013.07.049

Mazandarani, A., Mahlia, T. M. I., Chong, W. T., & Moghavvemi, M. (2011). Fuel Consumption And Emission Prediction By Iranian Power Plants Until 2025. *Renewable and Sustainable Energy Reviews*, *15*(3), 1575–1592. http://doi.org/10.1016/j.rser.2010.11.043

McAuley, A. (2016). UAE Eyes New Clean Energy Generation Target By 2030.

McAuley, A. (2017). Saudi Arabia's Slow Pace On Renewables A Risk to Oil Exports. Retrieved March 25, 2017, from http://www.thenational.ae/business/energy/saudi-arabias-slow-pace-on-renewables-a-risk-to-oil-exports

McDermott, M. (2012). Saudi Arabia Aims For 41 GW Solar Power By 2032. Retrieved December 9, 2016, from https://www.treehugger.com/renewable-energy/saudi-arabia-aims-for-41-gigawatts-solar-power-2032.html

MESIA. (2017). Mena Solar Market Outlook, (January).

Mittal, S. (2015). UAE Reiterates Target Of 24% Clean Energy Share by 2021 CleanTechnica. Retrieved August 12, 2016, from https://cleantechnica.com/2015/10/30/uae-reiterates-target-24-clean-energy-share-2021/

Mohammadnejad, M., Ghazvini, M., Mahlia, T. M. I., & Andriyana, A. (2011). A Review On Energy Scenario And Sustainable Energy in Iran. *Renewable and Sustainable Energy Reviews*, *15*(9), 4652–4658. http://doi.org/10.1016/j.rser.2011.07.087

Mokri, A., Aal Ali, M., & Emziane, M. (2013a). Solar energy in the United Arab Emirates: A review. *Renewable and Sustainable Energy Reviews*, *28*, 340–375. http://doi.org/10.1016/j.rser.2013.07.038

Mokri, A., Aal Ali, M., & Emziane, M. (2013b). Solar Energy in The United Arab Emirates: A Review. *Renewable and Sustainable Energy Reviews*, *28*, 340–375. http://doi.org/10.1016/j.rser.2013.07.038

Mondal, M. A. H., Kennedy, S., & Mezher, T. (2014a). Long-term Optimization Of United Arab Emirates Energy Future: Policy Implications. *Applied Energy*, *114*, 466–474. http://doi.org/10.1016/j.apenergy.2013.10.013

Mondal, M. A. H., Kennedy, S., & Mezher, T. (2014b). Long-Term Optimization Of United Arab Emirates Energy Future: Policy Implications. *Applied Energy*, *114*, 466–474. http://doi.org/10.1016/j.apenergy.2013.10.013

Moshiri, S. (2015). *Sustainable Energy Strategy for Iran*.

Mostafaeipour, A., Jadidi, M., Mohammadi, K., & Sedaghat, A. (2014). An analysis of wind energy potential and economic evaluation in Zahedan, Iran. *Renewable and Sustainable Energy Reviews*, *30*, 641–650. http://doi.org/10.1016/j.rser.2013.11.016

Müller, S., Brown, A., & Ölz, S. (2011). *Policy Considerations For Deploying Renewables. IEA*. Retrieved from https://www.iea.org/publications/freepublications/publication/Renew_Policies.pdf

Najafi, G., Ghobadian, B., Mamat, R., Yusaf, T., & Azmi, W. H. (2015). Solar Energy In Iran: Current State and Outlook. *Renewable and Sustainable Energy Reviews*, *49*, 931–942.

Oxford Business Group. (2016a). Kuwait's Drive Toward Fuel Subsidy Rationalisation. Retrieved January 3, 2017, from http://www.oxfordbusinessgroup.com/news/kuwait's-drive-toward-fuel-subsidy-rationalisation

Oxford Business Group. (2016b). *Kuwait's Energy*.

Page, B. (2016). The Global Status of CCS, 1–28.

Parajuli, R., Hussong, C., Ntoka, C., Charisoulis, G., Tulucan, T., & Sperling, K. (2015). Beyond Oil And Gas: Possible Future Scenarios For The Electricity Sector In Saudi Arabia. *International Journal of Sustainable Energy*, *34*(2), 71–92. http://doi.org/10.1080/14786451.2013.821991

Pourhossein, M., & Nahavandi, N. (2014). Transition in Iran ' s Electricity Market Considering the Policies on Elimination of Electricity Subsidies : System Dynamics Application.

