Energy Transition in the Arabian Gulf Countries

A Major Qualifying Project submitted to faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science in Chemical Engineering.

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Date:

July 26th, 2020

Abstract

The Arabian Gulf Countries (AGC) are struggling to reach energy sustainability. Their dependence on oil and natural gas production as a main source of income and source of energy made them produce large amounts of CO_2 emissions. The goal of the project is to assist the AGC reach energy sustainability. The team researched the effects of the current energy production and consumption practices in those countries, its effectiveness, and how to make it beneficial. To deal with this struggle, several solutions must be considered such as the transition to low carbon energy sources, and carbon capture, utilization and sequestration. Three scenarios were created to showcase the effectiveness of those solutions.

Keywords: *direct air capture*, *carbon emissions, clean energy*, *renewable energy*, *Arabian gulf.*

Acknowledgement

The team members would like to thank our advisor, Professor Jennifer Wilcox, for her contributions and support towards this project. We would also thank her for helping us with her essential feedback through the process of our project. The team members would also thank Hélène Pilorge, Post-Doctoral fellow at WPI, for her contributions in our project and providing us with essential data and information that helped us complete our project.

Executive Summary

The Arabian Gulf Countries (AGC) that are going to be discussed in this paper are Saudi Arabia, Kuwait, Bahrain, Qatar, Oman, United Arab Emirates, and Iraq. Those countries cover around 3.0 million km^2 in size. Moreover, the AGC has one of the highest oil and natural gas production rates producing around 25% of the total oil production around the world.

This project addresses the struggle for AGC to reach energy sustainability. Moreover, it addresses the opportunities for an improved energy future in the region. Reaching energy sustainability for the AGC is difficult due to the dependence on fossil fuel for many years. However, the countries' vulnerability to the negative effects of carbon dioxide (CO_2) emissions and the increase in energy demand compels the transition for a cleaner and more sustainable energy sources. Due to the nature of the region, the AGC have a great potential in renewables, direct carbon air capture (DAC), and point-source carbon capture, utilization and sequestration (CCUS).

The goal of this project is to showcase that potential and its effect on the countries' emissions and future energy production and consumption. To do this, the team developed three scenarios. The scenarios main purpose is to demonstrate the different outcomes that could happen from taking three different paths. The scenarios are:

- **Scenario #1** "*Business as Usual*"
  - This scenario explains the effects continue using the same energy sources.
- **Scenario #2** *"Applying the Futuristic Plans"*
  - This scenario explains each country's energy sustainability vision.
- **Scenario #3** *"Potential of renewables, DAC, and CCS"*
  - This scenario showcases the potential for renewables energy, DAC, and CCS.

The first step in the calculations was estimating the energy consumption for the upcoming years. To do that, an estimation for the population in the upcoming years was taken into consideration. The trend for population changes in the previous years in addition to fertility rates, age of marriage, employment, health, life expectancy, average age, and living conditions were used to determine the population growth rate in the region. After that, the current energy consumption per capita was used to extrapolate the trend for the upcoming years 2020-2030.

Using the energy consumption per capita and population, the energy consumption was calculated. After that, the Kaya equation was used to estimate the emissions coming from the energy consumption. The kaya equation depends on multiple variables such as the intensity of carbon in energy, GDP, population, and energy intensity of the economy.

$$E = P \times \frac{GDP}{P} \times \frac{T}{GDP} \times \frac{E}{T} = P \times g \times I$$

Where *E* is the total carbon emissions, *P* is the population, *T* is the total energy consumption, *g* is the GDP per capita, *I* is the intensity of carbon per unit GDP.

In scenario #2, the team researched each of the countries' futuristic vision and focused on the energy sustainability parts of each vision. Saudi Arabia's 2030 vision, Oman's 2040 vision, Kuwait's 2035 vision, Qatar's 2030 vision, Bahrain's 2035 vision, UAE's 2050 vision were all analyzed. Unfortunately, Iraq does not have a vision regarding their energy sustainability. Thus, an assumption was made that they will continue using the same energy sources "scenario #1".

To calculate the change that those visions will do, each transition to renewables was quantified. These transitions were tracked to check what source of energy used to replace the source for that transition. After that, using the carbon content of the previously used fuel, the emissions that used to be emitted were calculated and subtracted from the total emissions in scenario #1. Moreover, energy efficiencies, DAC, CCUS in the visions were taken into consideration.

To reach the goal of scenario #3, two maps were developed. The first map showcases the potential for thermal and electrical direct air carbon capture and sequestration (DACCS) and the second map showcase the NG and oil powerplants in the region with the potential for point source capture and the switch to low carbon energy sources. The first step in doing that was a geological survey for the area to figure out the geological reservoirs that could be used for the sequestration of CO_2. The survey contained knowing where the sedimentary reservoirs, basalts, ultramafic rocks, and oil fields are. The second step was figuring out the potential for low carbon energy sources in the area. The focus was on wind and solar since it has the highest potential in the region. The third step was collecting data for the natural gas and oil powerplants in the AGC. The data was obtained from Enerdata (2019). Enerdata's database contains the information of each unit inside the powerplants. The data collected were the age of the units, net capacity of the units, and the location of the powerplant. The age of the units was used to estimate the decommissioning units in the area. The age of the units is used to see the potential for (1) Replacement with solar or wind if the powerplant is retiring. (2) Installing point source carbon capture if the powerplant still has life expectancy and located next to a low carbon energy source, sequestration or utilization potential.

The population in the region is increasing rapidly, which is causing the energy demand and consumption to also increase.

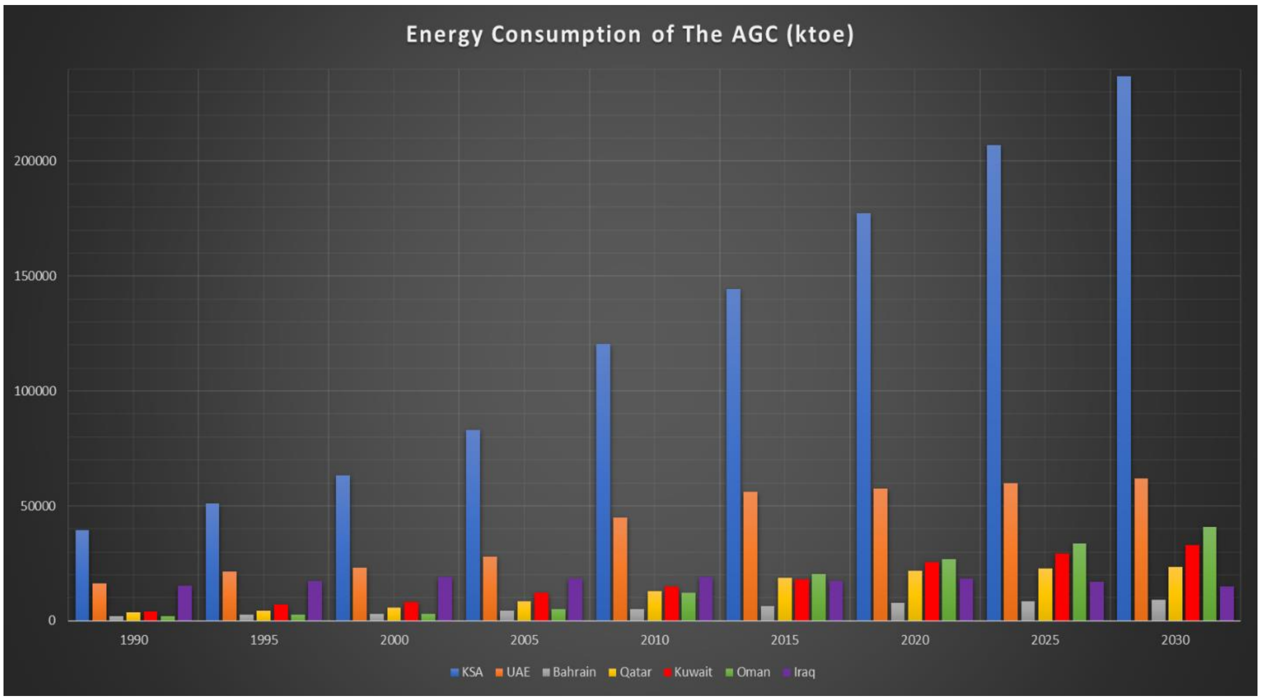

Figure 1 Shows the energy consumption of the AGC

For scenario#1, the energy consumption rises and the continuation of using the same fossil fuels without DAC or CCUS led to the continuous increase in CO_2 emissions. However, the futuristic visions in scenario#2 showed an optimistic decrease in the total CO_2 emissions.

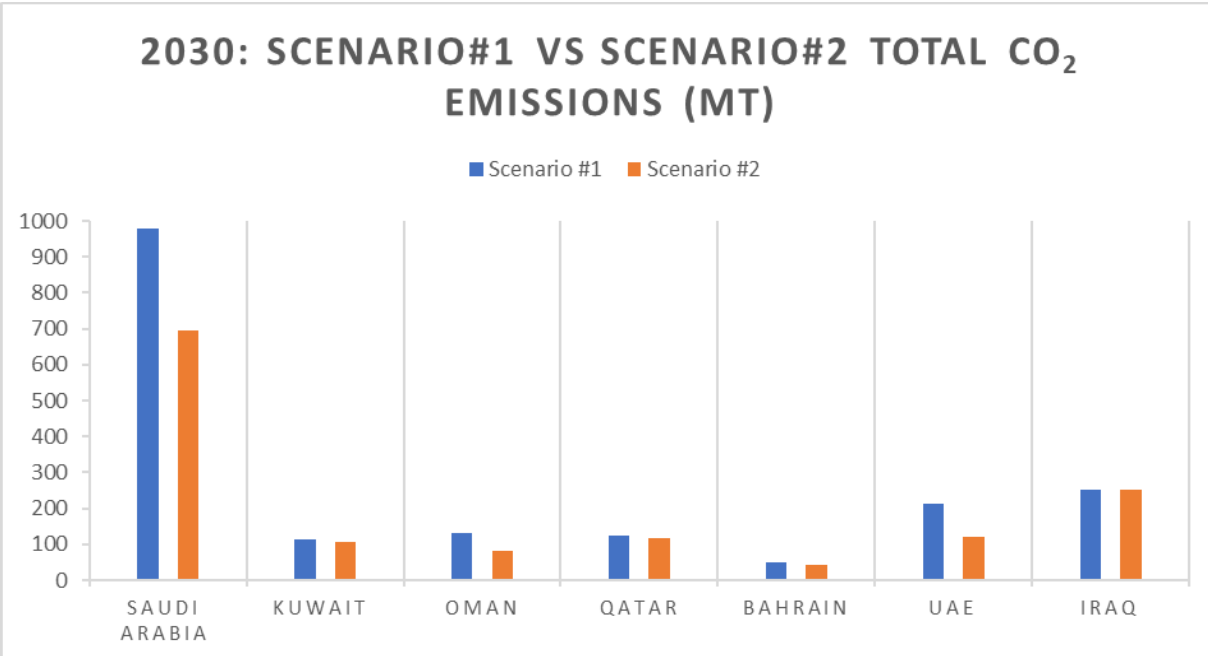

Figure 2 Showcases a comparison between the emissions in scenario #1 and scenario #2

In scenario #3, multiple opportunities for the potential of renewables, DAC, and CCUS were demonstrated on two maps. The first map showcased the potential of replacing fossil fuel powerplants to low carbon energy source such as solar and wind.

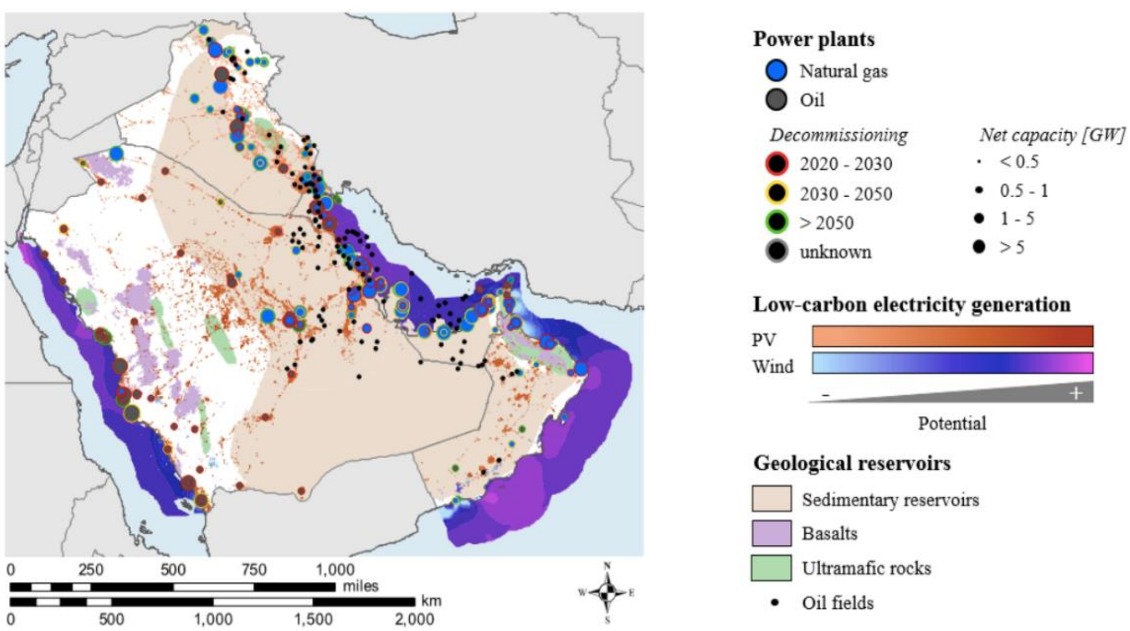

Figure 3 Mapping the potential of renewables and CCUS

We believe that units retiring between 2020-2030 could be replaced by renewable energy units if it is in the region where solar or wind can be used. Carbon capture technologies can be installed on units that has a longer life span. For carbon capture technologies to be installed, the plant must be in proximity of a renewable source potential in order to use it to power the technology and sequestration potential.

The second map illustrates the potential for DACCS. In this map, the potential for thermal and electrical DACCS is showcased. The goal of DACCS is to help sustain emissions coming from the use of fossil fuels and act as a bridge to a cleaner environment in the future.

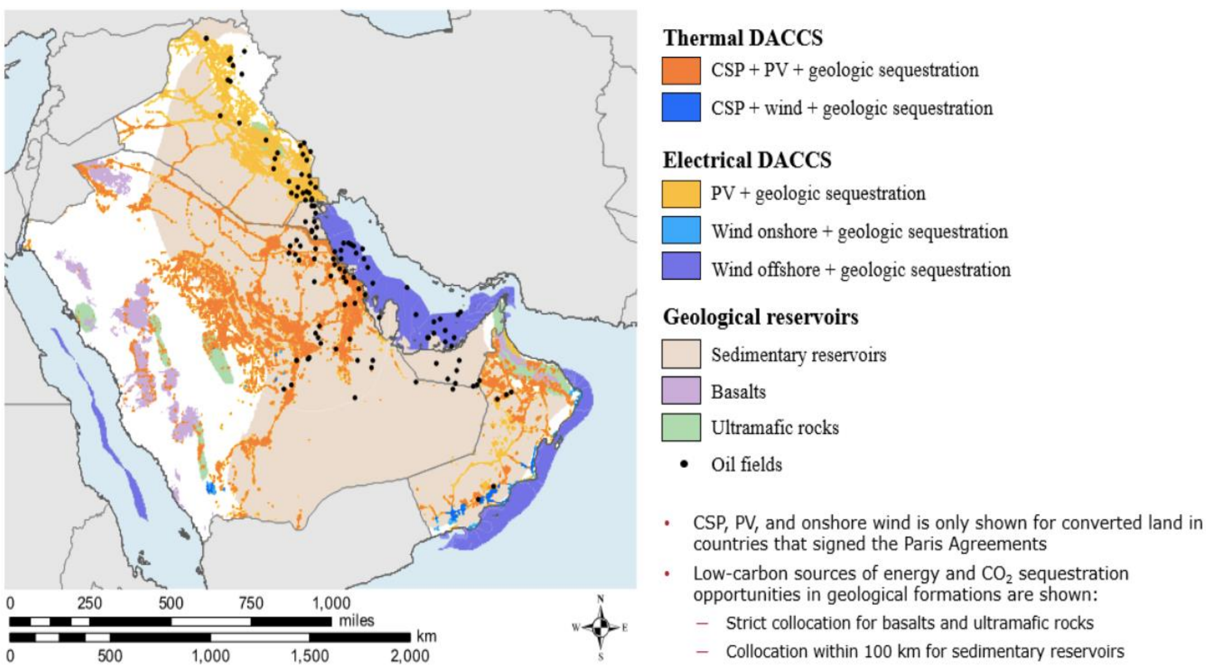

Figure 4 Mapping the DACCS potential in the AGC

We recommend that more data be published by the energy sector and more quantitative research should be done in the energy sector in the AGC. The lack of published data by the energy sector limited the work of the team. We believe that the availability of the data would motivate researchers from around the world to study the energy sector in the region. Those published data will also raise the awareness of the people in the AGC. Moreover, more quantitative data-based research can help improve the future of energy in the region.

Even though the AGC have been depending on fossil fuel for the past decades, the governments understand the effects of CO_2 emission caused by the energy demand in their countries. Therefore, the futuristic plans created by each country asserted the responsibilities the countries are considering. the AGC countries showed optimistic steps toward energy transitioning except for Iraq. The steps taken by the AGC are just beginning. Our paper can be used as base to start creating thoughts and projects about the use of potentials renewables, DAC, and CCS to have a cleaner energy-related future. However, they still need more quantitative research, more time in order to reach energy sustainability, and people to be aware.

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1.0 Introduction

The transition to energy sustainability became the goal of most of the countries around the world. The Arabian Gulf Countries (AGC) defines seven countries that are in the Middle East. Those countries are Saudi Arabia, United Arab Emirates, Bahrain, Kuwait, Iraq, Oman, and Qatar. They cover around 3.0 million km^2 in size. The region of the AGC has one of the highest oil and natural gas production rates, which makes it hard for them to reach energy sustainability. It produces around 25% of the total oil production around the world. The AGC has great opportunities for renewable energy, Direct Air Capture (DAC), and Carbon Capture sequestration (CCS).

The AGC have been depending on fossil fuels as one of their main sources of income and energy source for decades. Some countries such as Saudi Arabia and Oman are reliant on their hydrocarbon sector for nearly 70% of their total revenue (Abdullah, 2019 & Figgins, 2019). Their dependence on oil and natural gas caused the region to produce large amounts of CO_2 emission yearly. Therefore, it is difficult for the region to convert to renewables and clean energy right away. They are currently trying to reduce their CO_2 emission to help improving the environment, public health, economy, and other aspects. The AGC's energy transition to clean energy must be controlled and long-term periods are needed to have effective impacts on the countries. Governments have been working on several visions to achieve this goal of energy transition.

Iraq was the first country to discover oil in the AGC in 1923 and the last was Oman in 1962 (Jassim & Goff, 2006). Moreover, Iraq was also the first country to detect Natural Gas in 1927 with Kuwait last in 2006 (KOC, 2012).

The goal of this project was to reach energy sustainability in the AGC region. In order to achieve this goal, we studied the energy demand, CO_2 emissions, and the future of the energy in each of AGC. To understand those aspects, we created three different scenarios to compare the effects of the energy demand and CO_2 emissions within the next ten years.

- **Scenario #1** *"Business as Usual"*
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- **Scenario #2** *"Applying the Futuristic Plans"*
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2.0 Background

This section going to discuss several matters about the Arabian Gulf Countries, AGC. The countries are Kingdom of Saudi Arabia, United Arab Emirates, Kingdom of Bahrain, Qatar, Iraq, Oman, and Kuwait. The demographics, economy, and the geography of the region is going to be explained. In 2019, the AGC produced around 25% of total oil around the world.

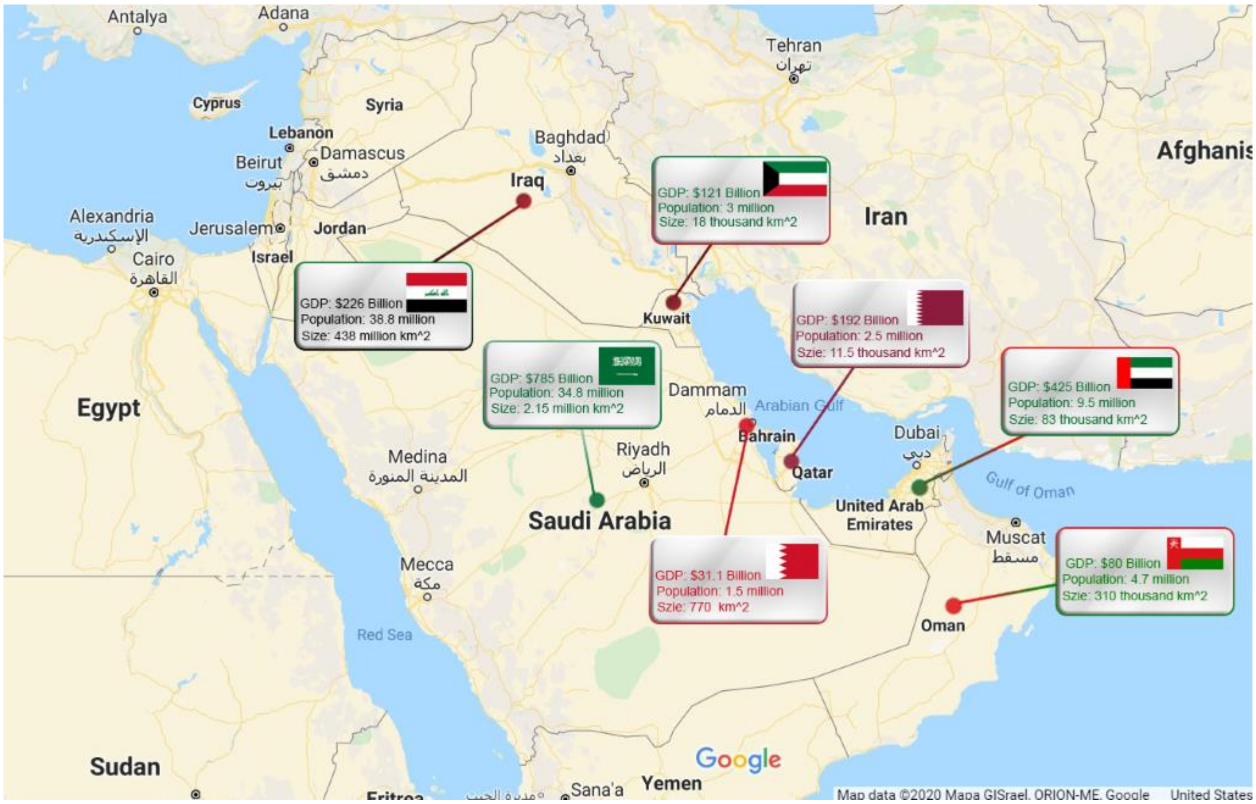


Figure 5 The map of the AGC

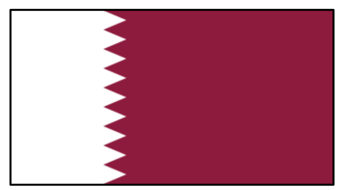
2.1 AGC Introduction:

2.1.1 The Kingdom of Saudi Arabia (KSA) is the largest country between the Arabian gulf countries. It is 2,150,000 km^2 in area, with the population of 34.8 million (Saudi Arabia Population, June 2020). The average age in KSA is around 30 years old (Plecher, 2020). It is the only country that have access to both the red sea and the Arabian gulf, as seen in *figure (5)*. KSA is divided into 13 administrative regions. The capital city of the country is Riyadh, located in Riyadh region, as marked as in *figure (5)*. KSA is known for being one of highest producers of oil in the world with 66% of their total revenue in 2019 (Abdullah, 2019). It is also known for having Makkah and Madinah, which are two holy cities in Islam, located in the west side of the country. Those two cities are great source of income during the seasons Muslims visit those cities. Due to its large area, KSA has different topography and climate through it borders. The center and the southeast parts of the country consist of mostly desserts. The climate of those regions is hot during summer, reaching well above 45°C. While in the winter, the temperature drops close to 0°C. The two coasts of the country have approximately the same topography and moderate climate compared to other regions. Some parts of the west and southwest of the country contain mountains, which change the topography and have a colder climate than the rest of the country (Geography of Saudi Arabia, 2020).

KSA's main source of income before the discovery of oil was the trades with the surrounding countries. Due to its location, KSA was able to trade with many counties such as Egypt, Yemen, and Iraq. Currently, KSA has the highest GDP between the Arabian Gulf Counties, 785 billion (Tradingeconomics, n.d.).

2.1.2 The United Arab Emirates (UAE) is the first country in the AGC to start the architectural and civilizational growth. The UAE consists of 7 Emirates that are almost 83,000 km^2 in size combined (Nations Encyclopedia, n.d.). Its capital city is Abu Dhabi, located in the north west side of the UAE. The UAE has a population of 9.5M (Crystal & Peterson, 2020). Most of its population in concentrated in Dubai and Abu Dhabi, where most of their trades and modern life are. Their average age is 33.5 years old (G.M.I., 2020). The GDP of the UAE is around 425 billion USD (Trading Economics, n.d.). Since the Arabian gulf covers most of their border, the climate is known for its extreme humid and hot weather during most of the year. They also depend a lot on their nature and location, therefore, fishing, pearling, and agriculture are some of the most dependable source of income, especially in the past (Crystal & Peterson, 2020). UAE is the only country in the AGC that does not depend on oil and energy as the main source of income. Based on the information shared in the official portal of UAE government, only 30% of their revenues was from oil in 2014. While tourism is known to be one their main sources of income.

