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A comparative analysis of the carbon dioxide emissions-energy profile in Kuwait: Status quo versus 2030

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ABSTRACT

Kuwait is among the leading countries globally in terms of its per capita consumption of electricity and water based on the energy outlook report released in 2019. In Kuwait, the CO_2 (carbon dioxide) emission rates have increased from the energy sector due to the burning of significant amounts of fossil fuels to meet the demands of electricity generation and water supply. Under these circumstances, the demanding analysis methodology to forecasting CO_2 emissions from the energy sector, the per capita energy consumption, and CO_2 emissions were 8.9 toe per capita and 21.1 tons of CO_2-eq emissions per capita, respectively. This paper aims to quantify a comparative analysis model and estimate a numeric magnitude for current and forecasting 2030 CO_2 production totals from Kuwait's energy sector and its impact on average atmospheric temperature and energy production. The aggregate carbon intensity (ACI) was used as an indicator to evaluate the current energy situation and predict a model for Kuwait's CO_2 emissions situation and identify how the energy demand and supply might evolve by 2030. The CO_2 emissions for 2030 and the electricity consumption trend were assumed to be the 'business-as-usual' model using 2nd set of Fuel Analysis USEPA, with five fuel blend scenarios used as the energy sector's predicted fuel blends. The results found that the total CO_2 emissions from the energy sector and the ACI of Kuwait in 2016 were 48.6 $MtCO_2$ and 0.69 $kgCO_2$/kWhr, respectively. The 2030 estimations indicated that using an 80% natural gas and 20% gas oil fuel blend in energy production resulted in CO_2 emissions of approximately 66 $MtCO_2$, with an ACI of 0.45 kgCO2/kW-hr. The CO_2 offset from upcoming renewable energy projects is projected to be approximately 13%.

Keywords: Aggregate Carbon Intensity (ACI); CO_2 production; Combustion equation; Emissions; Fuel consumption.

INTRODUCTION

High rates of per capita consumption of both electricity and water place a significant burden on power and desalination plants, increase the rate of pollution, and reduce the oil products and natural gas exports (Darwish *et al.,* 2009). Kuwait is one of the largest countries in the world in terms of its per capita consumption of electricity and water (Qader, 2009). Many sources contribute to increasing the amount of CO_2 emissions into the atmosphere, such as transportation, residential (services), oil refineries (oil and gas productions), industrial factories, electricity generation, and water desalination (energy sector). The scope of this work focuses on high CO_2 emissions rates from both electricity generation and water desalination (hereafter, the energy sector). CO_2 emissions have increased annually due to the burning of significant amounts of fossil fuels to meet electricity generation and water desalination demand. Under these circumstances, the per capita for energy consumption was 8.9 toe, and the value for CO_2 emissions from all sources was 21.1 tons of CO_2-eq emissions per capita (Kuwait Institute for Scientific Research, 2019).

Many international inventories have emissions factors methodologies used to predict CO2 emissions, such as the Intergovernmental Panel for Climate Change (IPCC), IEA, and USEPA. Many studies used different approaches to estimate and inventory CO_2 emissions from fuel combustion. Al- Mutairi *et al.* (2017) provided the carbon atlas of Kuwait and estimated the carbon dioxide emissions from the power generation sector of Kuwait at 41.6 MtCO2/yr. The stoichiometric ratio of CO_2 to hydrogen from balanced chemical equations is used to determine CO_2 emissions levels from refineries in the downstream industry in Kuwait (Al-Salem, 2015). Also, CO_2 emission rates were represented by different forms such as kg/kWh (Darwish *et al.*, 2008 part I , 2008 part II). Tracking the trend of CO2 emissions can monitor by Many forecasting models. Qader *et al.* (2022) provided an accurate model to estimate CO2 emissions from electricity power generation in Bahrain. Multiregional approaches simulation used to forecast CO_2 emissions (Intergovernmental Panel on Climate Change, 2013). An econometric method was utilized by different studies to predict CO_2 emissions (Zhao *et al.*, 2015 & Schmalensee *et al.*, 1998). Nassar *et al.* (2021) provided a study that depends on Life cycle assessment methodology to estimate CO2 emissions factors from energy flow supply by diesel fuel in Libya. The level of CO_2 emissions and the energy profile are analyzed and monitored by many different global indexes, which convert the values of measurements and calculations into a significant numeric index. The aggregate carbon intensity (ACI) is a measure or indicator that demonstrates the concentration of GHG emissions from electricity production (Ang & Su, 2016). Many studies were used ACI as an indicator to represent the carbon intensity per electricity produced and to show the changes that happen over the period (MA, 2021; Oliveira-De Jesus D *et al.*, 2020; Wang & Song 2022; Liu *et al.*, 2019; Wang *et al.*, 2018; Wang *et al.*, 2020; Goh *et al.*, 2018). It is a measurable tool that can quantify the GHG contribution of a power plant. It presents the quantity of CO_2 emissions (kilograms CO_2) released per power unit (Kilowatt hours). In this study, the ACI is used as an indicator to depict the level of carbon and compare it with other cases.