PRWEB. (2014). CSP Today Saudi Arabia Reveals Plans for Its First Power Plant Using CSP to Supply to the Grid. Retrieved September 22, 2016, from http://www.prweb.com/releases/2014/01/prweb11475419.htm

Ramadhan, M., Hussain, A., & Behbehani, D. (2013). The Prospect of Solar Energy in the Development of Power Stations in the State of Kuwait. *Journal of Renewable Energy*, *2013*(ii), 1–6. http://doi.org/10.1155/2013/374265

Ramadhan, M., & Naseeb, A. (2011). The Cost Benefit Analysis of Implementing Photovoltaic Solar System in The State of Kuwait. *Renewable Energy*, *36*(4), 1272–1276. http://doi.org/10.1016/j.renene.2010.10.004

Rehman, S., & Shash, A. (2005). Geothermal Resources of Saudi Arabia – Country Update Report DEMANDS AND FUTURE. *World Geothermal Congress 2005*, (April), 24–29.

Reuters. (2016). Saudi Arabia targets 9.5 gigawatts of renewable by 2030. Retrieved July 8, 2016, from http://english.alarabiya.net/en/business/energy/2016/04/26/Saudi-Arabia-targets-9-5-GW-of-renewable-by-2030.html

Reuters. (2017). Saudi Arabia to Launch a $30-$50 Billion Renewable Energy Program. Retrieved October 2, 2017, from http://fortune.com/2017/01/16/saudi-arabia-renewable-energy-program/

REVE. (2016). Wind energy in Iran: 4th Iranian Wind Power Congress.

Rezaian, J. (2010). Iran Remains Stable Despite Dramatic Price Increases. Retrieved January 3, 2017, from https://www.pri.org/stories/2010-12-20/iran-remains-stable-despite-dramatic-price-increases

Rostami, E. F. (2015). *Investment Opportunities For RE Projects in Iran*. Universitat Kassel.

Said, M. S., & El-Amin, I. (2004). *Renewable energy in Saudi Arabia*. Beirut, Lebanon. Retrieved from http://www.nortonrosefulbright.com/knowledge/publications/61454/renewable-energy-in-saudi-arabia

Samimi, J. (1994). Estimation of height-dependent solar irradiation and application to the solar climate of Iran. *Solar Energy*, *52*(5), 401–409. http://doi.org/10.1016/0038-092X(94)90117-K

Saurabh. (2016). Kuwait Commissions Its First Solar Power Project. Retrieved January 1, 2016, from http://cleantechies.com/2016/10/31/kuwait-commissions-its-first-solar-power-project/

Sgouridis, S., Abdullah, A., Griffiths, S., Saygin, D., Wagner, N., Gielen, D., … McQueen, D. (2016a). RE-mapping the UAE's energy transition: An economy-wide assessment of renewable energy options and their policy implications. *Renewable and Sustainable Energy Reviews*, *55*, 1166–1180. http://doi.org/10.1016/j.rser.2015.05.039

Sgouridis, S., Abdullah, A., Griffiths, S., Saygin, D., Wagner, N., Gielen, D., … McQueen, D. (2016b). RE-mapping the UAE's Energy Transition: An Economy-Wide Assessment Of Renewable Energy Options And Their Policy Implications. *Renewable and Sustainable Energy Reviews*, *55*, 1166–1180. http://doi.org/10.1016/j.rser.2015.05.039

Sgouridis, S., Griffiths, S., Kennedy, S., Khalid, A., & Zurita, N. (2013a). A sustainable energy transition strategy for the United Arab Emirates: Evaluation of options using an Integrated Energy Model. *Energy Strategy Reviews*, *2*(1), 8–18. http://doi.org/10.1016/j.esr.2013.03.002

Sgouridis, S., Griffiths, S., Kennedy, S., Khalid, A., & Zurita, N. (2013b). A Sustainable Energy Transition Strategy for The United Arab Emirates: Evaluation of Options Using An Integrated Energy Model. *Energy Strategy Reviews*, *2*(1), 8–18. http://doi.org/10.1016/j.esr.2013.03.002

Short, W., Packey, D., & Holt, T. (1995). A manual for the economic evaluation of energy efficiency and renewable energy technologies. *University Press of the Pacific*, *2*(March), 120.