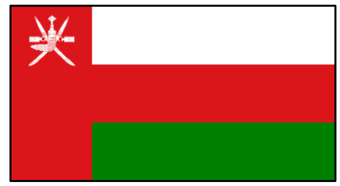
2.1.3 The Kingdom of Bahrain is the smallest country in the AGC with a total area of 770.9 km^2 (Abuzeyad, 2018). It is an archipelago made of 33 islands located on the Arabian gulf. Moreover, the kingdom has a population of 1.5 million with a GDP of $31.1 Billion (Bahrain eGovernment, 2020). The average age of the citizens in the kingdom is 31.7 years. Throughout the years, Bahrain had and continue to have a special status across the Arabian gulf countries being strategically positioned in the center of all the trade routes around the gulf. Since Bahrain was the second Arabian gulf country to discover oil in 1932, the country's economy depends heavily on it. The oil sector comprises 85% of the country's sources of income (Bahrain eGovernment, 2020). However, in the past 40 years, Bahrain tried to diversify its economy to move from its dependence on oil through adding real estate, manufacturing, communication, and metal mining to its sources of income. Before the discovery of oil, the country's economy was based on the rich pearl diving industry, fishing, and spice trade to the surrounding countries.



2.1.4 Qatar is known for being the richest country per capita in the world (Hukoomi, 2020). The gross national income (GNI) per capita of Qatar is $117,000. To put this number into perspective, Macao the 2nd richest country on earth has a GNI of $95,304. The country's small size (11,521 km^2) and small population (2.5 million) along with the huge oil and gas reserves contributes to Qatar being one of the richest countries on earth with a GDP of $191.4 billion (Hukoomi, 2020). Moreover, the country has a young population with an average age of 31.5 years. In the early 1800s, Qatar was a poor country colonized by Britain and it was mainly known for pearling. The climate of Qatar is desert with hot summers, warm winters, and scarce rainfall. Many inland seas are scattered across Qatar which has a topography of a flat rocky plain (Hukoomi, 2020). According to OEC (2018), Qatar's income is composed of mainly exporting petroleum gas (49.9%), crude petroleum (25.6%), and refined petroleum (14.6%). Other sources of income are metals mining (3%), and petrochemicals (6%).

2.1.5 Iraq is the second largest country in the AGC region. It is the only country to have two rivers, which make a great source of water in the country. According to the U.S. Central Intelligence

Agency in 2018, Iraq has a population of 38.8 million living is an area of 438,317 km^2, including 950 km^2 of water within its borders. Also, Iraqis' average age is 21 years old, which indicates that young people affect the life in Iraq a lot. The GDP of Iraq is around 225.5 billion USD (Trading Economics, n.d.). Oil is their main source of income, which is 89% of their revenues (U.S. Energy Information Administration, n.d.). They use the water from the river in their agricultural lands.



2.1.6 Oman is the oldest independent state in the AGC. The history of the country goes back to over 100,000 years ago (BBC Monitoring, January 2020). Located between three bodies of water, the Arabian Gulf, Gulf of Oman, and Arabian Sea, Oman lies on the south eastern part of the Arabian Peninsula (Nations Online, n.d.). Oman has a total area of 309,500 km^2. According to CIA (February 2018) 4,664,844 people live in Oman and 46% of them are immigrants. The average age in Oman is 26.2 years. Moreover, the weather in the summer is hot, arid, and cloudy, and in the winter is cold and dry (Weather Spark, n.d.). Oman's location has been strategically great for trading and controlling the region. The country is known for trading with silk, gold, spices, and pearls, and they connected the trades between the east and Europe (Viswanathan, 2017, January 18). Oman's GDP in 2019 was 79.5 Billion dollars, most of it came from the production oil and natural gas extraction (Trading Economics, n.d.). According to Figgins (2019), around 71% of Oman's revenue comes from the hydrocarbon sector.

2.1.7 Kuwait has the highest valued currency in the world valuing at $3.28 USD per 1 Kuwaiti Dinar (Balogun, 2020, February 21). Moreover, it has been ranked eighth regarding their GDP per capita estimated to be around $72,000 dollars (World Meters, n.d.). In 2017, Kuwait GDP was estimated to be $120.7 billion dollars. According to OEC (2018), 92% of Kuwait's income comes from crude petroleum, refined petroleum, and petroleum gas. Around 3 million people are living in Kuwait with an average age of 29.7 years old; however, only 30% of the citizens are Kuwaiti citizen. Kuwait is in the norther part of the AGC covering 17,818 km^2 and bordering with Iraq, KSA, and Arabian Gulf (CIA, February 2018). The weather in Kuwait is mostly hot during the summer and mild cold during the winter (Climates to Travel, n.d.).

Country	*GDP (billion $)*	*Size (km^2)*	*Population (Million)*	*Avg. Age (Years)*
Saudi Arabia	785	2,150,000	34.8	30
UAE	425	83,000	9.5	33.5
Iraq	225.5	438,317	38.8	21.2
Qatar	191.4	11,521	2.5	31.5
Kuwait	120.7	17,818	3	29.7
Oman	79.5	309,500	4.7	26.2
Bahrain	31.1	770.9	1.5	31.7

Table 1 Background information of the AGC

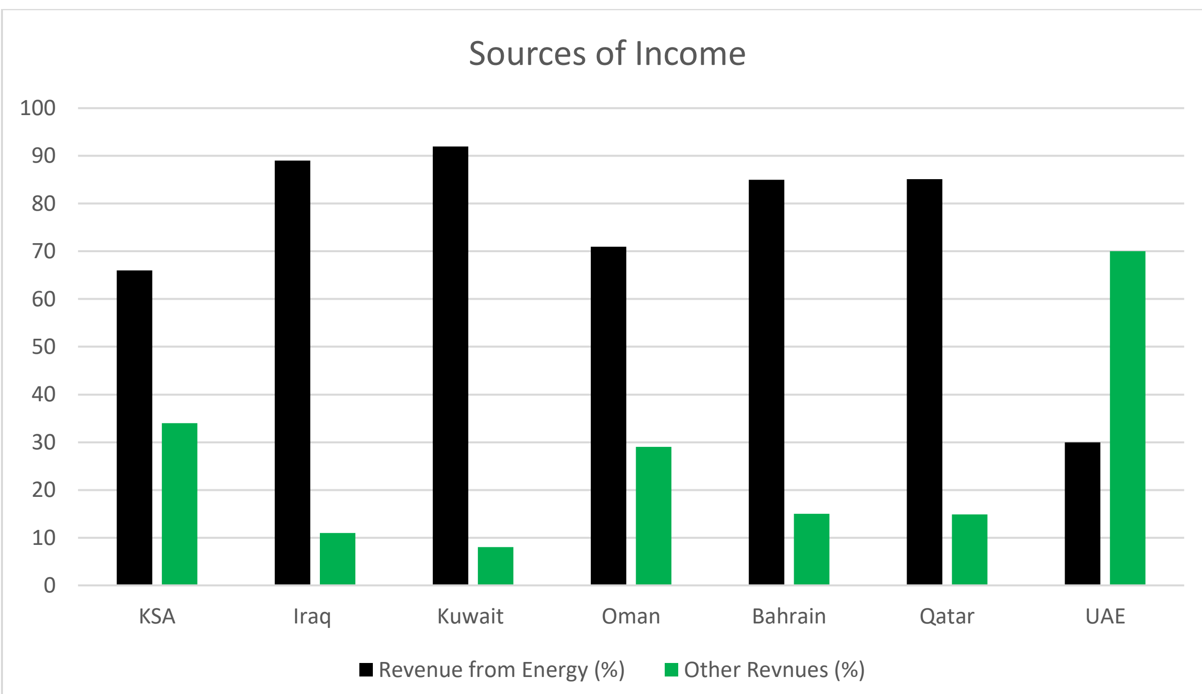


Figure 6 Sources of Income in the AGC

2.2 Energy Consumption In the AGC

According to the International Energy Agency (2017), mostly all the energy consumption in the region comes from the burning of fossil fuel. Renewable energy is rarely used in the area and only used in less than 1% in Iraq, Saudi Arabia, Kuwait, and the UAE. On the other hand, Qatar and Bahrain only use oil and natural gas to produce energy. The figures bellow demonstrate the exact energy consumption by source in each country.

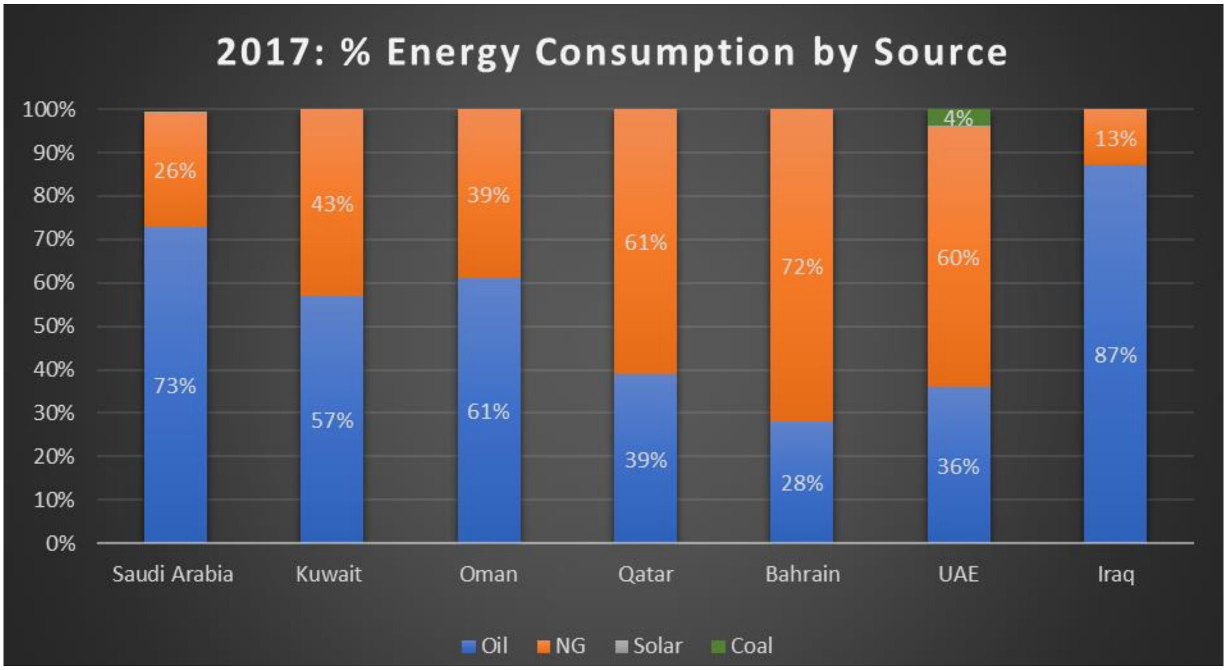


Figure 7 Percentage of energy consumption by source

2.3 The History of Oil in the Region

Oil and hydrocarbons were being used around the world for a long time. However, the uses of oil back in time were not the same uses we have today. The first known drilled oil well was in China in 347 (Ali, 2019). Back then, crude oil was mainly used as a material for construction or for lighting the lamps. In 1847, the Scottish chemist James Young distilled oil for the first time and the modern history of oil started. Distilling oil allowed Young to extract light material that he was able to use for lamps and a thicker material that he used for lubrication (Ali, 2019). Young continued to distill oil and discovered multiple liquids such as paraffin wax and tried to commercialize it. In 1850, the Canadian geologist Abraham Gesner was able to distill oil to kerosene which was a cheaper and cleaner liquid to burn and use for lighting the cities. Gesner discovery was the first success in the commercialization of fossil fuels, he was able to sell kerosene to the cities of the U.S. in 1850 (Ali, 2019). This success sparked companies' interest in oil. The search of oil started, and the first modern well was drilled in La Brea, Trinidad in 1857 with a depth of 280ft (Askari, 2013). The discoveries of oil were noticed by the oil baron John D. Rockefeller who started the world's first oil company in 1865 and called it the Standard Oil Company. Russia and Iran also followed the steps of the U.S. and invited geologists from around the world to start looking for oil. Oil was discovered in Iran in relatively large quantities in 1907 (Askari, 2013).

The discovery of oil in Iran motivated geologists and mining engineers from around the world to go to the AGC in search of oil. Especially, the father of oil "Abu Naft" in the region, the British Major Frank Holmes who was convinced that the AGC are rich in oil. Holmes convinced both the UK government and US government to initiate the oil ventures in the region in 1920 (Sorkhabi, 2008).

2.3.1 Iraq was the first country in the AGC to find an oil field. The discovery of oil was credited to the Turkish Oil Company, TPC, who helped finding oil in Iraq in 1923 (Jassim & Goff, 2006). A long-term deal has been signed for the TPC to explore the area and detect oil two years later, in 1925 (Jeffries, 2003). According to Sorkhabi, Morton & Thornton (2009), after detecting oil in the area, the TPC drilled several wells in Iraq. The first oil well was drilled in 1927 in a city called Kirkuk. Later, the construction of the TPC was reconstructed and became the Iraq Petroleum Company, IPC. Later, the IPC discovered several oil fields. Recently, Iraq has one of the highest oil production rate, 4.74 million barrel per day. This production rate placed Iraq at the sixth place behind USA, KSA, Russia, Canada, and China respectively (EIA, 2019).

2.3.2 Saudi Arabia: After the discovery of oil in countries close to KSA, Holmes reached out to King Abdulalziz asking him permission to start looking for oil in his land. After consulting with his advisors, the king agreed to rent Al-Hasa region to Holmes for £2,500 a year to start looking of oil in 1923. Holmes was not able to find oil in the region and stopped his exploration in KSA (Sorkhabi 2008). In 1932, King Abdulalziz was able to unite all the kingdom and was named the king of Saudi Arabia. However, the country was suffering financially. The king was seeking outside help to look for artesian water to help the country. Harry St. john Bridger Philby, who was a British friend to the king, convinced him to start looking for oil again instead of the water, which could not be found, to help with country's financial problem. Philby arranged a meeting between the king and American oil companies to negotiate the rights for oil exploration in the country. They agreed on paying the king £35,000 in gold before starting and £20,000 after 18 months. They also agreed on £5,000 rental fee for every year and a royalty from the oil extracted (Sorkhabi 2008).

As result of the agreement, The California Arabian Oil Company was founded to operate in the kingdom in 1933. The search of oil was not successful until 1938 oil started flowing from one of the wells, Dammam NO.7, starting a new era for both Saudi Arabia and the American company. After succeeding in finding oil, the two parties signed a supplementing agreement, £140,000 in gold up front and £25,000 yearly rental fee. Also, the company promised £100,000 if a new oil discovery was made plus a royalty on the extracted oil. In 1944, the California Arabian Oil Company was renamed the Arabian American Oil Company, Aramco. The company went through many changes until the Saudi government purchased the whole company by 1980 and the company was named the Saudi Arabia Oil Company, Saudi Aramco (Sorkhabi 2008).

2.3.3 Bahrain was where Holmes found his first success in his oil ventures which started in 1925 (Sorkhabi, 2008). Holmes knew that Bahrain needed water and in order to convince Sheikh Hamad Al-Khalifa to issue the oil concession, he drilled artisan water wells for the country. Holmes plan worked out and the sheikh allowed him to start digging for oil. Holmes went back to the oil companies and businessmen in the UK with geological samples that prove the discovery of oil in Bahrain. However, due to his failure in Saudi, no one was convinced to fund his ventures in Bahrain (Sorkhabi, 2008). Holmes did not give up and took his samples to the U.S. where the Gulf Oil Corporation agreed on funding him. In October 1931, the oil was discovered in Jabal Dukhan (Sorkhabi, 2008). Next, in 1934, Bahrain started exporting oil by producing almost 285,000 barrels of light crude oil. The first oil refinery was built in 1936 with the capacity to produce 10,000 barrels per day.

2.3.4 Qatar was motivated by the discovery of oil in Bahrain in 1931. Geologists from Britain started surveying the region in 1933 and found similarities between the geological aspects of Jabal Dukhan in Bahrain, where oil was found, and the highest hills in southeast Qatar (Qatar Petroleum, n.d.). The drilling started in 1938 and oil was discovered in late 1939.

Moreover, in 1940 Qatar started producing at a capacity of 4,480 barrels per day (Qatar Petroleum, n.d.). Qatar started exporting oil in 1949.

2.3.5 UAE's story of oil started before the emirates was united. Right around the time of the discovery of oil in the countries around, an oil company constructed in the lands of Abu Dhabi to find oil in 1936 (Morton & Sorkhabi, 2011). This was a British oil company called the Petroleum Development (Trucial Coast), PDTC. After three years, they have also signed a 75-year-old contract to discover oil in the area (Morton & Sorkhabi, 2011). According to Abu Dhabi National Oil Company (ADNOC), the PDTC spent around three decades to discover the first oil well in Abu Dhabi in 1958. Four years later, Abu Dhabi started exporting oil. After the UAE being united, in 1971, the Abu Dhabi National Oil Company was formed by Sheikh Zayed, an Emirati sheikh who was the prime minister of Abu Dhabi, to control the manufacturing of oil. Lastly, other oil wells were detected in the rest of the UAE and started exporting oil from other ports on the UAE coasts. Recently, the UAE produces three million barrels of oil on a daily basis. The UAE was ranked the fifth around the world in 2019 in exporting crude oil with a value of $66.1 billion (Workman, 2020).

2.3.6 Kuwait has been utilizing the Pearle exportation as a major revenue until a Japanese businessman started the trades of artificial Pearle cheap Pearle in 1930. This impacted Kuwait's money income (Sorkhabi, 2008). Thus, the Amir of Kuwait, Sheikh Ahmad al-Jaber al-Sabah, was looking for an alternative income option. With Bahrain discovering oil in the region different oil companies were interested in working in Kuwait. In 1932, the Amir of Kuwait received two separate offers from two oil companies, the Gulf Oil and the Anglo-Persian Oil Company (Tétreault, 1995). He wanted to get a good bargain, so he one side off the company against another. A year later, both two companies agreed to a 50-50 joint venture, called Kuwait Oil Company. The new company got an oil concession in Kuwait for 75 years in 1933. The exploration of oil started in 1935. Eventually, on February 23, 1938, oil was first discovered in Kuwait at a high-pressure sand zone area. Ultimately, the Kuwait Oil Company was nationalized in the 1970's (Sorkhabi, 2008).

2.3.7 Oman was first surveyed by the Indian government for coal and oil in Oman in 1904. They sent members of the Geological Survey to explore the Oman region. Their reports recommended India to not consider Oman as an oil prospect compared to Persia (Morton, 2020).

In 1925, the D'Arcy Exploration Company tried to do a geological survey in Kuwait; however, they didn't find any conclusive evidence of oil in the country. Twelve years later, IPC obtained 75 years of oil concessions in Oman through Petroleum Development Oman, Dhofar company (PDOD). After surveying the land, PDOD could not find oil in Dhofar. Therefore, they relinquished Dhofar from the concession in 1950, and renamed the company to PDO. The Sultan of Oman granted another American oil company the concession of Dhofar; however, they also relinquished Dhofar in 1967 for not being profitable. Later, PDO drilled their first well in 1956, but no oil was found. Four years later, most of the partners in PDO left the venture. In 1962, oil was finally discovered in Oman. By 1967, Oman started exporting oil to the world. (PDO, n.d.)

2.4 OPEC

By 1960, with all those countries around the world producing and exporting oil, the Organization of the Petroleum Exporting Countries (OPEC) was formed by Saudi Arabia, Iraq, Iran, Kuwait and Venezuela (Ali, 2019). The role of OPEC was to manage the market share and production of the oil exporting countries in order to ensure the value of it. Today, OPEC manages 44% of the global oil production and possesses 86% of the oil reserves around the world (Ali, 2019).

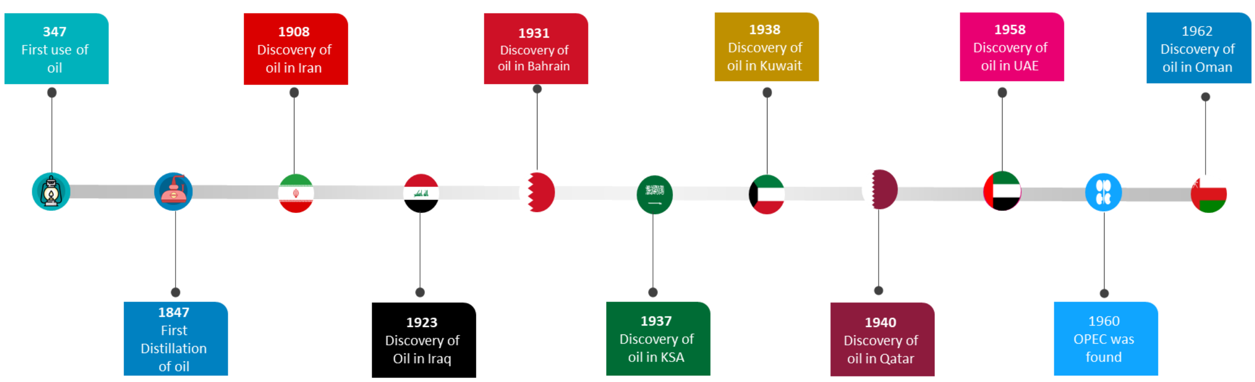


Figure 8 Timeline of oil discoveries in the AGC

2.5 The History of Natural Gas in the Region

Humans recognized natural gas for a long time, it was known as a flammable gas that seeps from cracks on the earth surface. However, no one understood its importance until 1000 BC in ancient Greece where it was identified as a "Miraculous gift of the gods" (Direct Energy, 2020). After that in 400 BC, China used natural gas effectively to speed up the brine evaporation. It was passed through bamboo pipelines to sites where it can be used.

The main component of natural gas is methane (CH_4), but it also contains hydrocarbon liquids, carbon dioxide, and water vapor. It forms deeply underground and can either be extracted as an associated gas with the extraction of oil or by itself. Natural gas used to be either reinjected to the oil well or burned on site until 1820 when scientists discovered the importance of natural gas in it becoming a cleaner, easier to transport, and more efficient than oil (EIA, 2019). In order to be exported, natural gas is either transported in pipelines or compressed into liquified natural gas (LNG).

2.5.1 KSA's natural gas is considered the associated type, which means it is associated with oil (Mabro, n,d). It was discovered with oil in 1937. The country has the fourth largest natural gas reserve in the world behind Russia, Iran, and Qatar. The extraction of natural gas began in mid-1970s (Saudi Aramco, n,d). Even though KSA has large amounts natural gas production, it is consumed in industries inside the country. The high demands for energy in the country, the seventh largest natural gas market in the world, consume most of the produced natural gas. Industries such as desalination of seawater and power plants and many other industries require huge amounts of energy that is supplied by the local natural gas production (Saudi Aramco, n,d).

2.5.2 Qatar today is the largest exporter of LNG in the world today (U.S Library of Congress, n.d.). However, the discovery of natural gas there is recent. According to Dargin (2010), Qatar's discovery to natural gas was in 1971. The discovery of the natural gas was in the northern region of Qatar and was called the North Field. Next, it took Qatar 20 years to announce the initiation of phase one of the LNG production plant in 1991. The delay was because Qatar's economy was only depending on oil. The Field started production and exporting in 1997. Today, Qatar account almost 14% of the whole world's natural gas reserves, ranking it 3rd after Russia and Iran.

2.5.3 Bahrain's natural gas history started in 1948 when it was detected by the Bahrain Petroleum Company (Archer, 2012). The country started exporting natural gas after the discovery of the offshore field "Abu Safah" in 1963. According to Bahrain Natural Gas Company (2020), Bahrain is only ranked 35th in the world when it comes to producing natural gas. The future is bright for Bahrain, in 2018, Bahrain announced the discovery of the largest oil and gas field in the history of the kingdom (BANGAS, 2020). However, Bahrain did not announce the specifics of the field.

2.5.4 The United Arab Emirates has always imported natural gas from countries around like Qatar. The first natural gas field was discovered in the emirate of Sharjah in 1983, even though it did not produce enough for the country. However, the government of the United Arab Emirates has discovered two large natural gas fields in the area early in 2020. One of the new natural gas fields produces a rate of 50 million cubic feet per day and was discovered in Sharjah (CNN, 2020). Few weeks later, a new spot between Dubai and Abu Dhabi was discovered and became one of the largest natural gas fields around the world, producing around 2.2 trillion cubic meters (Dipaola, 2020). The future of the UAE will be changed due to these discoveries. Natural gas in the UAE demand will be supplied from their own production instead of importing it from countries around like Qatar.

2.5.5 Iraq's Natural gas was discovered when the oil was found. According to Khalil (2017), the use of natural gas was minimal. The 1970's was the beginning of a new development by increasing the use of natural gas in the country. That is when Iraq started to use natural gas. Later in the 1980's, there was a huge development in the industry of natural gas in Iraq. Several gas projects were made in different parts of the country. Those projects have made a huge raise in natural gas production rates between the 1980's and the 1990's. Recently, Iraq has a fair amount of gas reserves. Iraq was ranked the 12th around the world regarding gas reserves (World Meter, 2015).