1.1 Fuel Consumption and CO_2 Emissions

The combustion of fossil fuels releases several air pollutant elements into the atmosphere. Air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), Volatile Organic Compounds (VOCs), and toxic metals (Lead and Mercury) (Vallero, 2014). Carbon dioxide is the major component of the combustion process (Usman and Makhdum, 2021) and accounts for up to 90% of combustion emissions. Each fuel or fuel blend used for combustion contains an emission factor or carbon content that determines the amounts of CO_2 released into the air. Coal is the highest carbon-containing fossil fuel (Jaramillo *et al.*, 2007). Qader (2009) evaluated the relationship between GHGs and electricity consumption in the Gulf region. His evaluation used the beyond petrol (BP) methodology to calculate GHG emissions. His study stated that "Kuwait and Qatar offer electricity almost for free." This fact should be rephrased, as the value of services is close to being free of charge and lacks bill collection. Alotaibi (2011) argued in favor of installing Multiple Effect Distillation (MED) technology for water desalination in Kuwait due to its higher energy efficiency than that of Multistage Flash (MSF) technology. He observed that operating at maximum load during the summer peak period causes a power plant to work at a lower thermal efficiency.

Many studies find the correlation and link between the increase in CO2 emissions and energy consumption (Yang *et al.,* 2020; Jahanger *et al.,* 2021a; Usman *et al.,* 2021b; Zhang *et al.,* 2021; Usman *et al.,* 2021c; Jahanger *et al.,* 2021a, b). Quadrelli and Peterson (2007) analyzed the driving factors of CO_2 emissions from fossil fuel burning. The considered elements were fuel types, socioeconomic indicators, regions, and sectors. Alshehry and Belloumi (2015) explored the causal relation among energy consumption, price, and economic activity in Saudi Arabia. Jia *et al.* (2019) investigated the association between the capacity of seawater desalination plants in China, energy consumption, GHG emissions, and unit cost. They found that the increasing rate of GHG emissions for ten years is 180%. They used Johansen's multivariate cointegration approach in their study, indicating that economic growth led to CO_2 emissions. This result supports the claim that the increase in economic growth in Kuwait is catalyzing the CO_2 levels. Al-Faris (2002) examined the effects of economic factors on electricity demand in the Gulf region using cointegration methods. The results inferred that income and price affect the rates of electricity consumption. Omri (2013) examined the link among CO_2 emissions, energy consumption, and economic growth using simultaneous equations models with data from 14 MENA countries. The results indicated a unidirectional causal relationship between energy consumption and CO_2 emissions. Done *et al.* (2004) compared GHG emissions associated with fossil fuel systems with nuclear and renewable energy systems. The life cycle analysis approach was applied. The results indicated that the dominant GHG emitted from fossil fuel power plants was the CO2 released from the boilers. A sustainable fuel source can reduce environmental impacts. A sustainable diesel fuel with a $SrCO_3$ can be delivered by catalytic conversion of waste tube tires and waste polypropylene (Singh, 2020).

Many researches provided different approaches to reduce and react with CO_2 emissions, such as using waste CO2 as an oxidant in the catalytic dehydrogenation of ethane to produce ethylene in the presence of potassium as a promoter (Li *et al*., 2021); the urgent need to reach zero CO_2 emissions by increasing the potential of the hybrid power system from solar energy and fossil fuel by providing three possible pathways (Hong *et al*., 2021), utilizing a highly efficient metal-nitrogen-carbon (M-N-C) catalyst to transform CO_2 into value-added products (Pellessier *et al*., 2021). This study demonstrated utilizing renewable energy as offset to reduce CO_2. In addition, many studies were conducted to capitalize the advance of integration of solar energy and thermal application to fossil fuel power plants (Chen *et al*., 2021).

1.2 The Status of Energy Consumption and Power Plants

The Ministry of Electricity and Water (MEW) is the authority responsible for generating and transmitting electricity, desalinating seawater, and providing potable water to consumers (Ministry of Electricity and Water, 2017). Kuwait relies on eight power plants for power production, all of which are strategically located near seawater, in accordance with the cogeneration technologies used in those power plants to simultaneously desalinate seawater MEW power plants operate on oil products and natural gas as fuel to generate electricity and water supplies. The types of fuels used include heavy fuel oil, crude oil, gas oil, lean gas, and liquefied natural gas (Darwish *et al.,* 2007). Each fuel has a specific emission factor concerning CO_2 emissions. The fuel with the highest CO_2 emission factor is heavy fuel oil (HFO). According to MEW statistics, the per capita electricity consumption was approximately 14,306 kWh in 2016. The per capita consumption rate increases annually at a rate of 0.8% (MEW, 2017). The rapid growth in the demand for electricity in Kuwait over recent decades has several explanatory factors. First, the economy was booming from oil export revenue. Additionally, the population was increasing at a steady rate due to improved living conditions.