Smith, J. C., Osborn, D., Zavadil, R., Lasher, W., Gómez-Lázaro, E., Estanqueiro, A., … Dale, L. (2013). Transmission planning for wind energy in the United States and Europe: Status and prospects. *Wiley Interdisciplinary Reviews: Energy and Environment*, *2*(1), 1–13. http://doi.org/10.1002/wene.8

Soofi, A. S., & Goodarzi, M. (2017). *The Development of Science and Technology in Iran: Policies and Learning*. Palgrave Macmillan.

Stanton, C. (2009). Kuwait become net gas importer.

Taleb, H. M. (2009). Barriers Hindering The Utilisation of Geothermal Resources In Saudi Arabia. *Energy for Sustainable Development*, *13*(3), 183–188. http://doi.org/10.1016/j.esd.2009.06.004

TAVANIR. (2014). *Statistical Report on 47 Years of Activities of Iran Electric Power Industry*. Tehran, Islamic Republic of Iran.

Tidball, R., Bluestein, J., Rodriguez, N., & Knoke, S. (2010). *Cost and performance assumptions for modeling electricity generation technologies. National Renewable Energy Lab, NREL, Subcontract Report.*

Trading Economics. (2017). Land Area Database.

U.S. Energy Information, a. (2013). *Annual Energy Outlook 2013. Office of Integrated and International Energy Analysis* (Vol. 1). Washingston, DC.

U.S. Energy Information Administration. (2011). *Annual Energy Review 2011.*

U.S Energy Information Administration. (2016). *Kuwait: Country Analysis Brief.* Retrieved from http://www.eia.gov/beta/international/analysis_includes/countries_long/Nigeria/nigeria.pdf

US department of the Interior Bureau of Reclamation Power Resources office. (2005). *Reclamation: managing water for the west. Hydroelectric Power.* United States.

Watson Farley & Williams. (2016). Renewable Energy in Iran. http://doi.org/58231623v1© Watson Farley & Williams 2016 All

World Bank. (2016). *World Development Indicators.* Washingston, DC. Retrieved from http://data.worldbank.org/sites/default/files/wdi-2016-highlights-featuring-sdgs-booklet.pdf

World Nuclear Association. (2015). Nuclear Power in Saudi Arabia. Retrieved January 1, 2017, from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Saudi-Arabia/

World Nuclear Association. (2017). Nuclear Power United Arab Emirates. *Www.World-Nuclear.Org.* Retrieved from http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Arab-Emirates/

Yessian, K., DeLaquil, P., Merven, B., Gargiulo, M., & Goldstein, G. (2013). Economic Analysis Of Clean Energy Options For Kuwait. *International Journal of Energy Sector Management*, *7*(1), 29–45. http://doi.org/10.1108/17506221311316461

Zhu, L., & Fan, Y. (2010). Optimization Of China's Generating Portfolio And Policy Implications Based On Portfolio Theory. *Energy*, *35*(3), 1391–1402. http://doi.org/10.1016/j.energy.2009.11.024

7. Conclusion

The thesis attempts to provide an overview of the role of low-carbon energy supply and renewable technologies in the reducing CO_2 emissions in the Middle East. The focus was given to four countries, which account for the largest segment of the region's emissions and power demand. Accordingly, the main objective has been to examine emissions implications from transition to natural gas usage in primary energy supply and to analyze the role of power sector in achieving climate targets through large renewable deployment. This has been linked to the 450-emission pathway developed for the Middle East and current planned renewable targets. The chapter presents an overview of the main topics addressed, provides a discussion on both findings, research contribution and concludes with recommendation on future research.

7.1 Synthesis of the Thesis Findings

One of the major challenges that threaten the future of energy in the Middle East is the great reliance on non-renewable fossil fuel resources. The increasing population expansion, economic development and rapid urbanization have largely induced the continuation of consuming cheap energy resources that are significantly carbon-intensive. Main findings from analysis conducted in Chapters 2 through chapter 6 are addressed along formulated research questions.