2.5.6 Oman discovered natural gas in 1962 when they first discovered oil. There was a huge amount of associated gas in Yibal well located near the Saudi borders (Media Portal Oman, n.d.). A sample was taken from the gas which was discovered to be nearly pure methane. However, the natural gas industry wasn't born until the first major gas process plant was built in Yibal in 1978 by the Sultan Qaboos (PDO, 2018). One main reason for building the plant was getting another source of energy for the electricity after the oil reserves started to deplete (Country Studies, n.d.). Moreover, around 1991, Oman discovered their first non-associated natural gas (Media Portal Oman, n.d.). Oman is ranked 28th in the world regarding gas reserves with 23 trillion cubic feet (World Meter, n.d.).

2.5.7 Kuwait is the last country in the AGC to discover natural gas. Even though they have discovered oil in 1938, their natural gas was only discovered in 2006 (KOC, 2012). They had multiple tests and examinations without disturbing or releasing the natural gas to evaluate the volume of gas stored (Alabaan, 2006). According to the Kuwait News Agency (2006), the examination's finding has increased Kuwait's natural gas reserves to 35 trillion cubic feet.

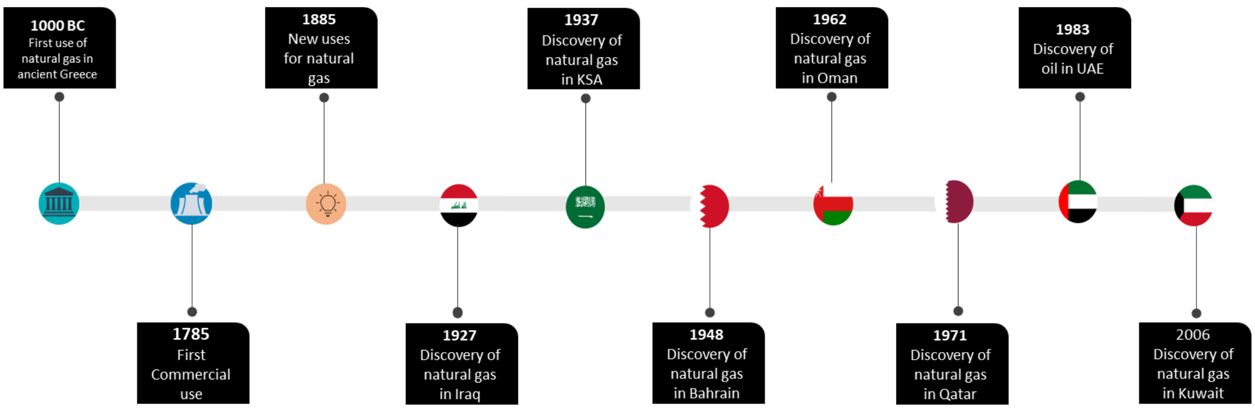


Figure 9 Natural gas timeline

2.6 The Futuristic Energy Plans in the AGC

The shift to renewable energies was identified as a national priority in the AGC (Olawuyi, 2017). The drivers that made the shift a national priority are the increment in energy demand, economic diversification, cleaner environment, and the rise of opportunity to invest in viable renewable sources in the region such as solar energy. Those drivers were a key part of the futuristic national visions of the AGC.

2.6.1 The Kingdom of Saudi Arabia led by the crown prince Mohammed Bin Salman, MBS, announced the 2030 vision on April 25, 2016. The main purpose of the 2030 is to improve quality of life the citizens of the country in all aspects. One of the main goals of the vision is decrease the oil dependence in the country GDP by increasing the non-oil related revenues. Another goal is increasing the efficiency of the energy sector. Saudi Arabia is working on increasing the production of renewable energy by 2030. Increasing the renewable energy production is going to be achieved in steps. First, increasing the production to 3.45 gigawatts by 2020. Then to 9.5 gigawatts by 2023. Also, the country is working in developing its nuclear energy program to support the high demand. The country is planning to reduce the emissions from burning fuel by continuously using the latest technology and equipment in their refineries and distribution network (Vision 2030, n,d).

2.6.2 Qatar's National Vision 2030 had energy plans as a core and critical part of its environmental and economic development pillars. Qatar understand that the continuation of only using non-renewable energy sources as an intergenerational injustice (Qatar Communication Office, 2020). Qatar aims to organize the World Cup 2022 as the first carbon neutral major sport competition. Newly developed cities around the country are developed to be highly sustainable. For example, Lusail city which is ranked amongst the most sustainable cities in the world (Attaullah, 2017). Regarding the transportation sector, Qatar's Minister of Energy and Industry stated that Qatar Rail has strict environmental requirements that cuts 30% of the carbon emissions of the country coming from the transportation sector. Moreover, the country aims to increase the numbers of electrical and hybrid cars by 10% in 2030 (Attaullah, 2017). Lastly, the country has a goal of cutting the overall carbon emission by 17% in 2022.

2.6.3 Bahrain's National Vision 2030 focused heavily on achieving affordable and clean energy. According to the Sustainable Energy Authority (2017), Bahrain aims to shift 5% of the energy consumption to renewables by 2025 and 10% in 2035. The energy sources that will be used are a mix of solar, wind, and waste to energy. The projected shift is going to allow the country to reduce its carbon gas emissions by 392,000 tons of CO_2 per year. The Sustainable Energy Authority developed three policies for this shift to happen. The first policy is to allow citizens to generate renewable, grid-connected energy. The second policy is to attract private investors to develop renewable energy projects. The last policy is to require new buildings and projects in the country to integrate renewable energy.

2.6.4 The United Arab Emirates' vice president, Sheikh Mohammed Al Maktoum, has announced an energy vision for the county. According the Ministry of Energy & Industry in the UAE (2017), the UAE will start a new energy plan for the next 30 years. The plans' goal is to rely mostly upon clean energy by 2050. The use of clean and renewable energy will be raised to

50% of the energy used in the United Arab Emirates. The ambition on the plan is to distribute the energy used into 44% of clean energy, 12% of clean coal, 6% of nuclear energy, and 38% of gas. Another ambition is to lower the carbon footprint in the country to by 70%. This will lead to conserve a huge amount of money. The performance of utilization of energy for individuals and companies will be raise by 40% to reduce the energy waste. This plan will assist the country and help equalize the production and consumption rates (WAM, 2017).

2.6.5 Iraq has been facing several political issues for decades. Due to all the unfortunate circumstances Iraq is facing, the country has been missing several development opportunities. However, this did not stop Iraq from building a future energy plan in 2014. The new energy plan is called the Integrated National Energy Strategy, INES, and it is planned to achieve its goals by 2030. According to Chatriwala (2014), the INES is mainly focused on increasing the revenues from oil and natural gas for their future investments and to create more jobs for people. INES claims that ten million jobs will be provided from the development of oil and gas industries.

2.6.6 Oman's 2040 vision aims to several achievements. First, to increase the non-oil sector and decrease oil sector the contribution to the GDP. Secondly, to build an ecosystem to protect the environment and sustain the natural resources. In 2017, the non-oil sector has contributed 61% of the GDP. Oman is planning to increase its non-oil sector to become 91.6% by embracing technology, knowledge, and innovation. This will result in improving all other sectors, such as tourism and education. Another vision Oman has been to increase the consumption of renewable energy. This ecosystem will decrease the economic costs of wastes and loss of non-renewable resources. Oman is ranked 200th out of 210 countries in the world regarding the percentage of renewable energy consumed to the total consumption with 0%. By 2040, Oman is targeting to increase the percentage to 39% by using more green renewable resources (Oman 2040 Vision, 2019).

2.6.7 Kuwait's 2035 vision is will help improve the economy and increase the sources of income to limit the country's dependency on oil revenues. More than 3,500 small projects are proposed to achieve that, such as improving the legislation in the market. Also, Kuwait is trying to improve sustainability and increase the use of renewable energy by 15%. They want to obtain this ecosystem by providing sustainable green projects and materials. One of the projects is building a water distillation plant to produce water using renewable energy (New Kuwait, 2019).

2.7 The CO_2 emissions in the AGC

The total CO_2 emissions have been increasing in the AGC countries in the past years. In this section, a timeline for the CO_2 emission per capita for each country will be presented and compared to the world average emissions. Moreover, the total CO_2 emissions in the region and the sectors contributing to it will also be presented for each country.

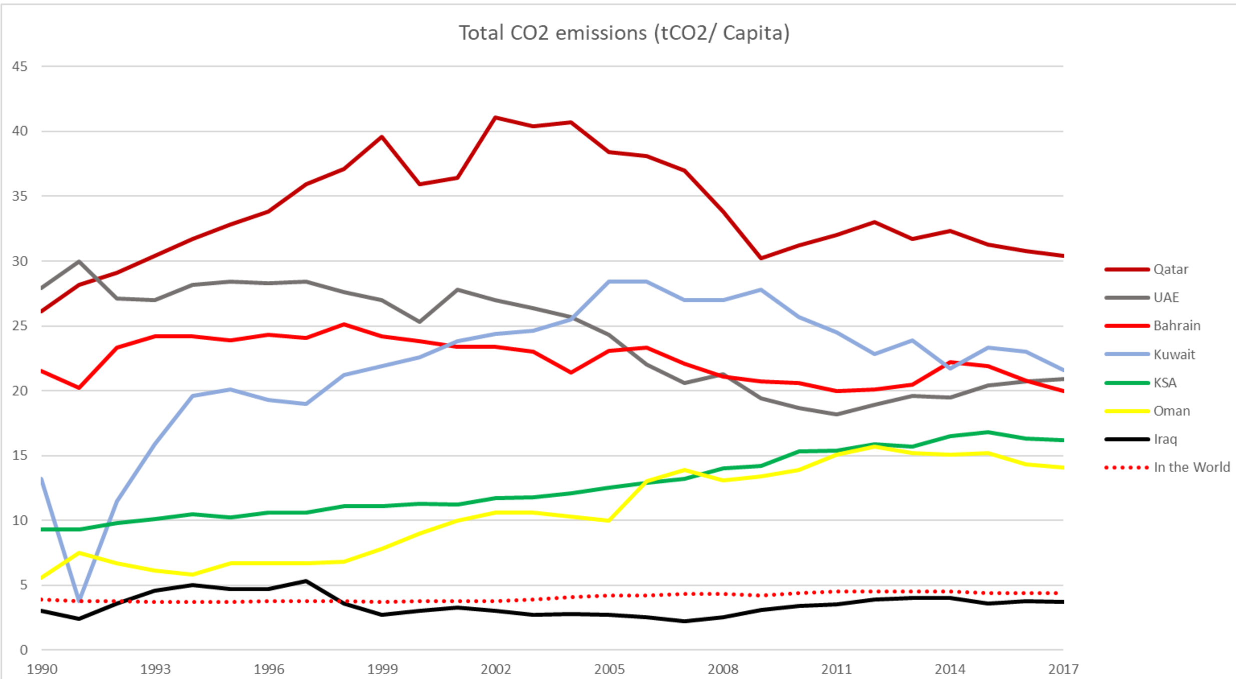


Figure 10 Total CO_2 emissions in the region

2.7.1 KSA has the highest amount of CO_2 emissions between the AGC, 532 Mt of CO_2 (IEA, 2017). The high energy demand in the country is the main reason for the high emissions. However, the CO_2 emissions per capita was 16.2 t of CO_2 in 2017, which is not as high as other in the AGC represented in *figure (10)* (IEA, 2017). The high population of the country compared to neighboring countries explains the high emissions. As shown in *figure (11)*, around seventy percent of the total CO_2 emissions is from heat and electricity production, transportation, and residential sectors.

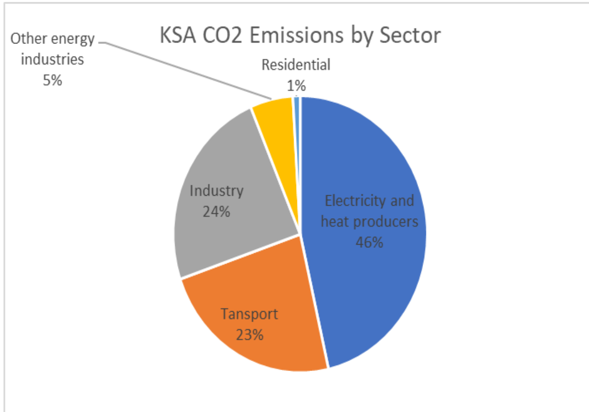


Figure 11 KSA CO_2 emissions by sector

2.7.2 UAE has a high rate of CO_2 emissions per capita in the AGC, with a value of 20.9 t CO_2/Capita and a total emission of 198 MT CO_2. Comparing this value to the average value of CO_2 emissions per capita in the world. The industrial revolution was a major contributor to the increment of CO_2 emissions. This caused the UAE to have more industries and need more electricity and heat. Moreover, transportation is an effective factor in raising the emissions of CO_2. The development of public transportation in the UAE was a main factor in increasing CO_2 emissions The UAE managed several projects to reduce those emissions. In 2019, the emirate of Dubai decreased their emissions by 19% and planned to reduce more in the future (Business Wire, 2019).

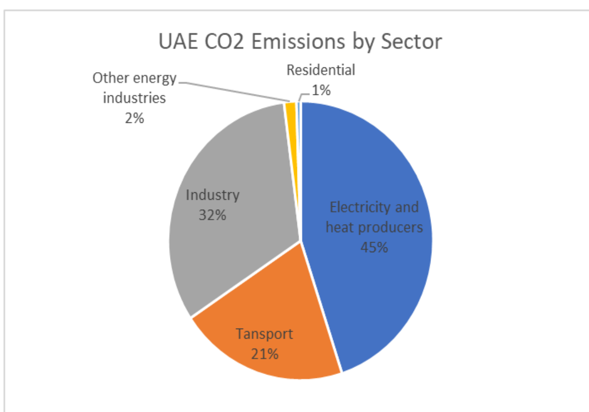


Figure 12 UAE CO_2 emissions by sector

2.7.3 Iraq has the third highest amount of CO_2 emissions in the AGC, even though it has the lowest value of CO_2 emissions per capita. Iraq's large population compared to the AGC is an effective factor that resulted in reducing the value of emissions per capita. The energy industry in

Iraq is the major contributor to its CO_2 emissions. In addition, transportation and electricity are two major factors that create most of CO_2 emissions in the country. As a result, the total CO_2 emissions value in Iraq is around 139 MT CO_2, while only 3.7 t CO_2 emissions is what an individual causes in the country.

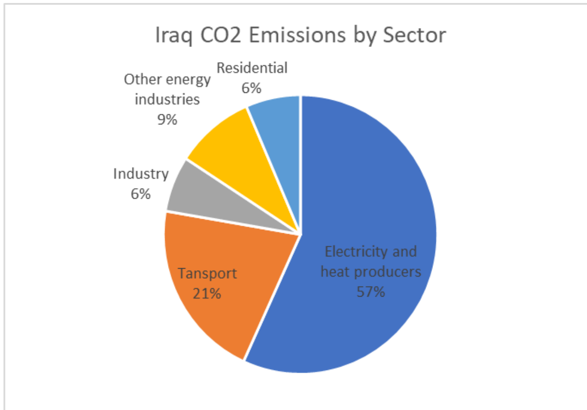


Figure 13 Iraq CO_2 emissions by sector

2.7.4 Bahrain has the lowest CO_2 emissions between in the AGC, with a value of 30 MT CO_2. However, the value of CO_2 emission per capita is one of the highest in the AGC. Electricity and heat producers are the major factors causing 67% of the CO_2 emissions in

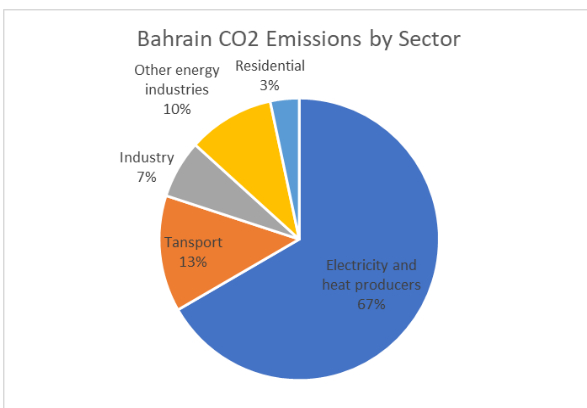


Figure 14 Bahrain CO_2 emissions by sector

Bahrain, 20 MT CO_2. Other factors in the country, shown in *figure (14)*, have not distributed as much in the CO_2 emissions. In addition, the small population and high energy demand in Bahrain is an important reason causing the value of CO_2 emission per capita to be large.

2.7.5 Kuwait has one of the highest CO_2 emissions per capita in the world. The CO_2 emission per capita in Kuwait has been declining in the past few years until it reached 21.6 Mt

CO_2 per capita in 2017 ranking Kuwait second in the AGC countries. In 2017, Kuwait has emitted 89 Mt CO_2, around half of the CO_2 emitted, was caused by the electricity and heat producers' sector with 48%. The residential sectors did not contribute much to the total CO_2 emission; however, the transport, industry, and energy industry has filled the rest of the total CO_2 emission.

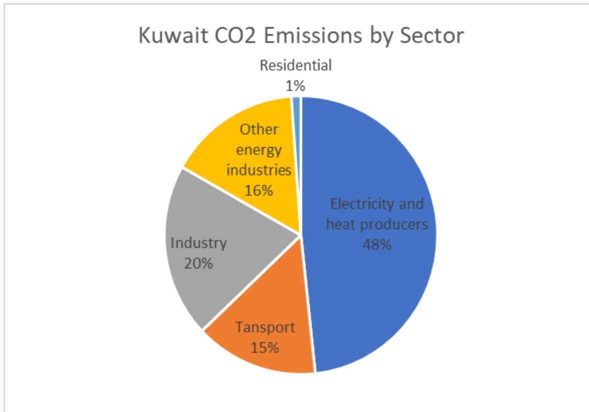


Figure 15 Kuwait CO_2 emissions by sector

2.7.6 Qatar has the highest CO_2 emission per capita between the AGC and the world with 30.4 MtCO_2 in 2017. These CO_2 emissions are way higher than the world average CO_2 emission per capita which is around 4.4 Mt CO_2 per capita. One main factor for this gap is due to Qatar's small population and being the largest LNG producer in the world (Al-Asmakh, 2018). However, Qatar's CO_2 emissions are not high as other AGC countries. Qatar is not the largest country to emission CO_2 in the AGC. Different sectors have contributed to Qatar's 80Mt CO_2 total emission. As the largest LNG producer, Qatar's energy industry was the biggest provider of CO_2 emission with 39%. Moreover, transport, industry, and electricity and heat production were major contributors to the total CO_2 emission. On the other hand, the residential sector had the lowest percentage due to the small population with 1%.

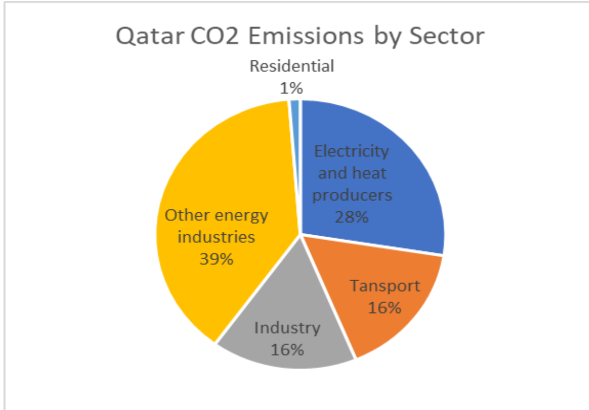


Figure 16 Qatar CO_2 emissions by sector

2.7.7 Oman's total CO_2 emission trend has been increasing in the past three decades after the processing of natural gas started in 1992. Relatively, the total CO_2 emission per capita has been also increasing. In 2017, Oman has emitted 14.1 Mt CO_2 per capita, nearly 10 Mt more than the world average. Both the electricity and heat producers' sector and the industry sector are responsible for 50% of the total CO_2 emission with 33 Mt of CO_2. The rest of CO_2 emission comes from different sectors, such as transport, energy industry, and commercial and public services.

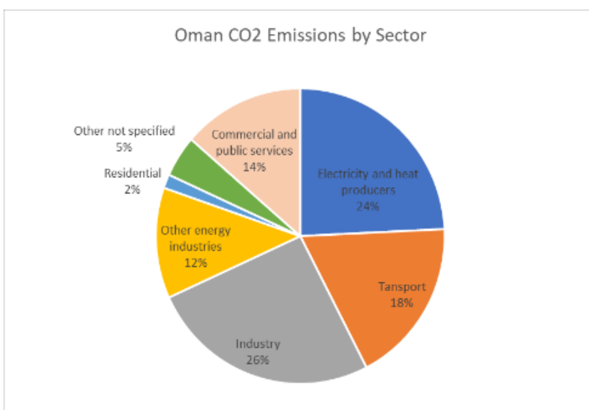


Figure 17 Oman CO_2 emissions by sector

2.8 The Effects of the Emissions and Introduction to Carbon Capture

The Intergovernmental Panel on Climate Change final report in (2014) affirms that the increase in anthropogenic greenhouse gas (GHG) emissions are directly related to the rise in the average global temperature, rise of sea levels, and the severe weather patterns around the world.

However, in the AGC region, there is a lack of research in the area of climate change. There are no studies that relate GHG emissions in the region to rise in average temperature. The peer-reviewed, non-biased studies on climate change are scarce and limited to multiple studies on the marine life (Ben-Hasan & Christensen, 2019). However, the high rates of emissions in the region coming from the energy sector negatively affects the health of the citizens by polluting the air. According to a study conducted by Abbas, Kumar & El-Gendy (2018), the emissions in the area exceeds the World Health Organization (WHO). Thus, there is a clear need for technologies to capture those emissions.

Enters **carbon capture** technologies which is not only needed in the region but needed in the whole world. The IPCC report in (2019) asserts that if the whole world continue business as usual in the energy sector, an increase of 2 °C in the average global temperature is not avoidable. Moreover, the IPCC report asserts that there is a crucial need to negative emissions which can be achieved using multiple methods such as increasing the greenery by planting trees and carbon capture technologies. The beauty of carbon capture technologies is that it can capture carbon directly from air or from a point source such as powerplants and petrochemical plants. However, due to CO_2 being too diluted in air (~0.05%), natural gas powerplants (~6%), oil powerplants (8%), and coal powerplants (12%), the technology is costly and requires a lot of energy (Wilcox, 2012). The cost to capture CO_2 from a coal powerplant costs $80-$100 per metric ton of CO_2 avoided, and the cost to capture CO_2 directly from air costs $600-$800 per metric ton of CO_2 avoided (Wilcox, 2014). The technologies today are clearly in need to higher levels of research and development to bring the costs down. The capturing of carbon is not the last step, the transportation and utilization of it also plays a role in the validity of the technology. Today, the utilization of CO_2 is mainly being in Enhanced Oil Recovery (EOR) (Wilcox, 2012). Other utilization opportunities can be biological convention, carbonated beverages, petrochemicals, fire extinguishers, refrigeration, liquid fuels, fertilizers, and mineralization.

Due to EOR, countries in the AGC have a great interest in carbon capture, utilization, and sequestration. The countries see it as an opportunity to act as a bridge to sustainable future for fossil fuel. Also, since the technology still in its beginning stages, the countries who have been working in separation and distillation of fossil fuel for years have the best chances of developing it.

In Saudi Arabia, CO_2 capture and utilization in EOR is already happening. Saudi Aramco's carbon capture plant in Hawiyah captures 45 million standard cubic feet of CO_2 per day and then transported for 85 km into Uthmaniyah oil field to be used in EOR (Saudi Aramco, 2020). Saudi Aramco, which has a plan to hit net zero GHG emissions, believes that carbon capture, utilization, and sequestration (CCUS) plays a central role in their future. The current plans for the company entail utilizing carbon in automotive fuels, plastics, and developing the EOR technologies. In 2030, the country plans to fivefold its CCUS capacity. Moreover, the

Figure 18 Mobilized carbon capture technology by Saudi Aramco

company is currently working on a game-changing transport technology (Saudi Aramco, 2020). The technology is using mobilized carbon capture planted in vehicles, the captured carbon is then offloaded in gas stations and transported to Aramco. Moreover, this technology could capture 25% of the carbon emission from the vehicle (Saudi Aramco, 2020).

Lastly, the country showcased its true interest in carbon capture by holding the first International Carbon Capture, Utilization, and Storage conference (ICCUS) 2020 in Riyadh.

In The UAE, CCUS is also already in use. According to the Massachusetts Institute of Technology (2016), ADNOC currently has the capacity to capture 800,000 metric tons of CO_2 per year in Al Reyadah facility. The country plans to expand its CCUS by 500% in 2030 by capturing 5 million metric tons of CO_2 per year.

The rest of the countries in the AGC have no current CCUS active plants. However, by 2025, **Qatar's** LNG industry plans to capture and sequester 5 million metric tons of CO_2 (Paraskova, 2019). While **Bahrain and Kuwait** are still in the research phase, **Iraq** shows no signs of research due to its political issues. **Oman** are currently showing positive signs of sequestering CO_2 by the in-situ carbon mineralization in its ultramafic rocks (Kelemen et.al, 2018).

2.9 Oil Prices

Oil prices have been fluctuating over the past 50 years, as shown in *figure (19)*. Different factors can influence the oil's price making it rise or fall in a minor and major way. One of the biggest factors that affect the current and future prices is how much supply and demand on the market for oil. If the production of oil decreased or became more expensive in the US, for example, the prices of oil will rise around the world (Lioudis, 2020). On the other hand, organizations, such as OPEC, try to control or manage the supply of oil; thus, stabilizing or increasing oil prices (Kosakowski, 2020). Moreover, natural disasters and political disputes can also influence oil prices.