Moreover, the technological advancements available for consumers contributed to electricity demand. There was also sizeable international labor emigration to Kuwait. However, one of the most electricity-demanding factors is the air conditioning (AC) units. ACs play a prominent role in directly increasing the electricity demand because of the hot arid climate (Alotaibi, 2011).

Kuwait Energy is supplied by eight power plants, with a generation capacity of 18 Giga Watts (Ministry of Electricity and Water, 2017). All power plants are cogeneration plants that produce electricity and water (Alhajeri *et al.*, 2019). The most common method for desalination in Kuwait is multistage flash (MSF) distillation technology. The Az-Zour North 1 power plant exclusively uses multiple effect distillation (MED). Kuwait's strategic plan until 2030 provisions six new power plants to keep up with the forecasted demand. These proposed power plants are being designed to use natural gas as their primary fuel, except for AlShagaya, which will have 100% renewable energy (Kuwait Times, 2018). Examining the CO_2 emissions from the power sector in Kuwait is a worthwhile endeavor. The increase in the electricity demand is driving the GHG emission levels in Kuwait (Qader, 2009). Kuwait Municipality developed a new national master plan into four regions: urban, northern, western, and southern Kuwait. Table 1 shows the attributes of MEW's power plants classified based on regions (Public Authority for Civil Information, 2018). The total power availability is 18.259 Giga Watts, and the total water production is 528 Million Imperial Gallons Per Day (MIGD).

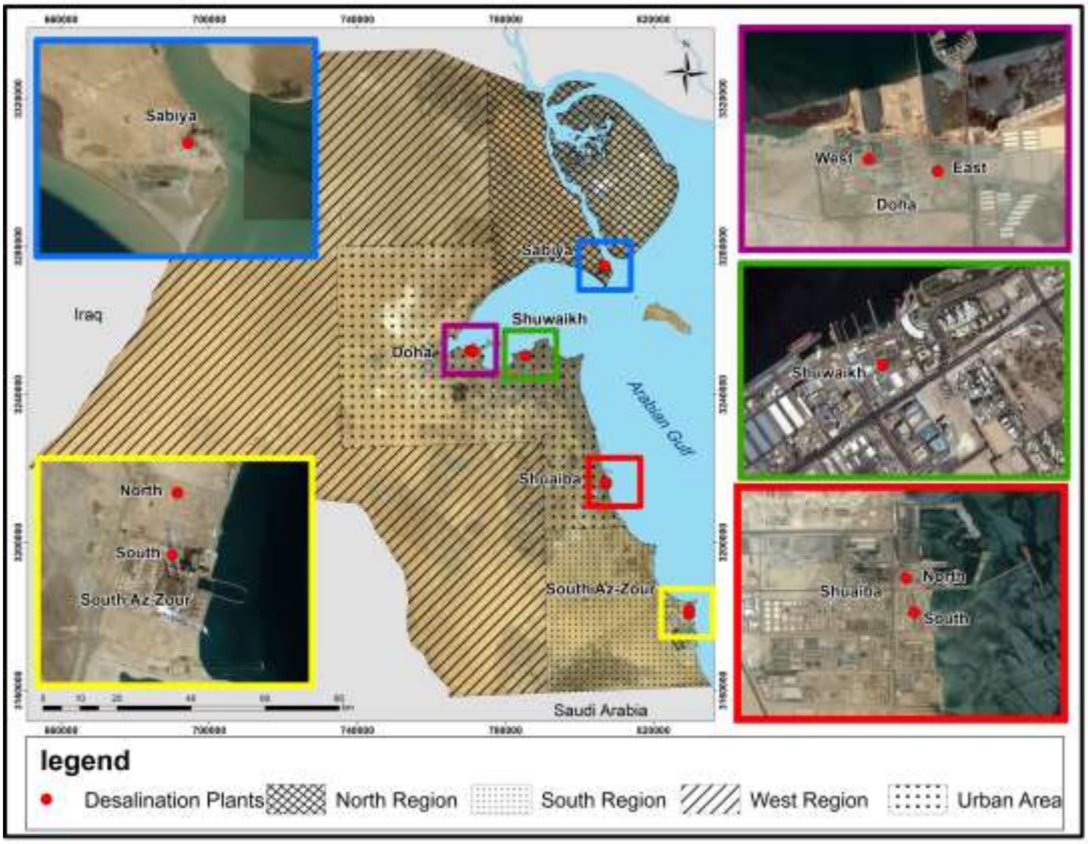


Figure 1. The Location of Power-desalination Complexes in the New National Master Plan of Kuwait.