Chapter 2 investigates energy trends in the Middle East region to understand the structure of its energy systems, key trends that are driving emissions and highlight the role of renewable energy resources:
What do current energy production and energy use trends mean for CO_2 emission escalation in the Middle East?

Analysis showed that the rapid growth of energy consumption in the Middle East indicates a growing trend will continue within the next few years. These trends will be underpinned by subsidized fuel prices, which will be a major obstacle the clean energy transition across the region. In addition, large reliance on fossil fuel resources for energy supply will be major challenge for the clean transition towards low carbon and clean energy technologies. Results from the analysis showed that decarbonization of power generation sector and expanding renewable penetration in specific, are crucial to meet emission reduction goals. The region has significant solar and wind potentials suitable to take part in the decarbonization of the power sector. Thus, the huge potential of renewable resources across the Middle East stands as a salvation for the region's energy problems. Yet, renewable energy technologies are still at a very early stage of development with a modest share of 1% of total primary energy supply. Mitigation strategies were found to be greatly differing across the region, liable to economic development and financial characteristics. Nevertheless, electricity generation sector holds the key role in low-emission pathway. Finally, long-term commitment to climate change mitigation showed that Middle Eastern countries have set ambitious targets for large renewable deployment; yet, they can only be achieved through supporting policies and institutional framework to push the development of low-carbon energy systems.

Chapter 3 examines energy structure in four countries that account for 77% of total carbon emission in the Middle East. The chapter focused on analyzing trends of energy production and consumption and their impact on the region's CO_2 emission increase. It concludes with a relative comparison of the performance of these countries versus global averages:
What is the role of countries with large fossil fuel base in the sustainable development of the Middle East's energy system?

Results from the analysis showed that challenges in the four countries are biggest due to their large fossil fuel reserves that account for more than 75% of the region's proven oil reserves and around 63% of its natural gas reserves. In addition, fossil fuels supply on average more than 95% of total energy supply with a merely small share of renewable resources in both Iran and the UAE. In addition, oil and natural gas usage varies greatly across the four countries. Some countries rely more on natural gas than oil such as Iran and the UAE, while others use more oil than natural gas such as Saudi Arabia and Kuwait. On the basis of emissions distribution, Iran and Saudi Arabia alone account for almost 60% of the region's CO_2 emissions. The structure of energy subsidy in the four countries indicated that it has largely induced the significant increase in energy consumption. Findings from performance analysis showed that the inefficient energy production, consumption have played a role in the deterioration of energy landscape of the four countries compared to the global energy system. Finally, the development of energy sector and sustainable development policies were largely ineffective during the past twenty years. Yet, there are some exception in countries like the UAE. In general, there is a huge need for these countries to pay attention to energy policies to improve their energy sector and mandate the way energy is consumed on a national level.

Chapter 4 analyzed power generation sector in the four countries, examined electricity-generating technologies, renewable energy resources potentials and outlined prospects for nuclear power generation: *How does the current structure of power sector affect the expansion of renewable technologies deployment? What are the potentials of large renewable deployment from the perspective of resource availability?*

Analysis on power generation sector showed that it is significantly reliant on fossil fuels especially natural gas. In addition, high levels of electricity consumption across the four countries was strongly linked to subsidizing electricity price for end-use sectors. It was also indicated that building sector accounts for the largest share in total electricity demand followed by industrial sector. After examining current power policies, it was found that nuclear power would play a significant role in the generation mix of Iran, Saudi Arabia and the UAE. Some countries are taking larger leaps in nuclear deployment than other like Iran and UAE. It has also been shown that there is a huge potential for renewable resources across the four countries, especially for solar and wind. In addition, among the four countries, UAE had the most ambitious energy plans. Finally, the chapter outlined electricity demand forecasts and expected power capacity in 2020 and 2030. From this analysis, it was concluded that renewable energy technologies are challenged with various technical, social and economic barriers. Policy legislation and the absence of legal framework to promote renewable deployment are two of major obstacles facing the decarbonization of power sector. In addition, demand side management across different economic sectors, especially building sector, is a critical in the near term.