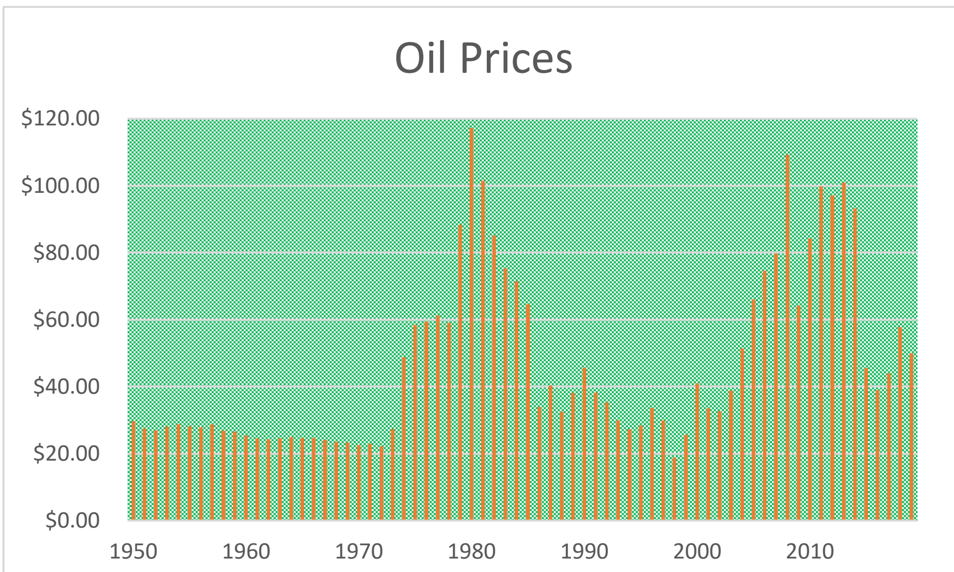


Figure 19 Oil prices history

2.10 Oil Recovery Techniques

Extracting oil from deposits depends heavily on the internal pressure of the well, porosity of the rock, and the viscosity of the oil. In the past, only 5-10% of the oil in a reservoir was recovered due to the lack of the technology to alter the previously mentioned characteristics (Sheng, 2010).

2.10.1 Primary oil recovery technique relies heavily on the natural rise of oil due to the well's internal pressure. The well's internal pressure fluctuates based on multiple characteristics of the well and the reservoir (Solaimany-Nazar & Zonnouri, 2011). The first characteristic is the expansion of the natural gas above the oil reservoir. The second characteristic is the expansion of the gas dissolved with the oil reservoir. Thirdly, the geological structure of the rocks in the well. The porosity of the rocks affects the flow and pressure of the reservoir. The last characteristic is the underground water movement in the well which also plays a role in the placement and pressure of the oil reservoir. Moreover, if the internal pressure in the reservoir falls, mechanical devices are utilized to pump oil from the reservoir. However, in this technique, the chemical properties of the oil are not altered. Therefore, the potential of this technique is limited and only recovers 5%-15% of the oil available in the reservoir (Solaimany-Nazar & Zonnouri, 2011).

2.10.2 Secondary oil recovery technique utilizes the extracted ground water and gasses from the well to alter the internal pressure and density of the remaining oil reservoir (Mijaylova, 2008). When the internal pressure of the well becomes insufficient for primary oil recovery technique, gas and wastewater extracted from the well as byproducts are re-injected in the well. This step increases the internal pressure of the well and reduces the density of the remaining oil reservoir. Therefore, the potential of the oil recovery increases to 20%-40% (Mijaylova, 2008).

2.10.3 Tertiary oil recovery technique, which is also called enhanced oil recovery (EOR), is the technique with the highest potential (60%-75%) and highest cost. The increment in the cost comes from introducing new chemical matters that plays a role in altering the wells internal pressure and the oil reservoir mobility in the well. According to US Office of Fossil Energy (n.d), there are three EOR processes in our world today. The processes are thermal, miscible process, and chemical process. The thermal process increases the heat of the oil reservoir in order to reduce its viscosity. The heat in the thermal process comes from the injection of hot water or steam into the well. Another way of increasing the heat is by the in-situ combustion process, which happens by flaming the sand face of the well in addition to the continuation of injecting air and gaseous mixtures rich in oxygen. Next, the miscible process which reduces the capillary force by creating a miscible zone. The creation of the miscible zone occurs by the injection of chemicals that are miscible at high pressure such as nitrogen, carbon dioxide, and hydrocarbons (Solaimany-Nazar & Zonnouri, 2011). Moreover, the chemical process also works on increasing the viscosity of the injected fluid, which is mostly water. The chemical process could occur by the flooding of polymers into the injected water, surfactant flooding, and caustic flooding. The caustic that is usually used is an alkaline chemical such as sodium hydroxide or sodium carbonate. The caustic works on reducing the interfacial tension between the injected water and oil (US Office of FossilEnergy, n.d.).

Figure 20 Summary of oil recovery techniques

3.0 Methodology

Since the goal of this project is to help the AGC reach energy sustainability, the team developed three scenarios for energy in the region. The goal of those scenarios was to provide an estimation for the future of energy in the region. Those scenarios were based on the increment in energy demand due to the expected increase in population. In the first scenario, the estimation was done based on the current energy consumption. The purpose of the first scenario was to provide an evaluation of what the future will look like if the AGC continue business as usual without any adjustment. The second scenario was built based on the countries' futuristic visions. Each country's futuristic vision was studied and the changes in the energy department were used to estimate the future of the energy after those changes. After reviewing the second scenario, the team assessed where improvements could be implemented and created the third scenario. In the third scenario, improvements in switching to renewables, CCUS, and DAC were researched and analyzed by the team.

3.1 Population

A study on the population of each country was conducted to assess in estimating the energy demand in the future. In addition to the trend for population in the previous years, multiple indicators were analyzed to estimate the population in the upcoming years. The indicators include fertility rates, age of marriage, employment, health, life expectancy, average age, and living conditions.

3.2 Scenario#1: Business as Usual

The goal of this scenario is to showcase what will be the outcome if the AGC continue consuming energy in the same current approach with an increase in the population. The assumption that are made in this scenario is that the countries are going to continue consuming energy from the same current energy sources. Moreover, the energy efficiencies are going to be constant. The main two variables in this scenario are the population and GDP of each country. Those variables directly affect energy consumption and carbon emissions.

The first step that was estimating the energy consumption in each country was estimating the energy consumption per capita from 1990 to 2019. To do that, the energy consumption for a specific year was divided by the population of that year. After that, linear regression was used to fit the trend for the upcoming years 2020-2030. Since the population for the upcoming years is already estimated, the energy consumption per capita is than multiplied by it to calculate the total energy consumption.

The second step was to estimate the emissions of that energy consumption. To do that, the Kaya equation was used. The kaya equation depends on multiple variables such as the intensity of carbon in energy, GDP, population, and energy intensity of the economy.

$$E = P \times \frac{GDP}{P} \times \frac{T}{GDP} \times \frac{E}{T} = P \times g \times I$$

Where E is the total carbon emissions, P is the population, T is the total energy consumption, g is the GDP per capita, I is the intensity of carbon per unit GDP. In order to use the Kaya equation, the forecast GDP of each country was studied. Moreover, the intensity of carbon per unit GDP was also studied for the years between 1990-2019 and linear regression was used to estimate it for the upcoming years 2020-2030. Next, the percentage of error was used to correct the results by using the Kaya equation to estimate the total emissions for the years 1990-2020 and comparing it to the known actual total emissions. Lastly, the carbon emissions per capita was calculated by dividing the total carbon emissions by the population.

Finally, a study on the effect of the calculated carbon emissions was conducted. The study was to analyze how those emissions would affect the countries' public health, economy, and environment. The countries' geography, current challenges by emissions, and health were used to assess the analysis.

3.3 Scenario#2: Each Country's Futuristic Plan

As explained in the background section, each country in the AGC has its own futuristic plans. In this scenario, the team researched those visions and focused on the energy sustainability parts of each vision. Saudi Arabia's 2030 vision, Oman's 2040 vision, Kuwait's 2035 vision, Qatar's 2030 vision, Bahrain's 2035 vision, UAE's 2050 vision were all analyzed. Unfortunately, Iraq does not have an official futuristic vision for the energy sector. Thus, Iraq's scenario #2 was assumed to be identical to scenario #1. In each vision, the official governmental documents were researched. Each country had a section about energy sustainability. On that section, switching to renewables, improvements to energy efficiencies, and implementation of any type of carbon capture was reviewed. After quantifying all the numbers obtained from the documents, the total emissions for each country was calculated.

To calculate the total emissions, each transition to renewables was quantified. The transition was tracked to check what source of energy used to be the source for that transition. For example, if a country stated that 20% of its electricity is going to be switched to renewables. That 20% is than tracked and figured out to be 10% oil and 10% natural gas. After that, the content of carbon that used to be emitted if it was 10% oil and 10% natural gas was calculated using the data obtained by the EIA (2020) for the pounds of CO_2 emitted per million of British Thermal Units (BTU).

Table 2 Carbon content of different fuels

Fuel Type (million Btu)	**Pounds of CO_2 Emitted**
Coal (anthracite)	228.6
Coal (bituminous)	205.7
Coal (lignite)	215.4
Coal (subbituminous)	214.3
Diesel and Heating Oil	161.3
Gasoline (no Ethanol)	157.2
Natural Gas	117.0
Propane	139.0

After that, the content of carbon that used to be emitted is subtracted from the total CO_2 emissions in scenario #1. In addition to the energy transition, energy efficiencies, CCUS, and DAC were researched in the futuristic visions and were accounted for in the calculations. After calculating the total carbon emissions, the carbon emissions per capita was calculated. After that, a pie chart for the updated energy sources used in each country was developed. Lastly, in order to determine the difference that those visions made on each country's total carbon emissions a graph was made to showcase total emissions in 2030 in scenario #1 vs scenario #2.

3.4 Scenario#3: Potential of Renewables, DAC, and CCS

In this scenario, the goal is to showcase the potential for renewable energy, CCUS, and DAC in the region. To do that, two maps will be developed. The first map should showcase the potential for thermal and electrical direct air carbon capture and sequestration (DACCS). The second map should showcase the NG and oil powerplants in the region with the potential for point source capture and the switch to low carbon energy sources. The first step in doing that was a geological survey for the area to figure out the geological reservoirs that could be used for the sequestration of CO_2. The survey contained knowing where the sedimentary reservoirs, basalts, ultramafic rocks, and oil fields are. The oil fields data was obtained to figure out the potential for EOR. The second step was figuring out the potential for low carbon energy sources in the area. The focus was on wind and solar since it has the highest potential in the region. The nature of the region and the current developments was studied to determine the potential of implementing both solar power and wind power in the region (Baruch-Mordo, 2019). The geography and the topography of the region was studied determine the locations for renewable energy implementations. Current developments include the current use for the land and its accessibility. The third step was collecting data for the natural gas and oil powerplants in the AGC. The data was obtained from Enerdata (2019). Enerdata's database contains the information of each unit inside the powerplants. The data collected were the age of the units, net capacity of the units, and the location of the powerplant. The age of the units was used to estimate the decommissioning units in the area. The estimated lifetime of a NG and oil that was used to estimate the decommissioning units is 40 years (Mills, Wiser & Seel, 2017). The age of the units is used to see the potential for (1) Replacement with solar or wind if the powerplant is retiring. (2) Installing point source carbon capture if the powerplant still has life expectancy and located next to a low carbon energy source, sequestration or utilization potential.

4.0 Results and Analysis

In this section, the results for the study is going to be showcased and discussed. The change in population and total energy consumption which we assume to be changing in the same rate for all three scenarios is going to be analyzed first. Next, the effect of each scenario on the AGC's total CO_2 emissions, CO_2 emissions per capita is going to be discussed.

4.1 Population and Energy Consumption

After analyzing the population in the region, it was determined that the population is expected to grow in all the AGC. The analyzing contained studying several factors that play a role in affecting the population growth. Those factors are fertility rates, age of marriage, employment, health, life expectancy, average age, and living conditions (Population Pyramids, 2019). The following graph show how the population in the AGC is expected to grow compared to each other.

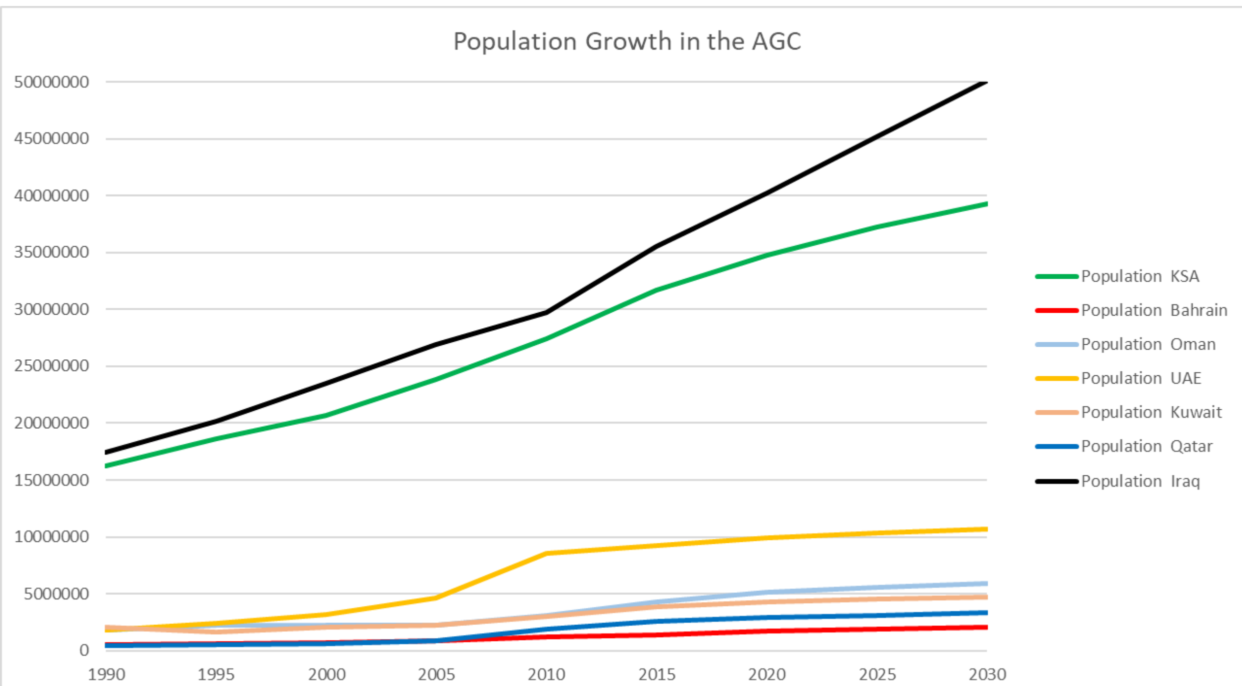


Figure 21 Population growth in the AGC

The energy consumption has been increasing in the past years. The rate of change varies between the countries due to the variance in population growth rate. Moreover, energy consumption is expected to keep growing in the AGC except for Iraq. After studying the energy consumption per capita for each country, it was discovered that Iraq's energy consumption per capita is the only that is not expected to increase similarly to the other countries in the Arabian Gulf. Iraq's political issues in the last few years have been causing several issues regarding energy in the country. Iraq's energy capacity these years is far from meeting the growth demand (Mohammed, 2018). The population in Iraq is expected to grow in the future, so does the demand of the energy. According to our data, the current demand of energy is not met. Therefore, the expected population growth poses a serious threat to Iraq's energy future. On the other hand, the graph shows a huge increase in energy consumption in KSA. This is attributed to the current transition in different sectors in the country, mainly in tourism, transportation, and industrial. KSA is moving fast toward completing many projects in those sectors to improve the quality of life in the country.

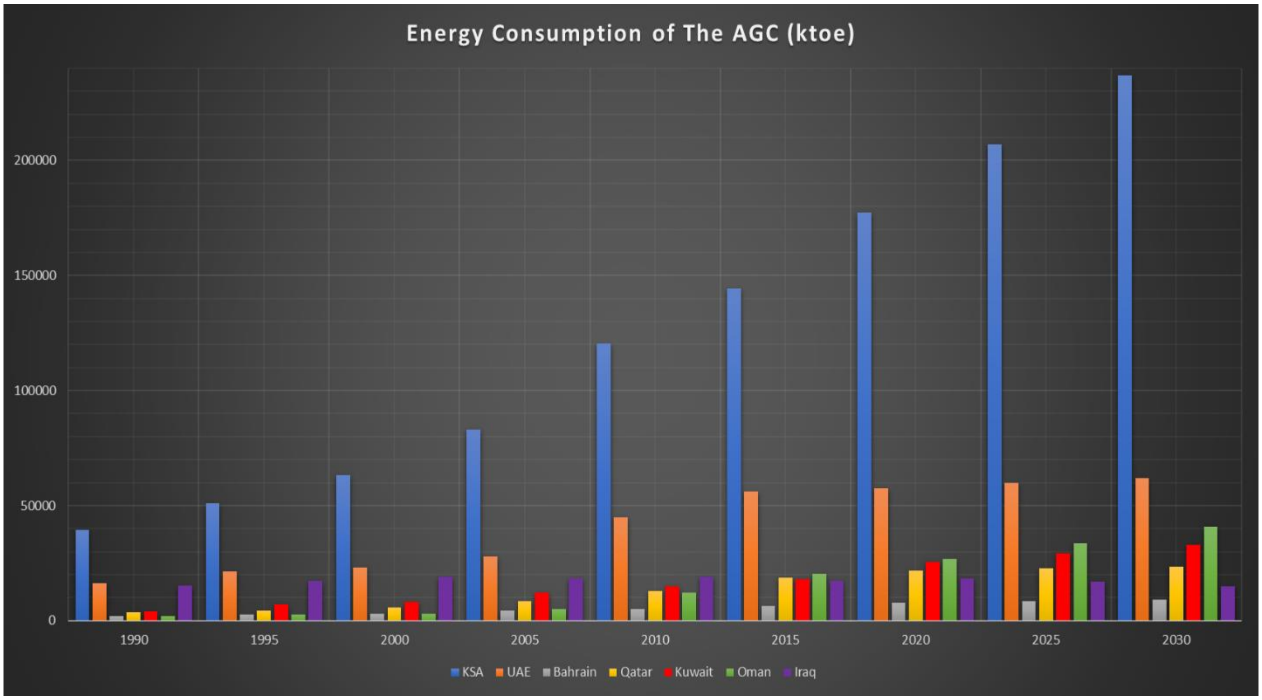


Figure 22 Expected energy consumption in the AGC

4.2 Scenario#1: Total CO_2 Emissions and CO_2 Emissions per Capita

Our analysis asserted that the CO_2 emissions in the AGC is expected to increase rapidly in the upcoming years due to the expected increase in energy consumption. This is assuming that carbon content in the energy sources will be constant and no use of CCUS.

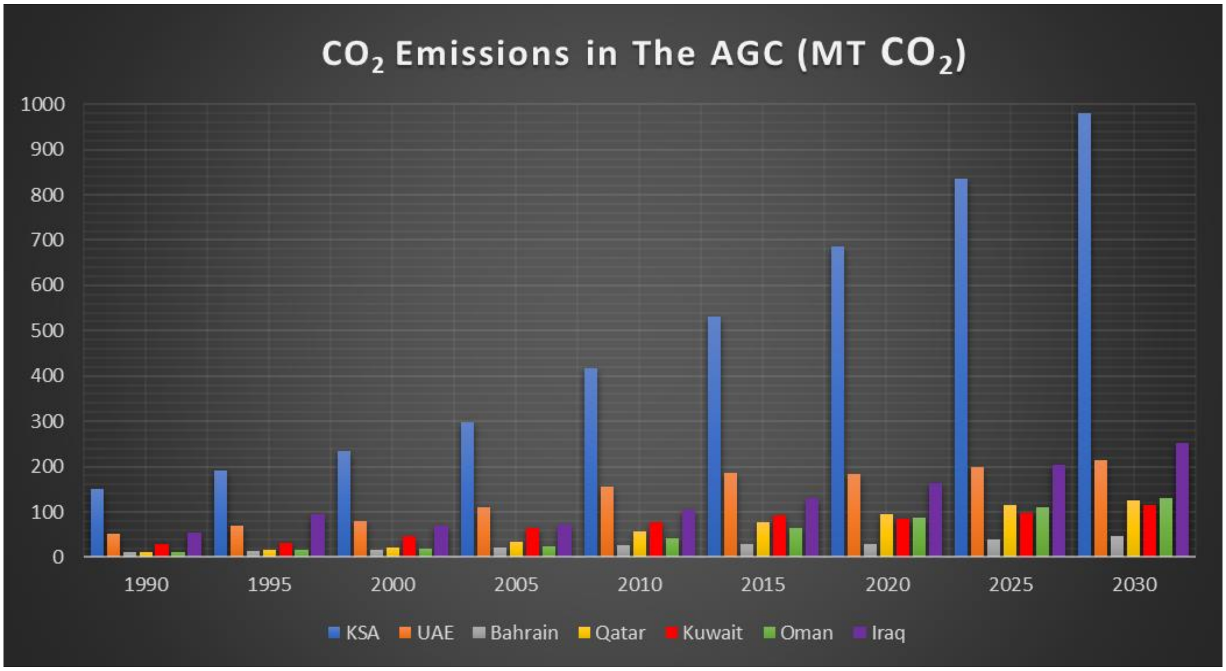


Figure 23 Scenario#1 CO2 emissions in the AGC

Our study showed that the increase in population is proportional to the increase in CO_2 emissions in the AGC. This is reflected in the following graph for the CO_2 emission per capita. All countries had insignificant increase in the emissions per capita due to this relationship.

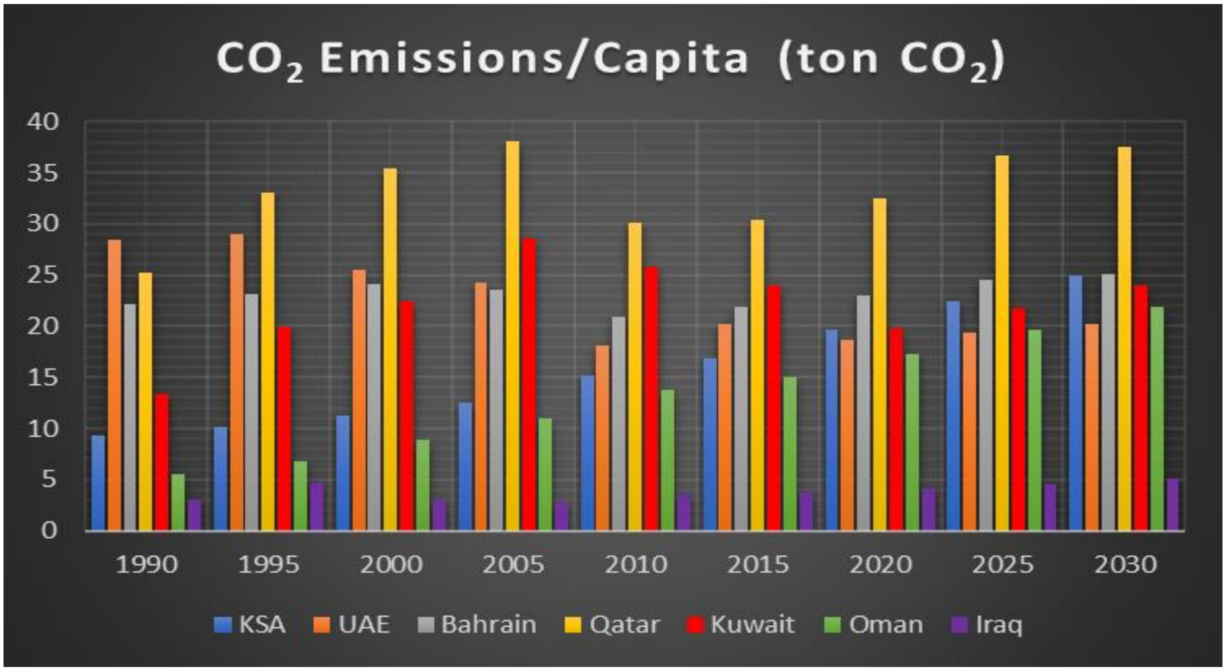


Figure 24 Sceanrio#1 CO2 emissions per capita

It is confirmed that there is a relationship between the increase in CO_2 emissions and global warming. Due to the desert climate and nature of the region, the AGC show signs of vulnerability to climate change. If the AGC continue business as usual and reach the numbers we predict in this scenario, extreme weather conditions, rise of sea level, the health of the citizens, natural resources, and the biodiversity of the region is going to be in danger.

4.3 Effects of the Increase of the Total CO_2

The region shows many signs for climate change. **Extreme weather conditions** are noticeable in many countries in the AGC. These conditions include decrease in average annual rainfall, increase in dust storms, increase in the extreme temperatures in the summer. For example, Kuwait has recorded many dust storms in the recent years, and it is expected to increase further. Also, the annual average temperature in Kuwait is expected to increase between 2.7 ˚C to 4.5 ˚C (Kuwait Environment Public Authority, 2019). Moreover, Iraq has already faced an increase in the mean annual temperature by 0.7˚C per century. In 2050, Iraq is expected to face an increment in the annual temperature by 2˚C (U.S. Agency International Development, 2017). Rainfall is also affected negatively in Iraq. The average annual rainfall is expected to decline by 17% in Iraq.

Extreme weather conditions are directly related to **the public health** in the region. Since dust storms increase the level of air pollution and the increase in temperature lead to more exposure to thermal extremes, the food-borne diseases.

Table 3 Level of air pollution (World health organization, 2019)

Country	PM2.5 (µg/m³)	Deaths
Qatar	91	176
KSA	88	10021
Bahrain	71	231
Iraq	62	13193
Kuwait	61	952
UAE	41	1496
Oman	41	694

As seen above in *Table (3),* the level of **air pollution** is extremely above the recommended by the world health organization, which is 10 µg/m³ (World health organization, 2019). The long term of this level of air pollution is known to create major health problems such as lung cancer, chronic respiratory illnesses, heart strokes, and heart attacks. A study in Al-Razi health center in Bahrain showed that almost 62% of the climate related diseases is related to heat stress (Bahrain's Second National Communication, 2012). Moreover, food-borne diseases can also be noticed to increase in the July-August period when the temperature is at its highest.

The sea levels are also expected to rise with the increase CO_2 emissions in the AGC. This rise is posing a threat for the AGC which will cause flooding, agriculture soil contamination, and the loss of environment habitants. For example, Bahrain is expected to lose their coastlines in their mainland due the rise of sea levels. The graph shows that by 2050 and 2100 the sea levels will increase covering most of their costal border (Bahrain's Second National Communication, 2012).

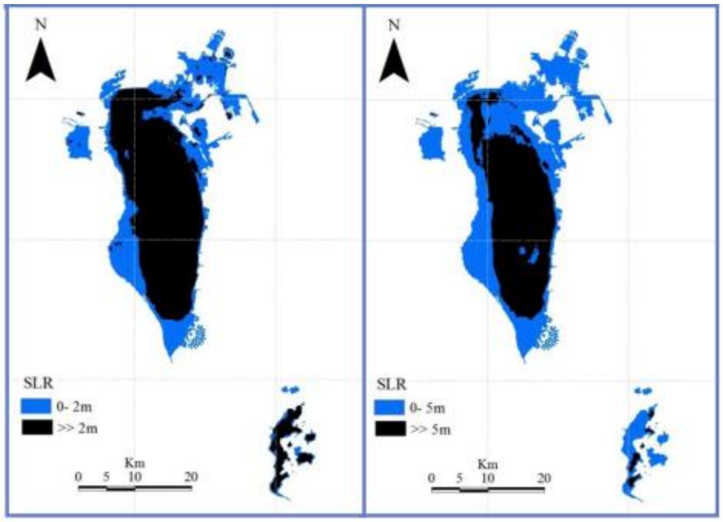


Figure 25 Expected level of sea rise in Bahrain

Moreover, inland flooding is expected to affect 18.2% of Qatar if the sea levels rose to 5 meters above sea levels, which can affect at least 13.7% of Qatar population. The increase of sea levels can also affect the upstream and downstream oil and gas facilities, petrochemicals factories, oil and gas export terminals, and power and water generating facilities in the AGC. Most of these facilities are usually located offshore and coastal areas; thus, the increase of sea levels might disturb the process in these faculties (Meltzer, Hultman & Langley, 2014).

Due to the nature of the region, most AGC are struggling to fulfill **the demand on water** in their country since hundreds of years. The water scarcity in the region could be affected negatively by the intrusion of seawater to ground water due to the rise of sea levels. Currently, the desert climate and rapid increase in the population made this problem worse. For example, the demand on water is increasing very fast in Qatar, around 12% (Meltzer, Hultman & Langley, 2014). Another example is the decrease of ground water levels due to the rise in temperatures and the low annual rainfalls in KSA (DeNicola et al, 2015).

4.4 Scenario#2: Energy Consumption Sources

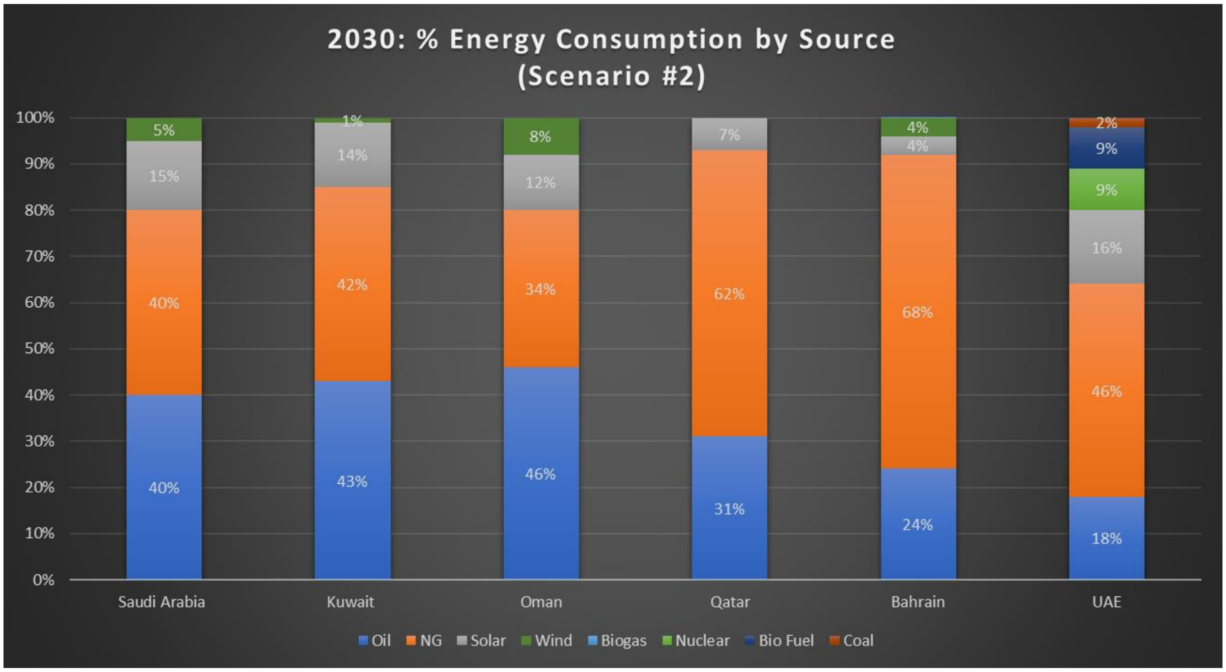


Figure 26 Scenario#2 energy consumption by source in 2030

4.5 Scenario#2: Total CO_2 Emissions and CO_2 Emissions Per Capita

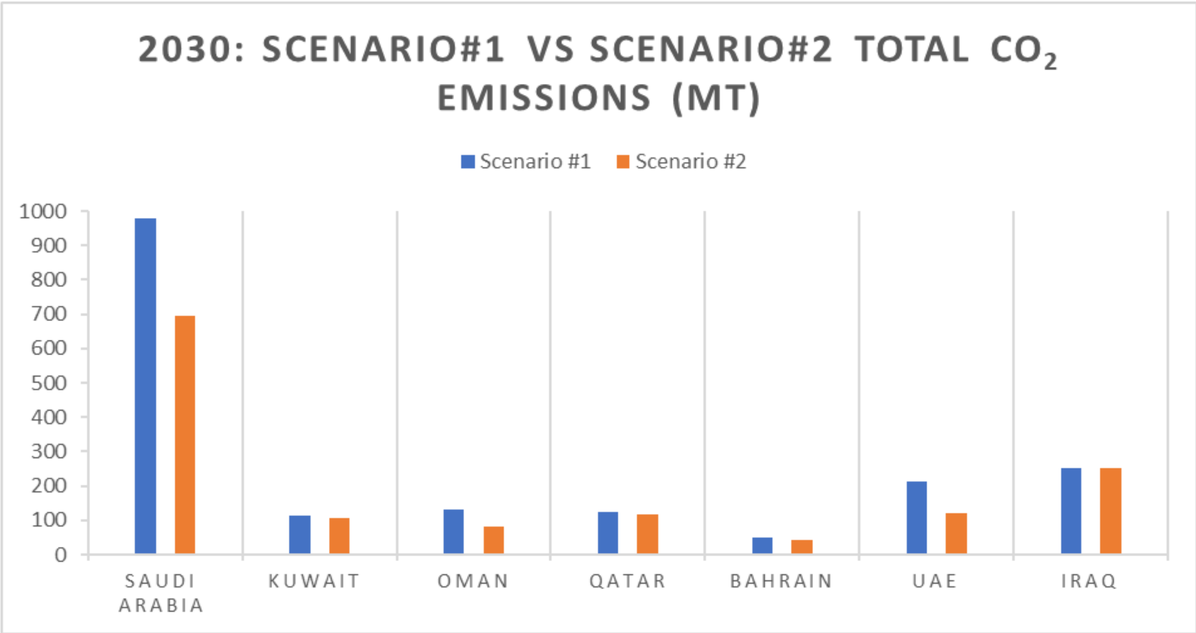


Figure 27 Comparison between the total emissions in scenario #1 vs Scenario#2

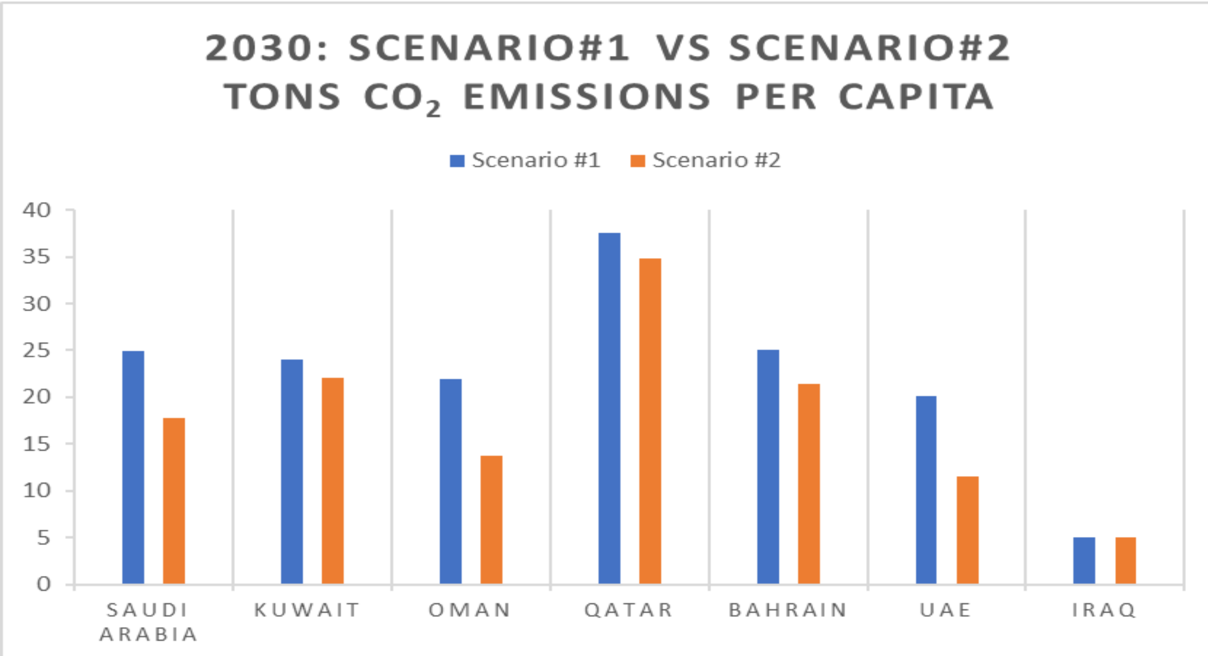


Figure 28 Comparison between the emissions per capita in scenario #1 vs scenario #2

Studying the futuristic plans, visions that was mentioned in the background sections and analyzing the future of energy sustainability in the AGC showed optimistic results.

Almost all countries utilized a portion of the available renewable energy potential especially wind and solar. For example, the energy consumption from renewables in Saudi made up 0.01% of the total energy consumption in 2017 and in 2030 makes up to 20%. However, only Saudi Arabia, UAE, and partially Qatar showed interest in CCUS and DACCS. Also, Bahrain was the only country who specified that the public knowledge of improving energy consumption efficiency should be increased.

Applying those visions to Scenario #2 showed a decrease of CO_2 emissions in all of the countries except for Iraq because it did not have any published official vision. This is due to the transition to cleaner energy sources as shown in *Figure (28)* and improving the efficiency of energy production and consumption.

As established before, the population in the AGC is increasing rapidly. Thus, the emissions per capita is still not close to the global average emissions per capita. However, as stated before, the results are still optimistic for countries that have been depending on fossil fuel for a long time. For example, the UAE's emission per capita was 20-ton CO_2 and now is expected to be 11-ton CO_2 by 2030.

4.6 Scenario#3: Potential of CCUS, DACCS, and Renewables in the Region

After analyzing our results from scenario #2, areas of improvements were clear. First, the potential for cleaner energy sources was not fully used. Secondly, CCUS and DACCS was not focused on the futuristic vision. In this section, the potential for those is going to be showcased on the map of the AGC.

In this scenario, the focus was on the energy consumption and production transition to cleaner, and more efficient energy sources. Thus, a study was conducted on all of the natural gas and oil powerplants in the region.

There are 784 natural gas powerplant units across all the AGC, 675 of those are currently operational. Those units vary in age and net capacity. The graphs below showcase the current state and age of all of those units.

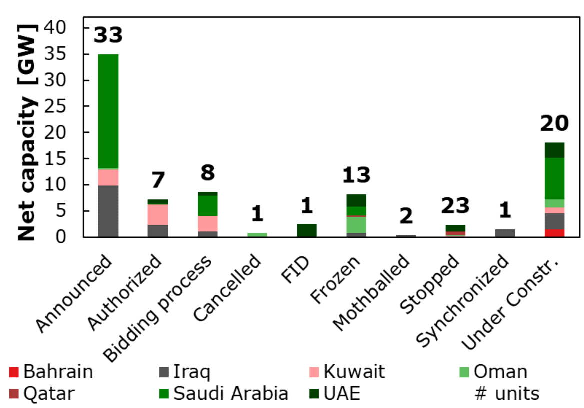


Figure 30 other NG powerplant units stats

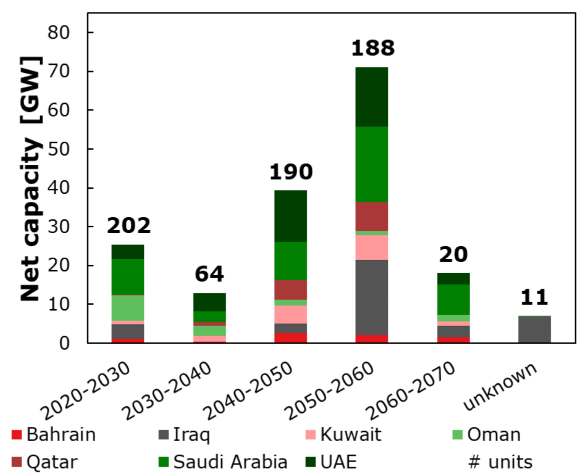


Figure 29 Operational NG powerplant units decommissioning year

On the other hand, there are 797 oil powerplant units across all the AGC, 741 of those are currently operational. The records show that Qatar does not have any oil powerplants. The graphs below showcase the current state and age of all those units.

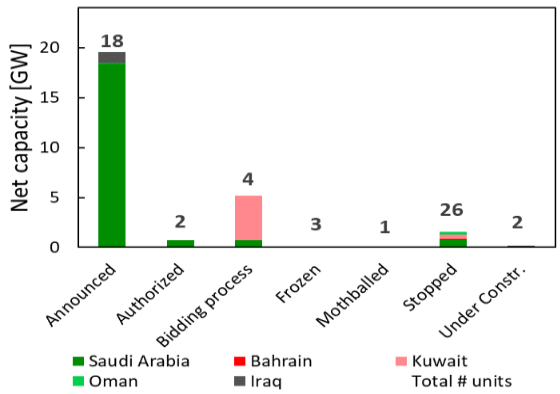


Figure 32 other oil powerplant units stats

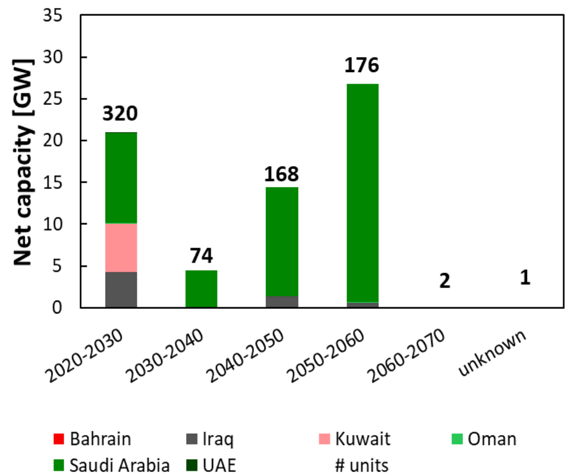


Figure 31 Operational oil powerplant units decommissioning year

In order to make use of this data, all the powerplants were mapped along with the solar and wind potential. We believe that units retiring between 2020-2030 could be replaced by renewable energy units if it is in the region where solar or wind can be used. Carbon capture technologies can be installed on units that has a longer life span. For carbon capture technologies

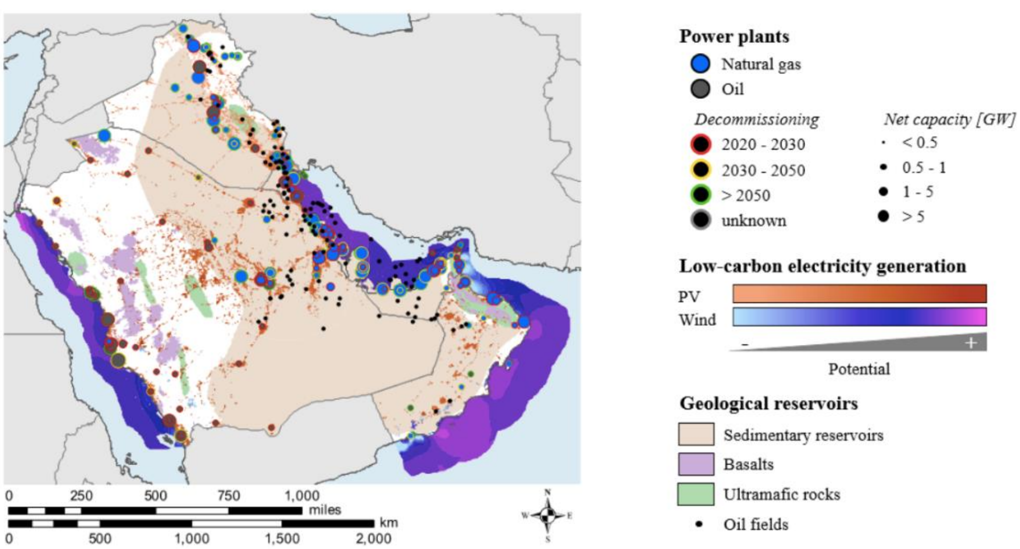


Figure 33 Mapping the potential for renewables and CCUS

to be installed, the plant must be in proximity of a renewable source potential in order to use it to power the technology and sequestration potential.

The second step in scenario #2 was to showcase the potential for DACCS. In this map, the potential for thermal and electrical DACCS is showcased. The oil fields were used in this map since we believe that EOR can be an excellent utilization and sequestration for CO_2.

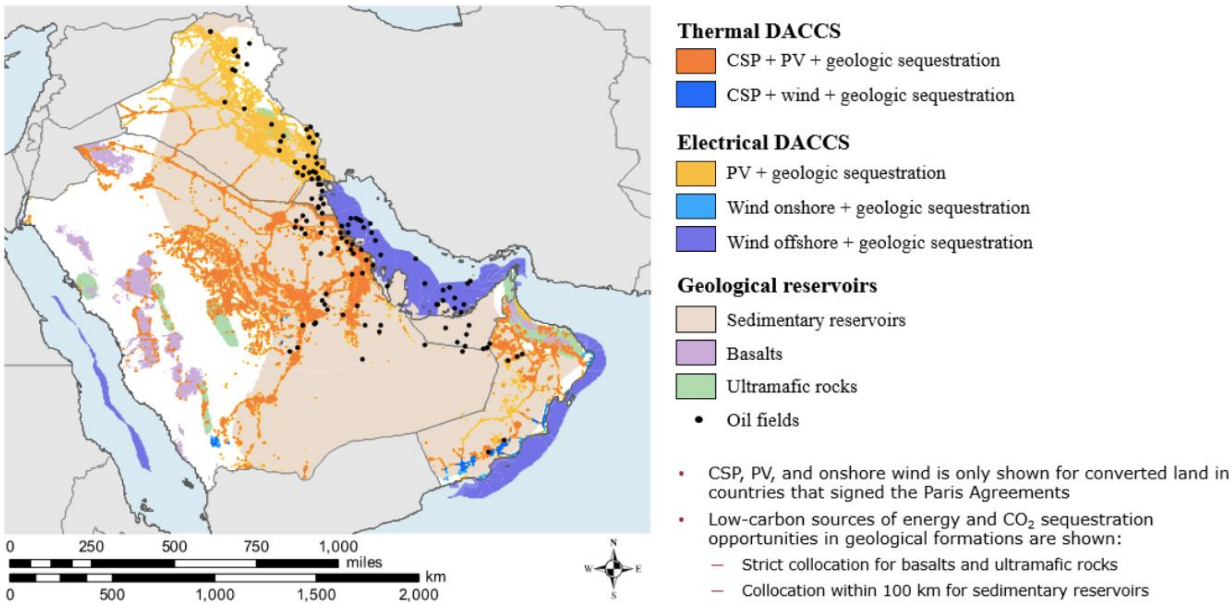


Figure 34 Mapping the potential of DACCS

The goal of this scenario is to further expand the work on scenario #2 and showcase the potential that could be worked on to reduce CO_2 emissions and reach energy sustainability in the region. The maps above can be used to develop the futuristic plans discussed in scenario #2 to match the expected increase in energy demand.

5.0 Recommendations and Conclusion

In this section, we recommend energy sectors in the AGC to publish more data to the public. We also recommend conducting more quantitative research in order to achieve sustainability. We then discuss the responsibility of the AGC regarding the futuristic energy plant in the region.

5.1 More Energy-Related Data to Public

The published data regarding the energy sector in the AGC are limited. There are some data that showcase the current usage of energy within the region; however, most of them are published by a third party and not the energy sectors. For people to understand the effect of the energy transition to the current energy usage, more data should be published by the energy sector that could help researchers improve this sector. Also, providing the public with such data will help increase the public awareness toward the energy sector.

5.2 More Quantitative Research

In addition, more quantified data must be collected by official entities in order to accurately utilize the potentials mentioned in scenario #3. Due to lack of quantitative information shared, the data were collected from third parties and not officially from the energy sectors. Those potentials depend on several aspects such as geological reservoirs, oil and natural gas power plants ages and production, and others that are be determined by the current situations of each location. For future research, those quantitative data will help show a clear idea of how and where those potential will be beneficial. Quantitative data will help specify more favorable potentials locations in the region regarding local economy, environment, and health. For example, locations with higher CO_2 emissions are more convenient for the potentials mentioned in scenario #3. This would help reducing more emissions with lower costs. While locations with lower CO_2 emissions would cost the same with less carbon capture. We believe a further economical, and geological investigation on scenario #3 would lead to great results that would hopefully guide the AGC to energy sustainability.

5.3 The Countries' Responsibility to Energy Transition

In conclusion, the AGC except for Iraq showed optimistic and motivating steps in the right direction in their futuristic plans. The news showcase that those countries are heading into the right direction and we hope that our paper is going to contribute to that. The countries are facing a rapid increase in the energy demand, coupled with vulnerability to climate change, and fluctuation in their economy due to their dependence on fossil fuel which makes the road towards energy sustainability not an easy one. However, as mentioned earlier, the countries are taking the first appropriate steps. More attention to DACCS, CCUS, and renewable energy sources is the second step for those countries.

"The best way to raise the awareness of the need to energy sustainability is by talking about it" Prof. Wilcox (2019). We believe that the governments are heading towards the right direction, but the citizens need to hear more about it to raise the awareness. Energy transition should be taught to the current and next generation in order to bring eyes to it and have more research.