Chapter 5 examined the relationship between the increase of CO_2 emissions and the structure of the energy supply mix across the Middle East. Then, the focus was given to investigate how individual countries, namely the four major emitters, could contribute to the region's emissions reduction goals under "BAU" projections. Emissions were projected with a modified model of the Kaya identity, in which CO_2 emissions were decomposed based on proportional growth rates of the total primary energy supply (TPES). Then, the chapter constructs a regression model to forecast total primary energy demand to examine the impact of transitioning to natural gas usage from the perspectives of energy demand and energy supply:
How can countries with large fossil fuel reserves contribute to regional emission reduction goals? Can shifting to natural gas act as a technology bridge to fill emission gap?

Results of emissions distribution across the Middle East showed there is causal link between fossil fuel reserve size, and the structure of energy supply. As generally, resource-rich countries are the ones who emit more. In addition, five clusters of Middle Eastern countries are identified in which CO_2 emission volume is clearly affected by the structure of energy supply mix. Findings from BAU projections indicated that the four major emitters are significantly driving the increase of CO_2 emissions in the Middle East accounting for 79% of total emission increases by 2040. In addition, it was found that nearly 980 Mt of emission saving could be attained by 2040 from shifting towards more natural gas usage. Forecast results from regression model underlined that there is a strong, growing demand for natural gas that is expected to surge in the next decade. This was clearly seen in countries that are largely reliant on oil in their primary energy supply, such as Iran and Saudi Arabia. Finally, the chapter outlined main barriers hindering the shift towards more usage of natural gas. It was found that, domestic gas supply has lagged behind growing demand across the four countries. In addition, there was a gap between gas demand and sufficient investment in infrastructure, in cases like Iran, Saudi Arabia and Kuwait.

Chapter 6 examined how electricity generation sector can reach the 450-emission goal through the integration of low carbon technologies. The analysis was performed using mean variance portfolio optimization model to delineate optimal generation mix and associated capacity to meet the 450-emission target:
What mix of renewable technologies are more effective to reach emission targets? Which obstacles and challenges can be expected when applying different renewable mixes?

Results from the mean variance model showed that the 450- emission target could be achieved with current energy strategies with the use of Carbon Capture (CC) technology but at higher cost. Renewable generation technologies were allocated based on the distribution of resource potentials taking into account expected power and current installed power capacity. Solar PV and CSP technologies had the largest share in Saudi Arabia, Kuwait and the UAE. Hydropower and wind will collectively have the largest share in Iran's annual generation, growing from 5% in 2010 to 15% in 2030. For Kuwait, RETs penetration will expand to nearly 48% of total generation in 2030. Finally, a sensitivity analysis of discount factors showed that there is a strong relationship between the discount rate value and the economic viability of renewable deployment. These results indicate that achieving emission reduction targets through renewable generation expansion is not limited to overall resources availability, but by adequate use of economic and technical choices to facilitate their success.

7.2 Recommendation for Future Research

The research questions addressed in this thesis are directed towards a better understanding of power sector role in curbing CO_2 emission under specific climate policies and possible reduction from switching to natural gas usage. A number of areas were explored in the thesis in differing detail to work towards the optimization of electricity generation mix and the estimation of natural gas transition pathway. Although there are several gaps in the overall analysis, the contribution of this work stems from presenting a conclusive and reasonable study that can be used as a foundation for further investigations of the energy landscape of the Middle East.

With respect to presented application, there is still further analysis needed to understand implications from natural gas transition. Analysis presented in chapter 5 used a simple regression model to forecast energy demand in the four countries of interest. Yet, further investigation with projections from different economic sectors is useful to highlight if results would still be true. Analysis in chapter 5 looked solely at potentials of natural gas shift without taking into consideration effects of renewable deployment. Thus, analyzing implication of current renewable strategies alongside natural gas transition would be relevant to examine possible emissions reduction. Assumptions presented in chapter 6 omit a number of technical characteristics in the development of the optimization framework. Specifically, changes in the overall efficiency and technological improvement in the future was not considered. Yet, considering these factors would provide a more precise recommendation on which technologies are more suitable for larger deployment. In addition, the integration of renewable technologies did not assess the impacts of adding storage to the overall system costs. The pressing issue of intermittence in renewable deployment should be analyzed with respect to cost drawbacks from storage. Further analysis may include RETs' ability to match the load profile with storage and estimate associated costs. Finally, the model framework do not capture the effect of energy efficiency on the overall expected demand and associated emissions. Thus, it is pertinent to investigate whether these results holds true under different energy efficiency measures.