References

Abbass, R., Kumar, P., & El-Gendy, A. (2018). An overview of monitoring and reduction strategies for health and climate change related emissions in the Middle East and North Africa region. Atmospheric Environment, 175, 33–43. https://doi.org/10.1016/j.atmosenv.2017.11.061

Abdullah, I. (2019, December 10). مستوى قياسي للإيرادات غير النفطية في 2019 .. قفزت 148 % في 5 أعوام. Retrieved June 17, 2020, from https://www.aleqt.com/2019/12/10/article_1727151.html

Abuzeyad, F., Alqasem, L., Al Farras, M., Al Jawder, S., Al Qasim, G., & Alghanem, S. (2018). Emergency Medicine in the Kingdom of Bahrain. International Journal of Emergency Medicine, 11(1), 1–8. https://doi.org/10.1186/s12245-018-0163-1

ADNOC (n.d.). *Our History.* Retrieved from https://www.adnoc.ae/en/about-us/our-history

Alabaan, N. (2006). Fahad: 35 Trillion Cubic Feet of Gas in Kuwait. Retrieved June 24, 2020, from https://bit.ly/3hYQmuN

Ali, U. (2019, March 07). History of oil and gas industry from 347 AD to 2019. Retrieved June 24, 2020, from https://www.offshore-technology.com/comment/history-oil-gas/

Archer, S. (2012, January 21). Bahrain: 80 Years and Still Producing. Retrieved June 24, 2020, from https://www.geoexpro.com/articles/2012/12/bahrain-80-years-and-still-producing

Askari, H. (2013). Oil—Discovery and Production in the Persian Gulf (1900–1945). *Collaborative Colonialism*. doi:https://doi.org/10.1057/9781137353771_2

Ataullah, S. (2017, November 27). Qatar to adopt first renewable energy strategy. Retrieved June 24, 2020, from https://www.thepeninsulaqatar.com/article/27/11/2017/Qatar-to-adopt-first-renewable-energy-strategy

Bahrain eGovernment. (2020, March 15). About Bahrain. Retrieved June 17, 2020, from https://www.bahrain.bh/wps/portal/!ut/p/a1/jZDLDoJADEW_xQVbWhgcRncj8Q3R-ECcjUEzjhpkDKL4-aJuNPHVXZtz0tuCgAhEGp-3Ks63Oo2TWy_oojNAatnM7jG_SpD7oUM97FtO6JbA_BlAQprIB9QdumHNpgz_89EO

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Bahrain Natural Gas Company. (2020, January 25). Bahrain Natural Gas. Retrieved June 24, 2020, from http://www.banagas.com/index.php?option=com_content&view=article&id=47&catid=35&Itemid=58

Bahrain's Second National Communication. (2012, February). Under the United Nations Framework Convention on Climate Change. Retrieved July 12, 2020, from https://unfccc.int/resource/docs/natc/bhrnc2.pdf

Balogun, S. (2020, February 21). *Top 10 highest currencies in the world 2019*. Legit. Retrieved from https://www.legit.ng/1116550-highest-currency-world-2019-top-10.html

Baruch-Mordo, S., Kiesecker, J., Kennedy, C., Oakleaf, J., & Opperman, J. (2019). From Paris to practice: sustainable implementation of renewable energy goals. *Environmental Research Letters*, *14*(2), 1–8. https://doi.org/10.1088/1748-9326/aaf6e0

BBC Monitoring (2020, January 13). *Oman country profile.* BBC. Retrieved from https://www.bbc.com/news/world-middle-east-14654150

Ben-Hasan, A., & Christensen, V. (2019). Vulnerability of the marine ecosystem to climate change impacts in the Arabian Gulf—an urgent need for more research. Global Ecology and Conservation, 17. https://doi.org/10.1016/j.gecco.2019.e00556

Business Wire. (2019, June 30). Dubai Achieves 19% Reduction in Net CO2 Emissions. Retrieved June 26, 2020, from https://www.businesswire.com/news/home/20190630005063/en/Dubai-Achieves-19-Reduction-Net-CO2-Emissions

Chatriwala, O. (2014, April 15). Developing a National Energy Strategy in Iraq. Retrieved June 24, 2020, from https://www.worldbank.org/en/results/2014/04/15/developing-a-national-energy-strategy-the-iraq-experience

Central Intelligence Agency. (2018, February 1). The World Factbook: Iraq. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/iz.html

Central Intelligence Agency. (2018, February 1). *The World Factbook: Kuwait.* Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/ku.html

Central Intelligence Agency. (2018, February 1). *The World Factbook: Oman.* Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/mu.html

Climates to Travel (n.d.). *Climate - Kuwait.* Retrieved from https://www.climatestotravel.com/climate/kuwait

CNN Arabic. (2020, January 27). الإمارات: اكتشاف أول حقل للغاز الطبيعي في الشارقة. Retrieved June 24, 2020, from https://arabic.cnn.com/business/article/2020/01/27/uae-dsicovery-first-natural-gas-filed

Country Studies. (n.d.). Hydrocarbon Sector. Retrieved June 24, 2020, from http://countrystudies.us/persian-gulf-states/49.htm

Crystal, J. A., & Peterson, J. E. (2020, June 14). United Arab Emirates. Retrieved from https://www.britannica.com/place/United-Arab-Emirates

Dargin, J. (2010, July 29). Qatar's Gas Revolution. Retrieved June 24, 2020, from https://www.belfercenter.org/sites/default/files/legacy/files/Qatars_Gas_Revolution.pdf

DeNicola, E., Aburizaiza, O., Siddique, A., Khwaja, H., & Carpenter, D. (2015, November 27). Climate Change and Water Scarcity: The Case of Saudi Arabia. Retrieved July 13, 2020, from https://www.sciencedirect.com/science/article/pii/S2214999615012217

Direct Energy. (2020). History of the U.S. Natural Gas Industry. Retrieved June 24, 2020, from https://www.directenergy.com/learning-center/history-of-natural-gas-industry

Dipaola, A. (2020). UAE finds 80 tcf gas field, the world's biggest since 2005. Retrieved June 24, 2020, from https://www.worldoil.com/news/2020/2/6/uae-finds-80-tcf-gas-field-the-world-s-biggest-since-2005

EIA. (2019). Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA). Retrieved June 29, 2020, from https://www.eia.gov/tools/faqs/faq.php?id=709

Figgins, A., Lansdell, J., & Dentons, Y. T. (2019, June 1). Oil and gas regulation in Oman: overview. Thomson Reuters Practice Law. Retrieved from https://ca.practicallaw.thomsonreuters.com/9-567-1725

Geography of Saudi Arabia. (2020, April 07). Retrieved June 17, 2020, from https://fanack.com/saudi-arabia/geography/

Global Media Insight (2020, April 28). UNITED ARAB EMIRATES POPULATION STATISTICS (2020). Retrieved from https://www.globalmediainsight.com/blog/uae-population-statistics

Historical Crude Oil Prices (Table). (2020, April 08). Retrieved June 25, 2020, from https://inflationdata.com/articles/inflation-adjusted-prices/historical-crude-oil-prices-table/

Hukoomi. (2020, January 1). About Qatar. Retrieved June 17, 2020, from https://portal.www.gov.qa/wps/portal/about-qatar

IEA. (2017, July 1). International Energy Agency. Retrieved June 18, 2020, from https://www.iea.org/

IPCC. (2014, June 1). IPCC Reports on Climate Change. Retrieved June 26, 2020, from https://www.ipcc.ch/reports/

Jassim, S., & Goff, J. C. (2006). Geology of Iraq. Retrieved June 24, 2020, from https://books.google.com/books?id=LLH8aygMJFwC

Jeffries, L. M. (2003). *Iraq: Issues, historical background, bibliography*. New York, NY: Nova Science.

Kelemen, P., Aines, R., Bennett, E., Benson, S., Carter, E., Coggon, J., . . . Wilcox, J. (2018). In situ carbon mineralization in ultramafic rocks: Natural processes and possible engineered methods. *Energy Procedia, 146*, 92-102. doi:10.1016/j.egypro.2018.07.013

Kuwait Environmental Public Authorities. (2017). *First Biennial Update Report of the State of Kuwait*. https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/391865_Kuwait-BUR1-1-State%20of%20Kuwait%20-%20BUR.pdf

Khalil, S. (2017, April 24). The history of natural Gas in Iraq. Retrieved June 24, 2020, from https://rawabetcenter.com/en/?p=1921

Kuwait News Agency (2006). Natural Gas in Kuwait 2006. Retrieved June 24, 2020, from https://www.kuna.net.kw/ArticlePrintPage.aspx?id=1599735

Kuwait Oil Company. (2012). Important Dates. Retrieved June 24, 2020, from http://www.kockw.com/kocarabic/pages/About KOC/KOC History/SignificantDates.aspx?sm=2

Mabro, R. (n.d.). Saudi Arabia's Natural Gas: A Glimpse at Complex Issues. Retrieved June 24, 2020, from https://www.oxfordenergy.org/publications/saudi-arabias-natural-gas-a-glimpse-at-complex-issues/

Massachusetts Institute of Technology. (2016). ESI CCS Project Fact Sheet*: Carbon Dioxide Capture and Storage Project. Retrieved June 26, 2020, from https://sequestration.mit.edu/tools/projects/esi_ccs.html

Media Portal Oman. (n.d.). Oil and Natural Gas Sources. Retrieved June 24, 2020 http://5.37.56.186/pages/181/show/619

Mijaylova Nacheva, P., Ramírez Camperos, E., & Sandoval Yoval, L. (2008). Treatment of petroleum production wastewater for reuse in secondary oil recovery. Water Science and Technology: a Journal of the International Association on Water Pollution Research, 57(6), 875–882. https://doi.org/10.2166/wst.2008.202

Mills, A., Wiser, R., & Seel, J. (2017, November). *Power Plant Retirements: Trends and Possible Drivers* . Berkeley: Energy Analysis and Environmental Impacts Division Lawrence Berkeley National Laboratory from https://emp.lbl.gov/sites/default/files/lbnl_retirements_data_synthesis_final.pdf.

Ministry of Energy & Industry. (2017, January 10). UAE Energy Strategy 2050. Retrieved June 24, 2020, from https://www.moei.gov.ae/en/media-centre/news/10/1/2017/%D9%85%D8%AD%D9%85%D8%AF-%D8%A8%D9%86-%D8%B1%D8%A7%D8%B4%D8%AF-%D9%8A%D8%B9%D9%84%D9%86-%D8%A7%D8%B3%D8%AA%D8%B1%D8%A7%D8%AA%D9%8A%D8%AC%D9%8A%D8%A9-%D8%AF%D9%88%D9%84%D8%A9-%D8%A7%D9%84%D8%A5%D9%85%D8%A7%D8%B1%D8%A7%D8%AA-%D9%84%D9%84%D8%B7%D8%A7%D9%82%D8%A9-%D9%84%D9%84%D8%B9%D9%82%D9%88%D8%AF-%D8%A7%D9%84%D8%AB%D9%84%D8%A7%D8%AB%D8%A9-%D8%A7%D9%84%D9%85%D9%82%D8%A8%D9%84%D8%A9.aspx

Mohammed, N. A. (2018). Modelling of unsuppressed electrical demand forecasting in Iraq for long term. *Energy, 162,* 354-363. doi:10.1016/j.energy.2018.08.030

Morton, M., & Sorkhabi, R. (2011). The Abu Dhabi Oil Discoveries. Retrieved from https://www.geoexpro.com/articles/2011/03/the-abu-dhabi-oil-discoveries

Morton, M., & Smith, T. (2014, March 25). Once Upon a Red Line - the Iraq Petroleum Company Story. Retrieved June 24, 2020, from https://www.geoexpro.com/articles/2013/06/once-upon-a-red-line-the-iraq-petroleum-company-story

Morton, M., Sorkhabi, R., & Rasoul Sorkhabi, P. (2020, April 15). The Search for Oil in Oman. Retrieved June 24, 2020, from https://www.geoexpro.com/articles/2012/06/the-search-for-oil-in-oman

Nations Encyclopedia. (n.d.). United Arab Emirates - Location, size, and extent. Retrieved from https://www.nationsencyclopedia.com/Asia-and-Oceania/United-Arab-Emirates-LOCATION-SIZE-AND-EXTENT.html

Nations Online (n.d.). *Oman - Country Profile - Nations Online Project*. Retrieved from https://www.nationsonline.org/oneworld/oman.htm

New Kuwait. (2019). New Kuwait 2035 vision. Retrieved June 24, 2020 form http://www.newkuwait.gov.kw/r7.aspx

OEC. (2018, January 1). Bahrain (BHR) Exports, Imports, and Trade Partners. Retrieved June 17, 2020, from https://oec.world/en/profile/country/bhr/

OEC. (2018, February 1). Qatar (QAT) Exports, Imports, and Trade Partners. Retrieved June 17, 2020, from https://oec.world/en/profile/country/qat/

OEC. (2018). *Kuwait*. https://oec.world/en/profile/country/kwt

US Office of FOSSIL ENERGY. (n.d.). Enhanced Oil Recovery. Retrieved June 26, 2020, from https://www.energy.gov/fe/science-innovation/oil-gas-research/enhanced-oil-recovery

Olawuyi, D. S. (2017, October 4). *Energy Transition in Qatar and the Middle East*. Lecture. Retrieved June 24, 2020.

Oman 2040 Vision. (2019). Oman 2040 Vison Document. Retrieved June 24, 2020 from https://www.2040.om/wp-content/uploads/2020/06/Oman2040Vision-Document-%E2%80%93-EN-Copy1.pdf

OPEC. (n.d.). *Kuwait*. Retrieved from https://www.opec.org/opec_web/en/about_us/165.htm

Paraskova, T. (2019, October 08). Qatar Builds The Biggest Carbon Capture Plant In The Middle East. Retrieved June 26, 2020, from https://oilprice.com/Latest-Energy-News/World-News/Qatar-Builds-The-Biggest-Carbon-Capture-Plant-In-The-Middle-East.html

Paraskova, T. (2020, April 02). Price Collapse Halves Iraq's Oil Revenues. Retrieved June 24, 2020, from https://oilprice.com/Latest-Energy-News/World-News/Price-Collapse-Halves-Iraqs-Oil-Revenues.html

PDO (2018). ALFAHAL Special Edition 2018. Retrieved 2020, from https://www.pdo.co.om/en/news/publications/Publications%20Doc%20Library/Al%20Fahal_Oct_2018_Gas_Supplement_Bilingual.pdf

PDO's HISTORY. (n.d.). Retrieved June 24, 2020, from https://web.archive.org/web/20130316121015/http://www.pdo.co.om/expatriate_site/pdohistory.htm

Plecher, P., & 7, A. (2020, April 07). Saudi Arabia - median age of the population 1950-2050. Retrieved June 17, 2020, from https://www.statista.com/statistics/262482/median-age-of-the-population-in-saudi-arabia/

Population Pyramids of the World from 1950 to 2100. (2019). Retrieved July 12, 2020, from https://www.populationpyramid.net/

Qatar Communication Office. (2020). Qatar National Vision 2030. Retrieved June 24, 2020, from https://www.gco.gov.qa/en/about-qatar/national-vision2030/

Qatar Petroleum. (n.d.). Qatar Oil History. Retrieved June 24, 2020, from https://qp.com.qa/en/AboutQP/Pages/QPHistory.aspx

Saudi Arabia GDP1968-2019 Data: 2020-2022 Forecast: Historical: Chart: News. (n.d.). Retrieved June 17, 2020, from https://tradingeconomics.com/saudi-arabia/gdp

Saudi Arabia Population (LIVE). Retrieved June 17, 2020, from https://www.worldometers.info/world-population/saudi-arabia-population/

Saudi Aramco. (n.d.). Carbon management. Retrieved June 26, 2020, from https://www.saudiaramco.com/en/creating-value/technology-development/globalresearchcenters/carbon-management

Saudi Aramco. (n.d.). Gas Production. Retrieved June 24, 2020, from https://www.saudiaramco.com/en/creating-value/products/gas

Solaimany-Nazar, A., & Zonnouri, A. (2011). Modeling of asphaltene deposition in oil reservoirs during primary oil recovery. Journal of Petroleum Science and Engineering, 75(3-4), 251–259. https://doi.org/10.1016/j.petrol.2010.11.017

Sorkhabi, R. (2008). The Emergence of the Arabian Oil Industry. Retrieved June 24, 2020, from https://www.geoexpro.com/articles/2008/06/the-emergence-of-the-arabian-oil-industry

Sorkhabi, R., Morton, M. Q., & Thornton, W. (2009). Oil from Babylon to Iraq. Retrieved June 24, 2020, from https://www.geoexpro.com/articles/2009/02/oil-from-babylon-to-iraq

Sorkhabi, P. (2010, January 21). The Qatar Oil Discoveries. Retrieved June 24, 2020, from https://www.geoexpro.com/articles/2010/01/the-qatar-oil-discoveries

Sustainable Energy Authority. (2017, January). Bahrain National Renewable Energy Action Plan. Retrieved June 24, 2020, from http://www.seu.gov.bh/wp-content/uploads/2018/04/03_NREAP_Executive-Summary.pdf

Sheng, J. (2010). Modern chemical enhanced oil recovery theory and practice. Gulf Professional Pub.

Tétreault, M. A. (1995). The Kuwait petroleum corporation and the economics of the new world order. Westport, CT: Quorum Books.

The United Arab Emirates' Government Portal. (n.d.). About Economy. Retrieved from https://u.ae/en/about-the-uae/economy

Trading Economics. (n.d.). Iraq GDP. Retrieved from https://tradingeconomics.com/iraq/gdp

Trading Economics (n.d.). *Oman GD*. Retrieved from https://tradingeconomics.com/oman/gdp

Trading Economics. (n.d.). United Arab Emirates GDP. Retrieved from https://tradingeconomics.com/united-arab-emirates/gdp

United States Agency International Development. (2017, March 01). Climate Risk Profile: Iraq. Retrieved July 12, 2020, from https://www.climatelinks.org/resources/climate-change-risk-profile-iraq

U.S. Energy Information Administration - IRAQ. (n.d.). Retrieved from https://www.eia.gov/international/analysis/country/IRQ

U.S. Library of Congress. (n.d.). Qatar- The Economy - Oil and Natural Gas. Retrieved June 24, 2020, from http://countrystudies.us/persian-gulf-states/73.htm

U.S. Energy Information Administration (EIA). (2019, December 6). Natural Gas Explained. Retrieved June 24, 2020, from https://www.eia.gov/energyexplained/natural-gas/

Vision 2030. (n.d.). National Industrial Development & Logistics Program. Retrieved June 24, 2020, from https://vision2030.gov.sa/en

Viswanathan, G. B. (2017, January 18). Oman *History: Explore the ancient Omani trading routes.* Times of Oman. Retrieved from https://timesofoman.com/article/100895/hi/this-weekend/oman-history-explore-the-ancient-omani-trading-routes

WAM. (2017, January 10). UAE Energy Plan for 2050 to achieve balance between energy production and consumption. Retrieved June 24, 2020, from https://gulfnews.com/business/energy/uae-energy-plan-for-2050-to-achieve-balance-between-energy-production-and-consumption-1.1959893

Weather Spark (n.d.). *Average Weather in Muscat*. Retrieved from https://weatherspark.com/y/105797/Average-Weather-in-Muscat-Oman-Year-Round

Wilcox, J. (2012). Carbon capture (pp. 1–323). Springer New York. https://doi.org/10.1007/978-1-4614-2215-0

Wilcox, J., Rochana, P., Kirchofer, A., Glatz, G., & He, J. (2014). Revisiting film theory to consider approaches for enhanced solvent-process design for carbon capture. Energy & Environmental Science, 7(5), 1769–1785. https://doi.org/10.1039/c4ee00001c

World Health Organization. (2019). Eastern Mediterranean Region. Retrieved July 12, 2020, from http://www.emro.who.int/about-who/rc61/impact-air-pollution.html

World Meters. (n.d.). *GDP Per Capita*. Retrieved from https://www.worldometers.info/gdp/gdp-per-capita/

World Meter. (2015). Iraq Natural Gas. Retrieved June 24, 2020, from https://www.worldometers.info/gas/iraq-natural-gas/

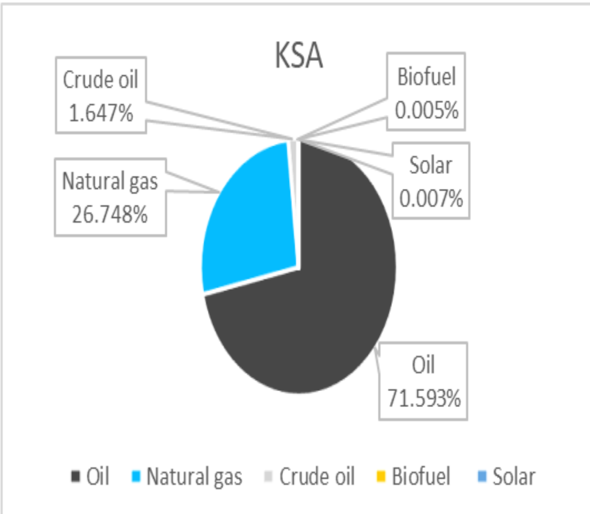
World Meter. (n.d.). Oman Natural Gas. Retrieved June 24, 2020, from https://www.worldometers.info/gas/oman-natural-gas/

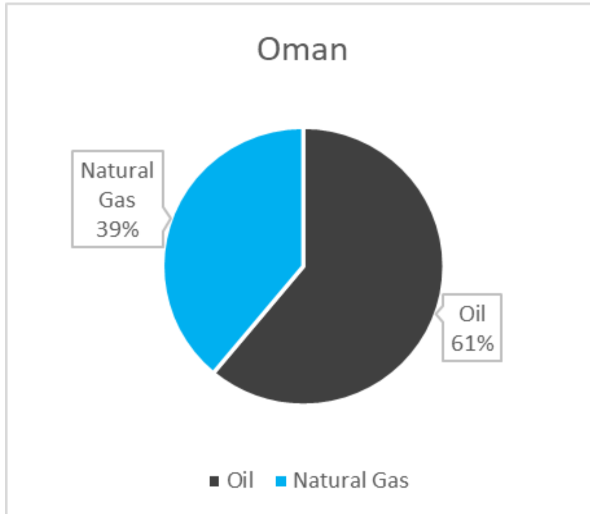
Workman, D. (2020, June 15). Crude Oil Exports by Country. Retrieved June 23, 2020, from http://www.worldstopexports.com/worlds-top-oil-exports-country/

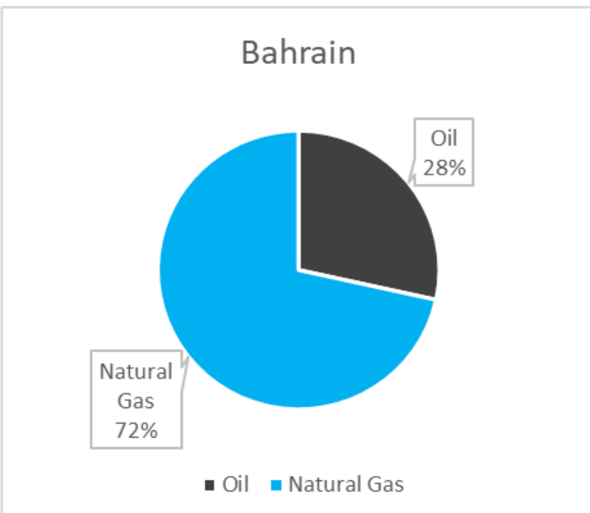
BBC Monitoring (2020, January 13). *Oman country profile.* BBC. Retrieved from https://www.bbc.com/news/world-middle-east-14654150

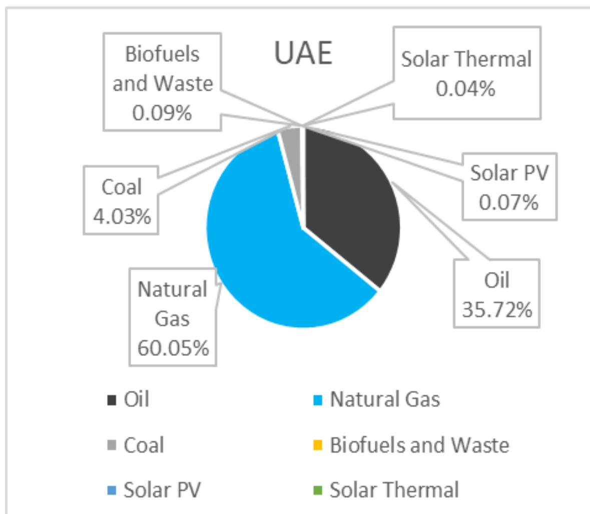
Appendices

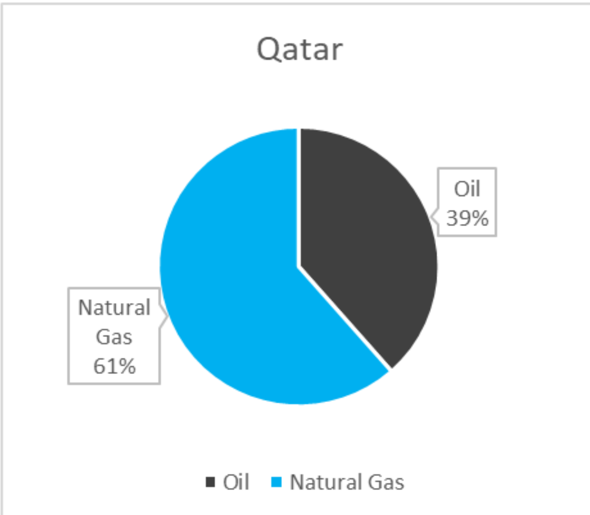
Appendix A: Energy Consumption by source of each country (2017)

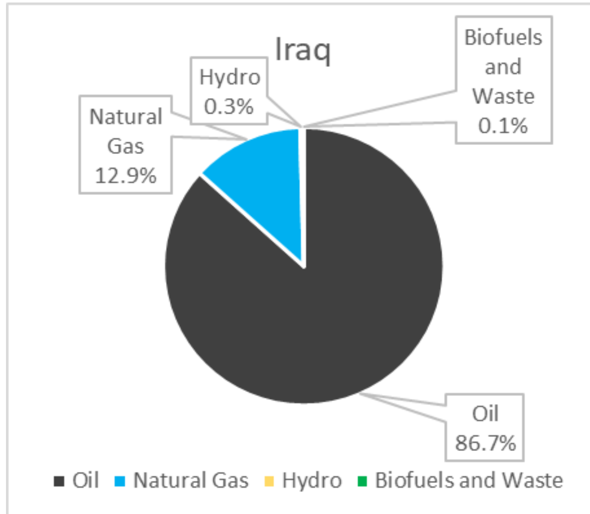


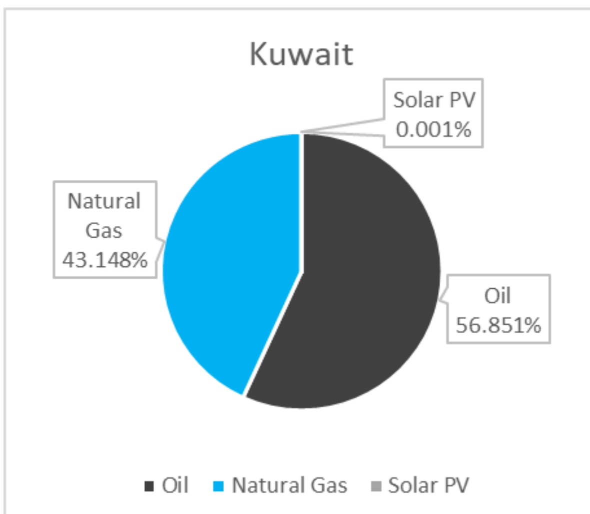




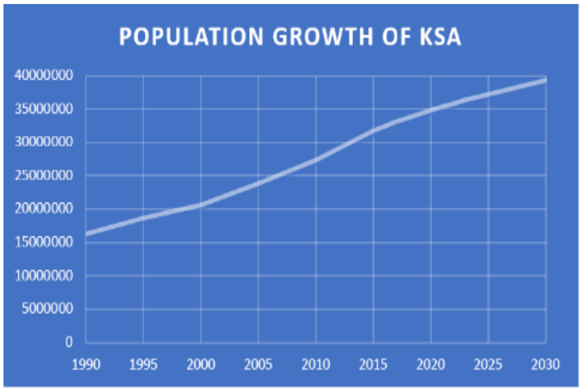


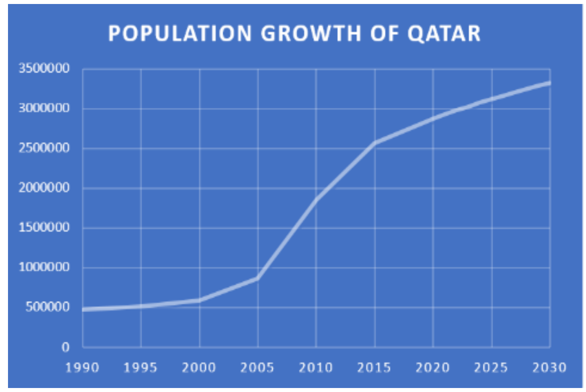

Qatar
Oil
39%
Natural
Gas
61%
Oil
Natural Gas

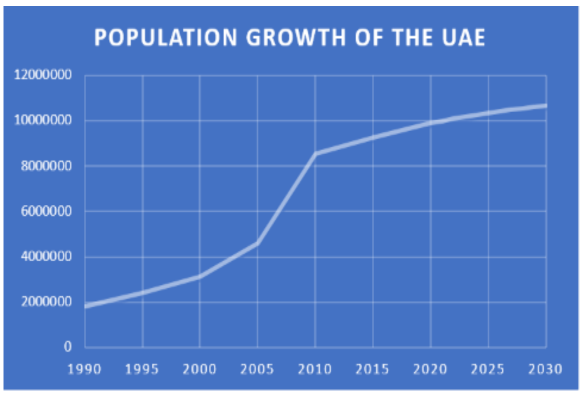

Iraq
Hydro
0.3%
Biofuels
and
Waste
0.1%
Natural
Gas
12.9%
Oil
86.7%
Oil
Natural Gas
Hydro
Biofuels and Waste

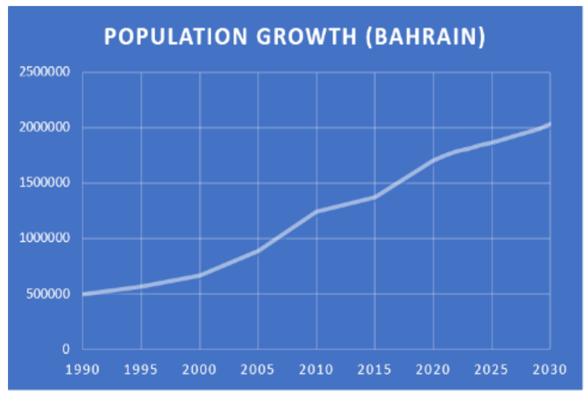

Kuwait
Solar PV
0.001%
Natural
Gas
43.148%
Oil
56.851%
Oil
Natural Gas
Solar PV

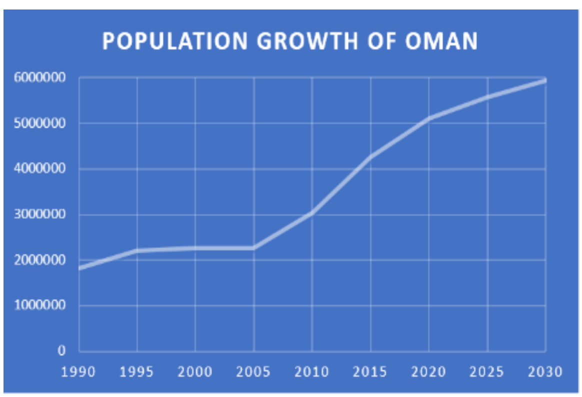
Appendix B: Population Growth of each country of the AGC (1990-2030)

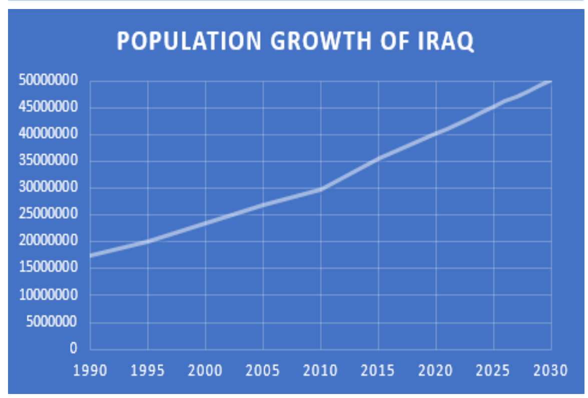


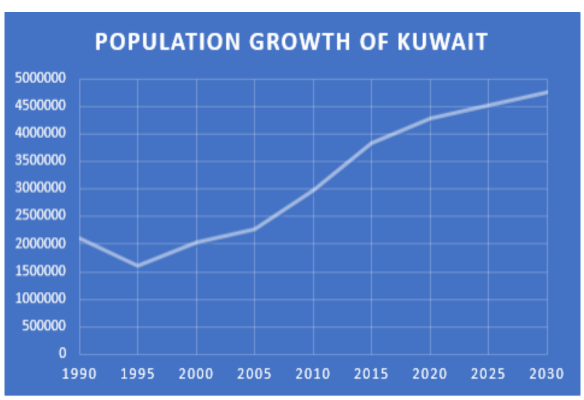




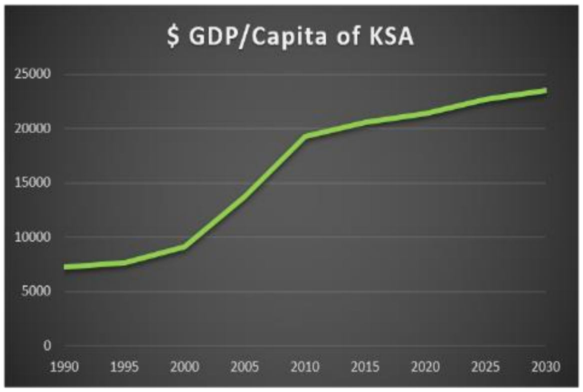


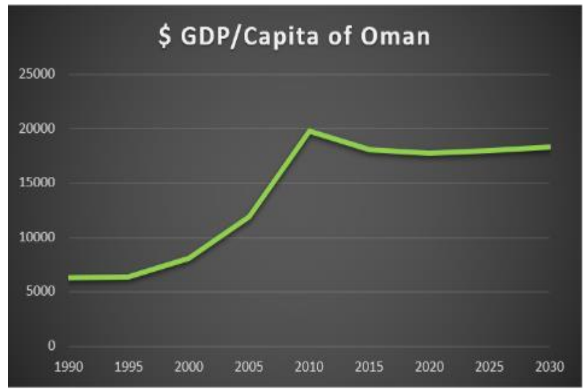


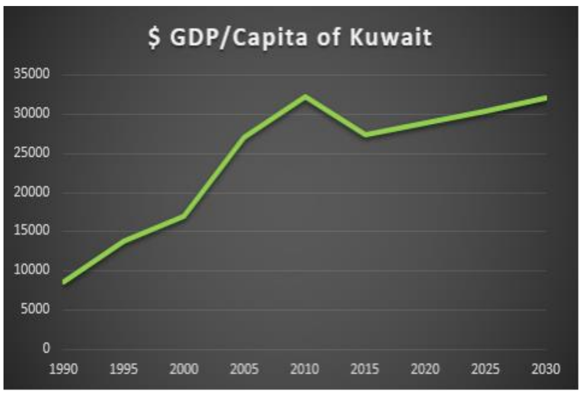


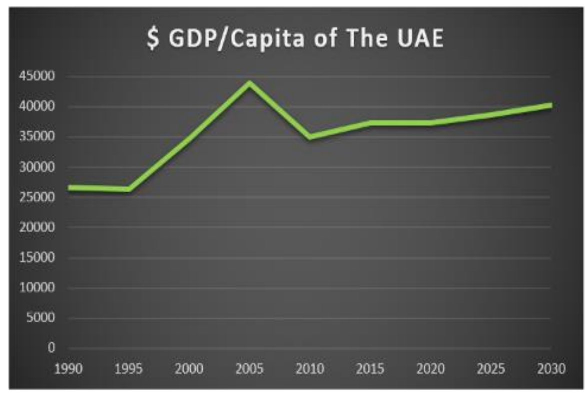


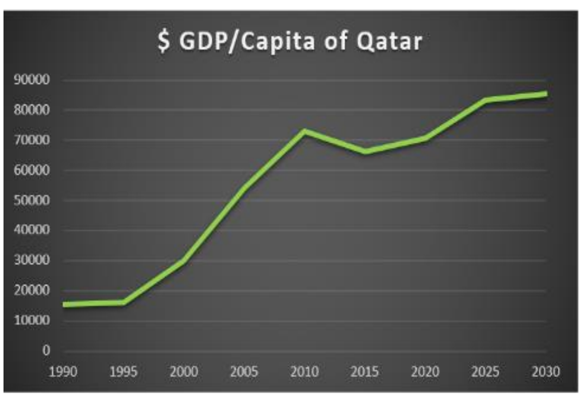
Appendix C: $ GDP per Capita for each country of the AGC (1990-2030)

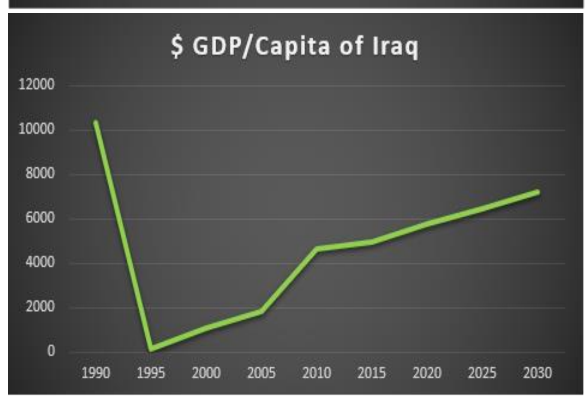


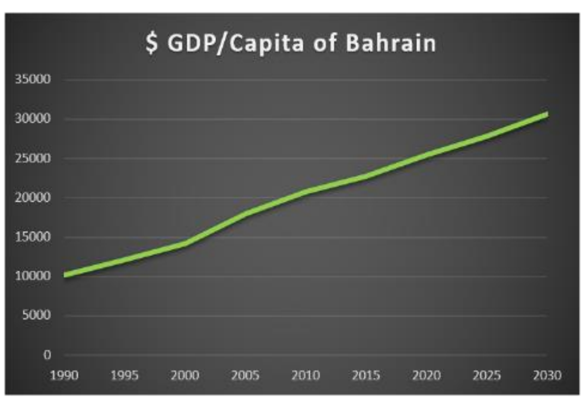




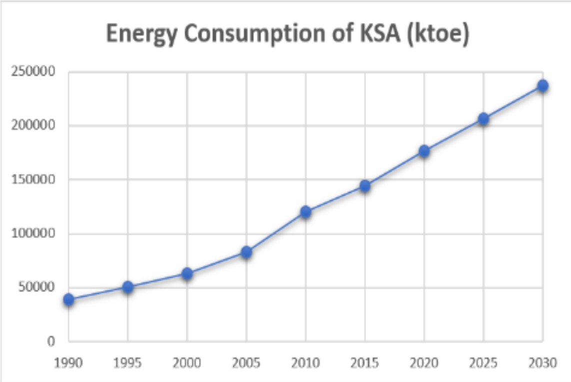


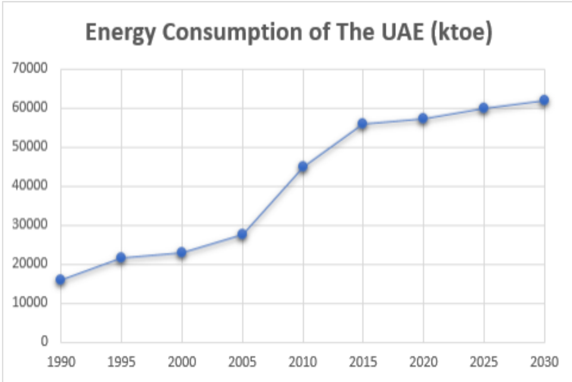


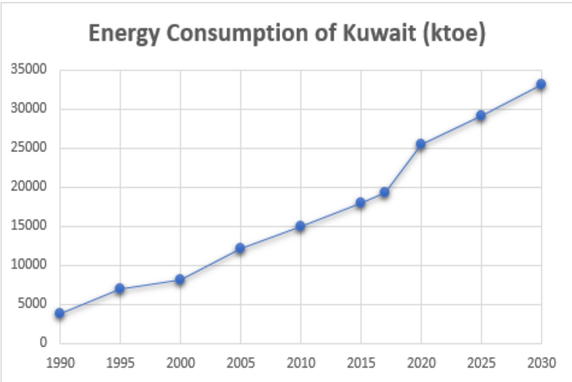


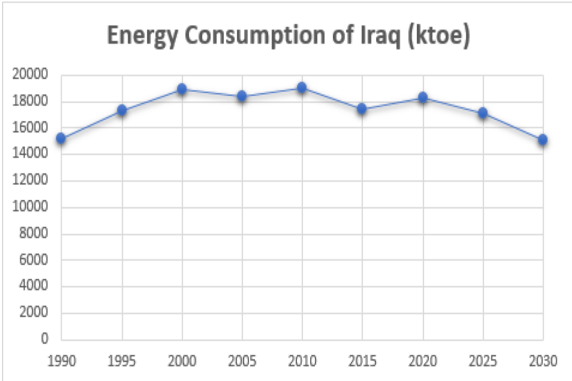


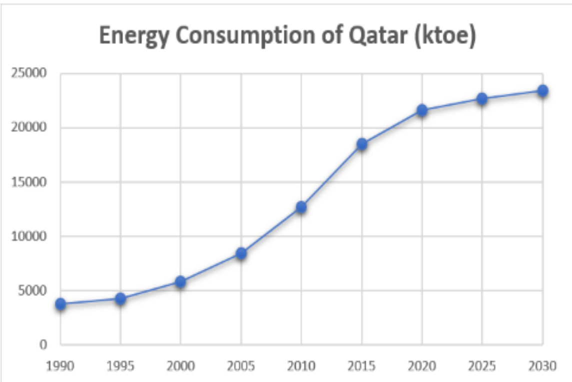
Appendix D: Energy Consumption of each country in the AGC (1990-2030)

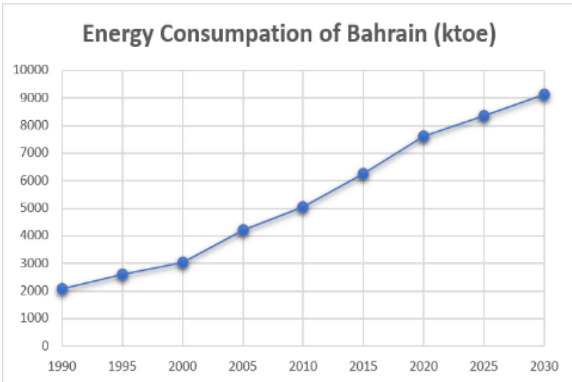


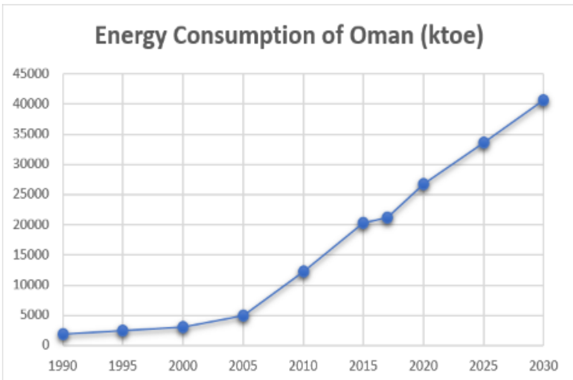




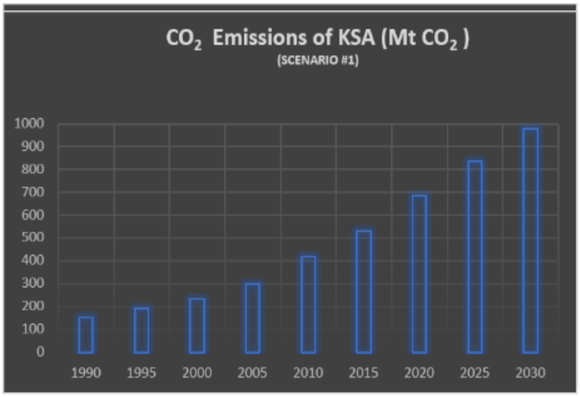


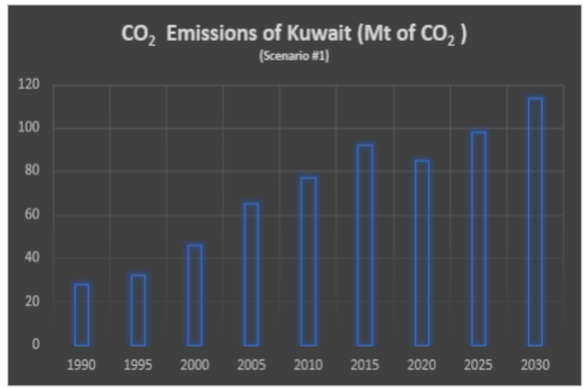


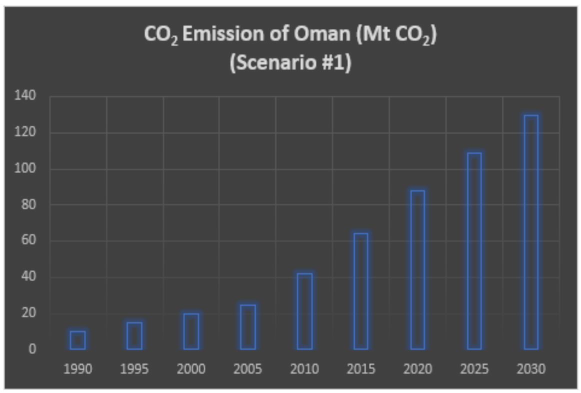


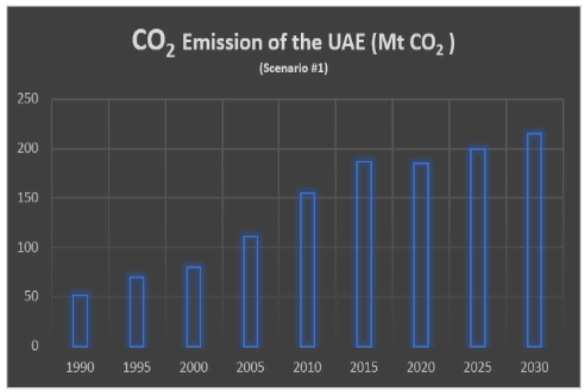


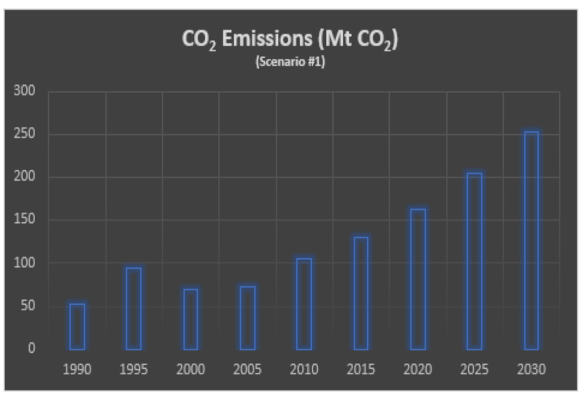
Appendix E: CO_2 Emissions of each country in the AGC for Scenario #1 (1990-2030)

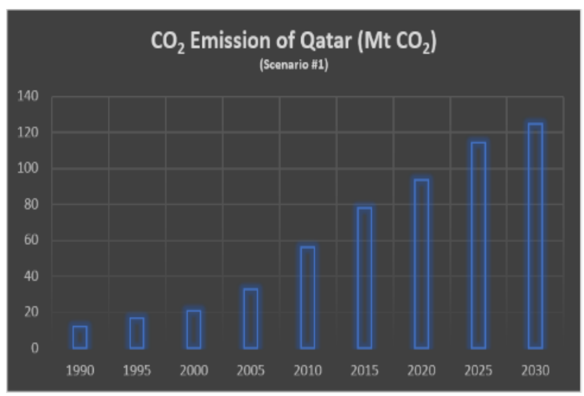


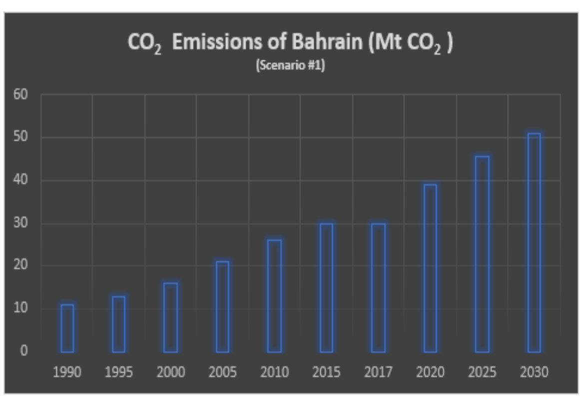




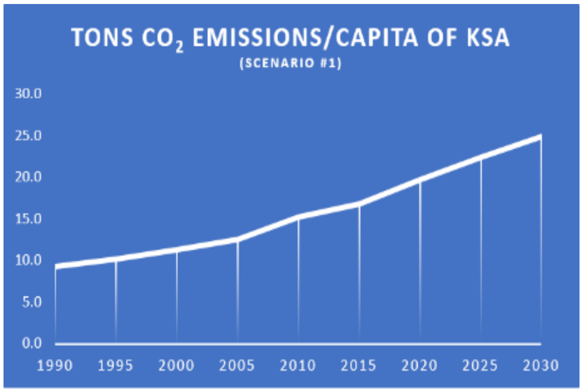


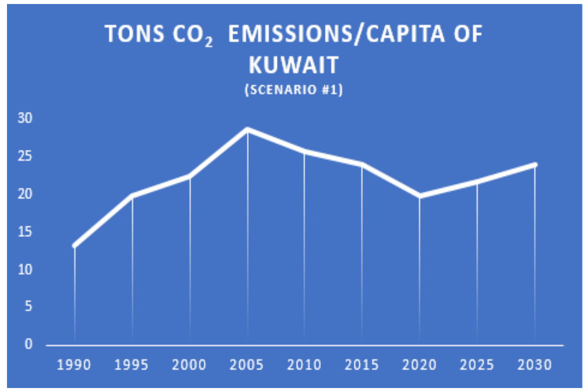


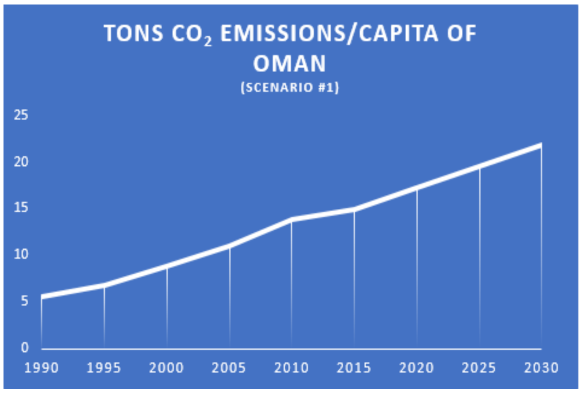


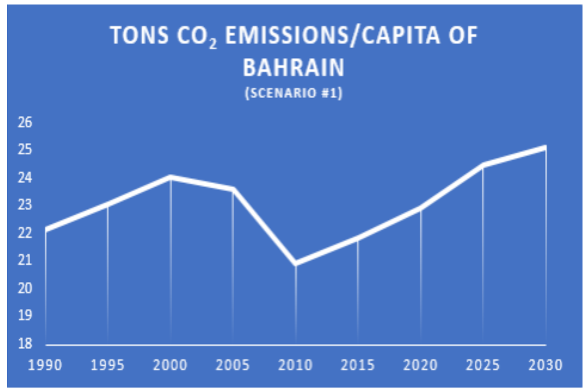


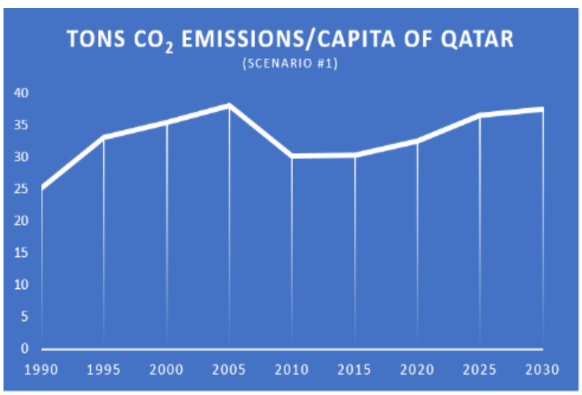
Appendix F: Tons CO2 Emission per capita of each country in the AGC (1990-2030)

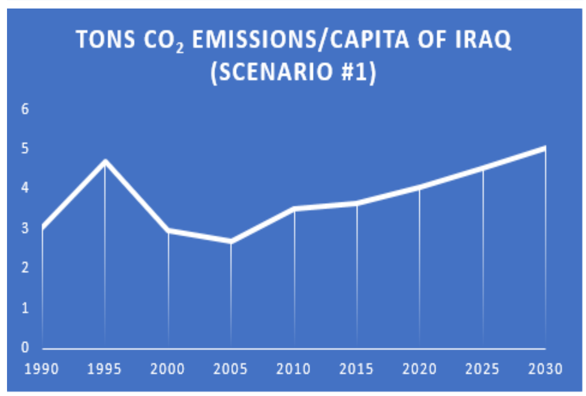


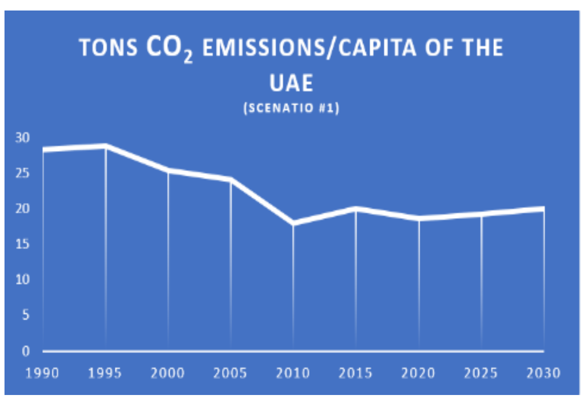




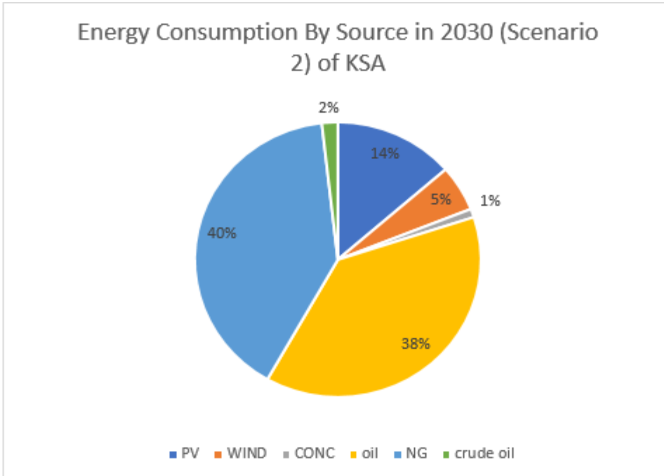


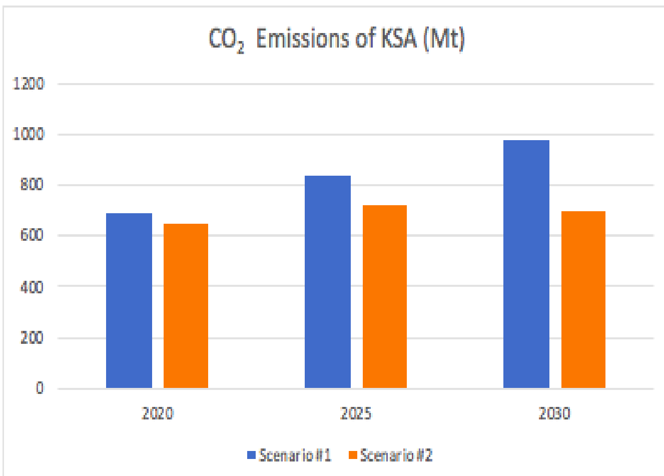


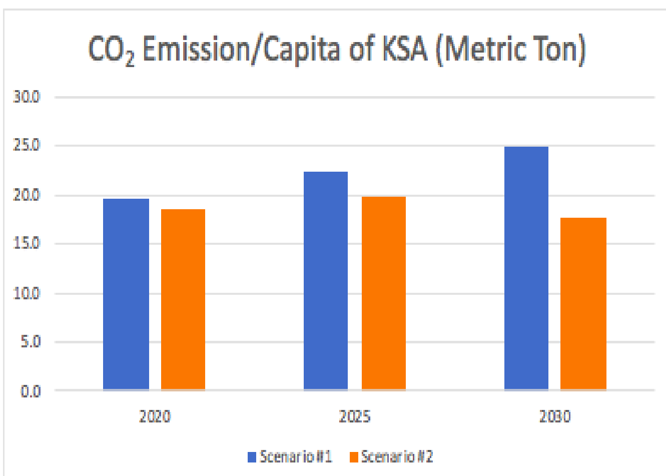




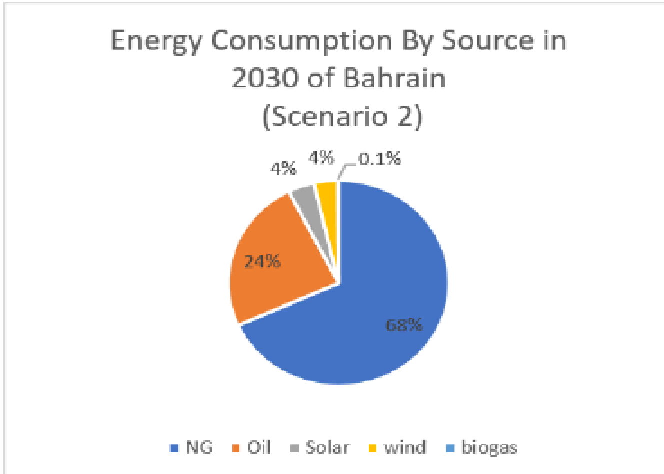
Appendix G: KSA results for Scenario #2

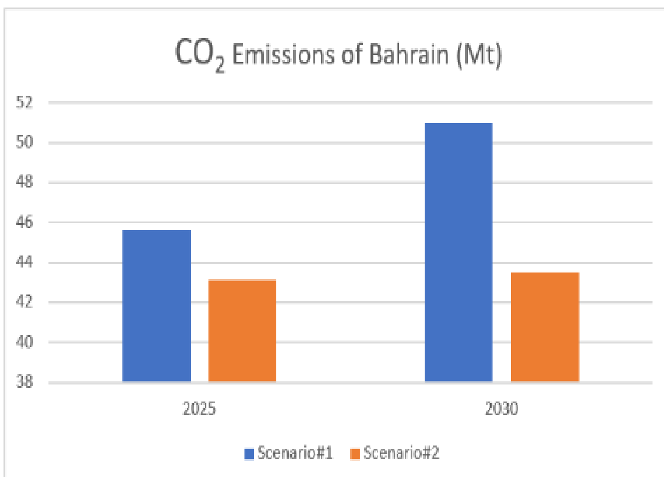


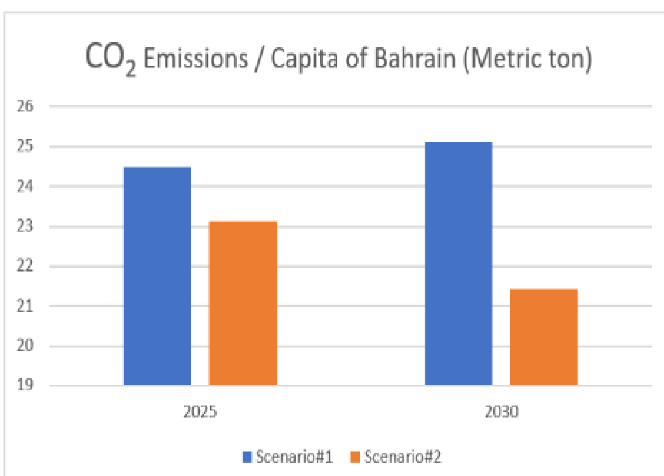




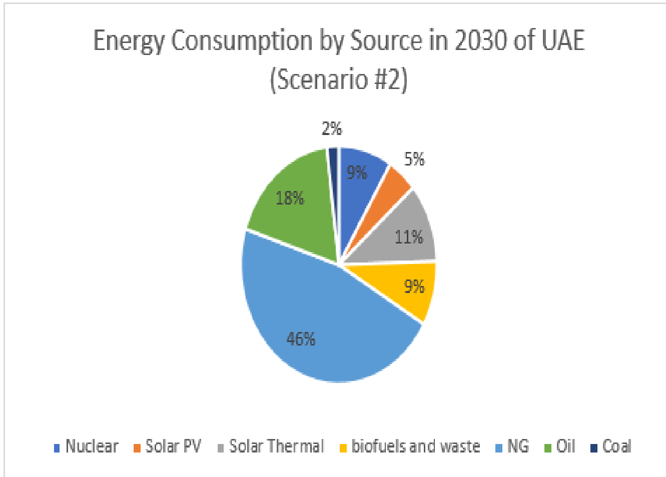
Appendix H: Bahrain results for Scenario #2

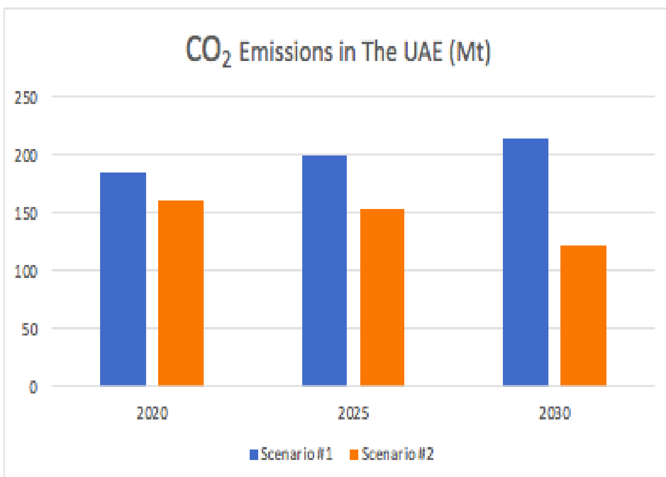


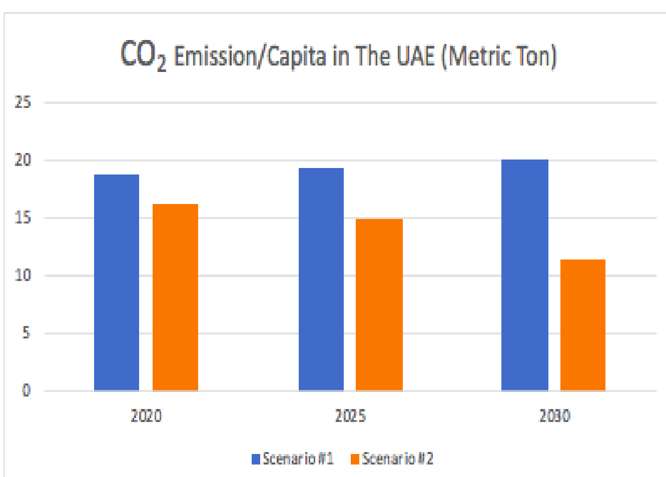




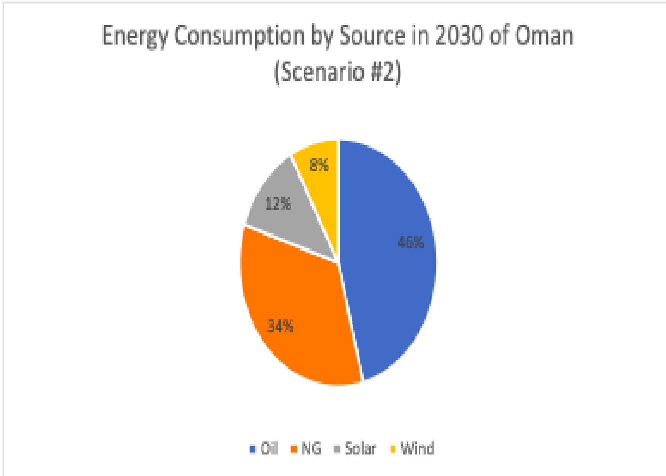
Appendix I: UAE results for Scenario #2

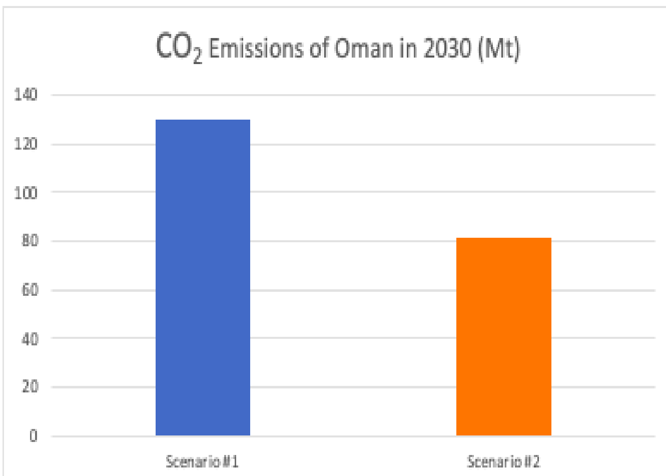


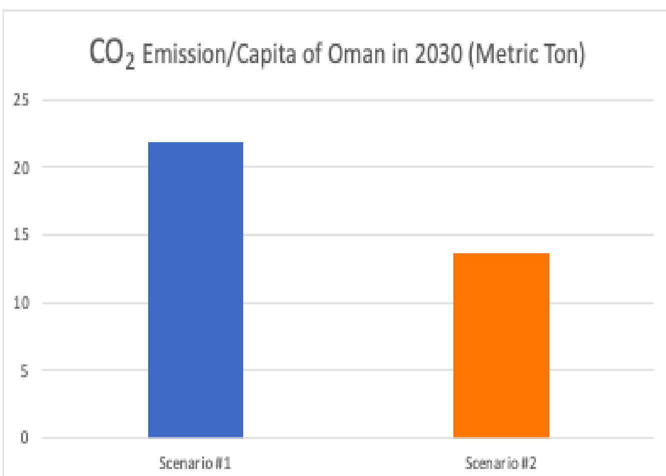




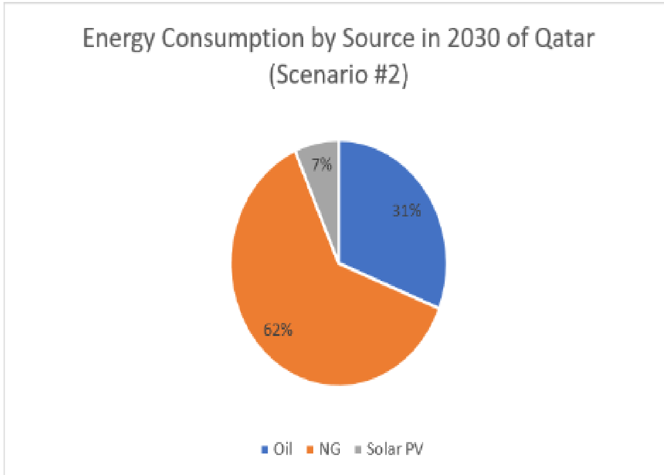
Appendix J: Oman results for Scenario #2

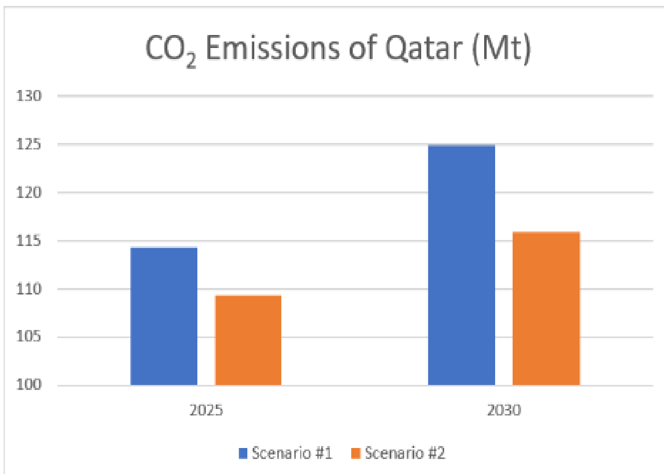


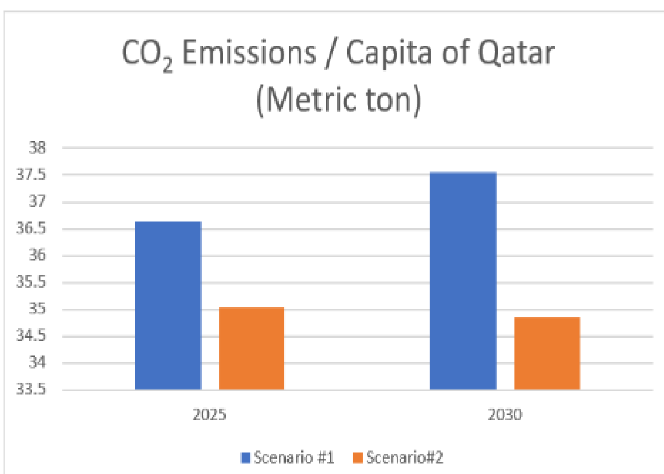




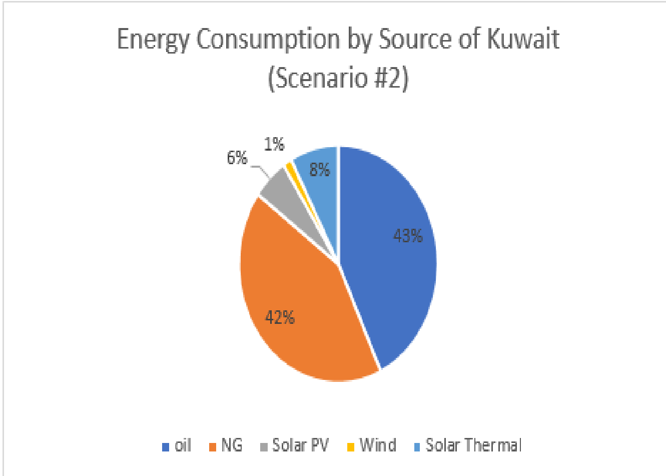
Appendix K: Qatar results for Scenario #2

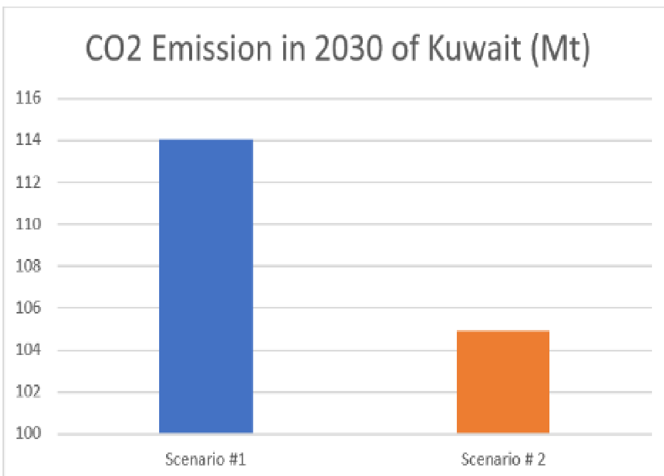


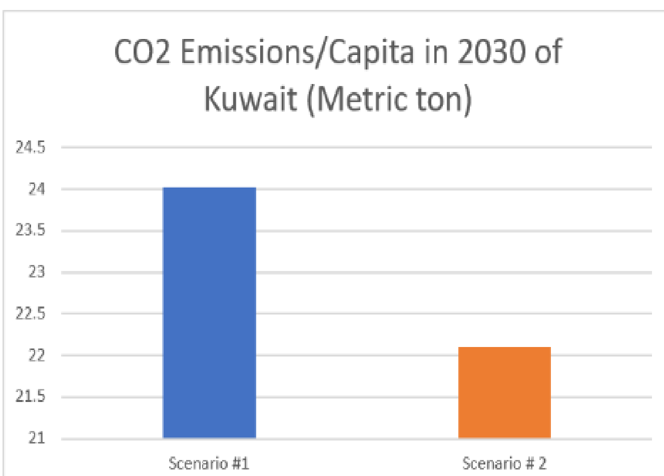




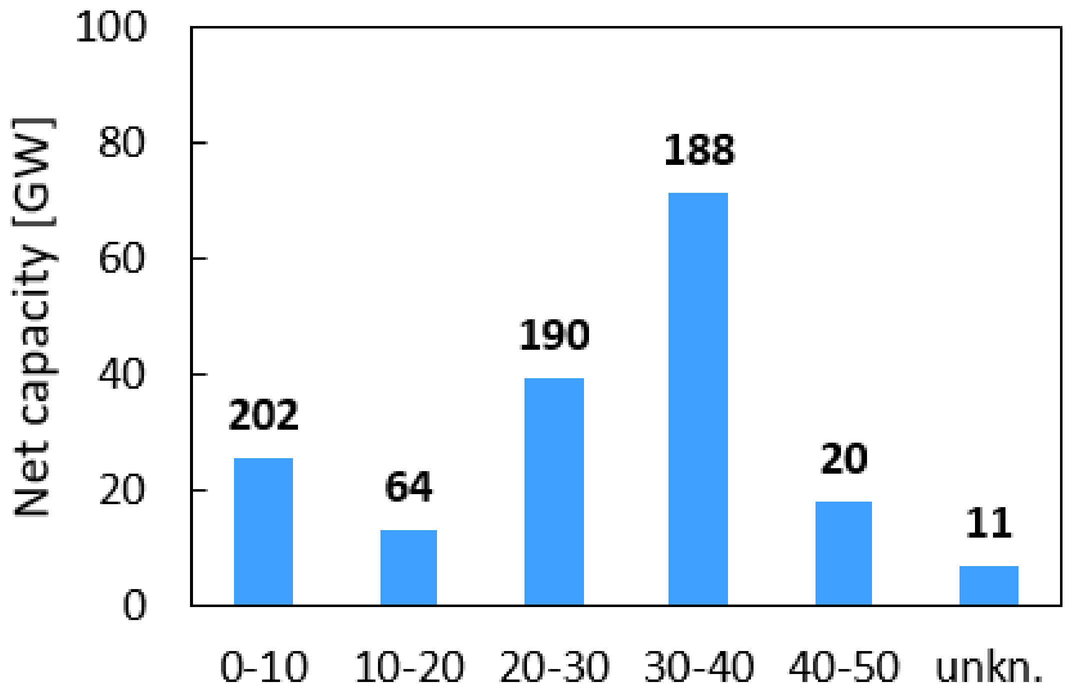
Appendix L: Kuwait results for Scenario #2



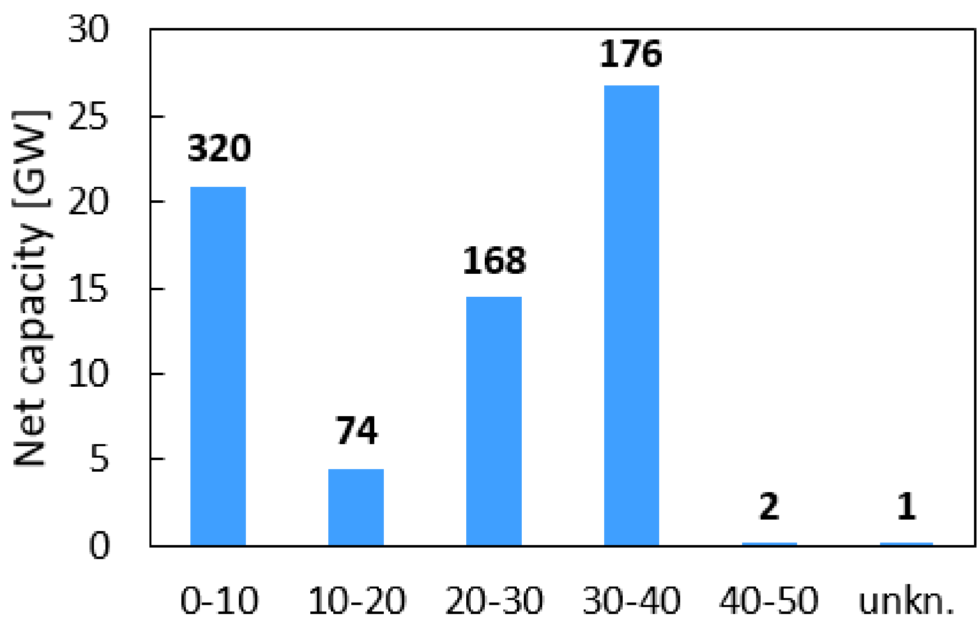




Appendix M: Remaining Powerplant Units and its Life Expectancy



NG POWERPLANT UNITS REMAINING LIFE EXPECTANCY



OIL POWERPLANT UNITS REMAINING LIFE EXPECTANCY