In Kuwait, energy production and oil refineries (oil and gas productions) account for 67% of CO2 emissions, while industry and transportation account for 33%. Figure 2 shows the historical levels of CO_2 in Kuwait in $MtCO_2$.

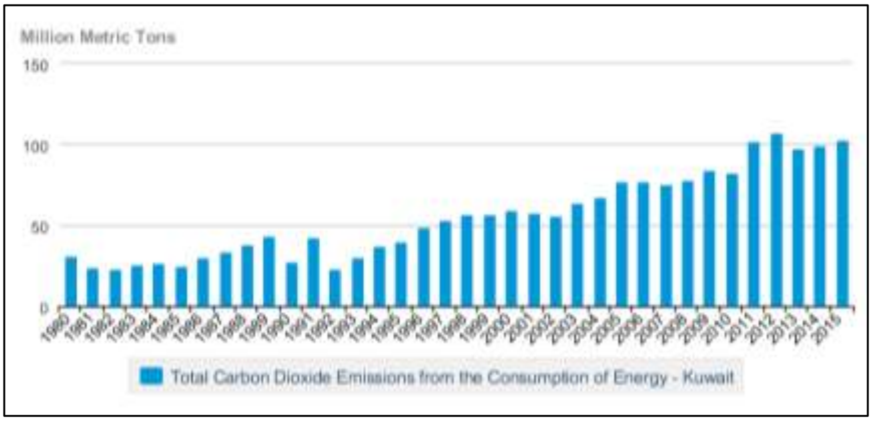


Figure 2. Total CO2 Emissions from Energy Consumption in Kuwait [citation (EIA)]

Table 1. The Attributes of Power Stations in Kuwait in 2016 (Ministry of Electricity and Water, 2017).

Region	Name	Power (MW)	Water (MIGD)	Natural Gas Quantities in 2016 (BSCF**)	Heavy Fuel Oil Quantities 2016 (BBL*)	Crude Oil Quantities 2016 (BBL*)	Gas Oil Quantities 2016 (BBL*)
Southern	Az-Zour South	5806	145	103.1	17458.5	213.0	1061.0
	Az-Zour North 1	1531	107	49.3	0.0	0.0	118.8
Northern	Sabiya	5367	100	105.1	11921.9	97.1	4074.2
Urban	Shuwaikh	252	50	9.7	0.0	0.0	0.0
	Shuaiba North	876	45	38.0	0.0	0.0	333.0
	Doha West	2541	110	21.4	16227.5	331.6	15.2
	Doha East	1158	42	15.3	2852.4	3416.2	0.4
	Shuaiba South	720	36	36.7	0.0	0.0	129.2
Total		**18259**	**528**	**378.5**	**48460.3**	**4057.9**	**5731.8**

*BBL: Barrels, **BSCF: Billion Standard Cubic Feet

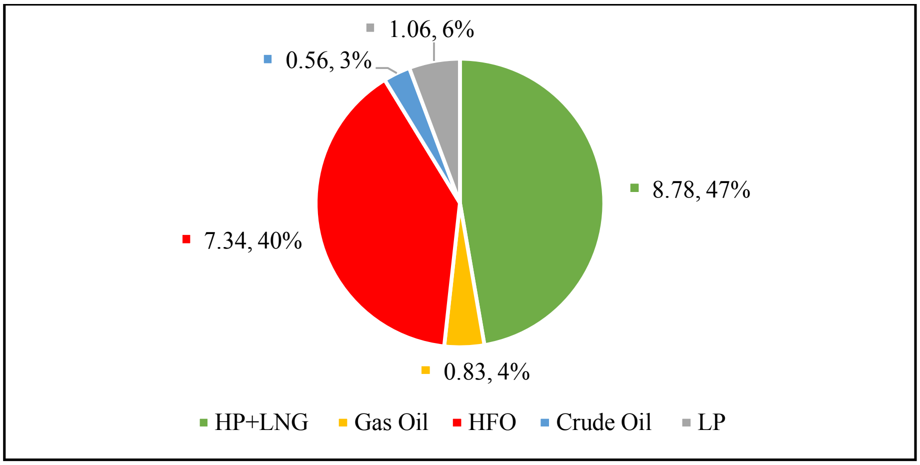


Figure 3. Total Fuel Consumption from Kuwait's Energy Sector in 2016 Millions of tonnes of oil equivalent (Mtoe) (Ministry of Electricity and Water, 2017)

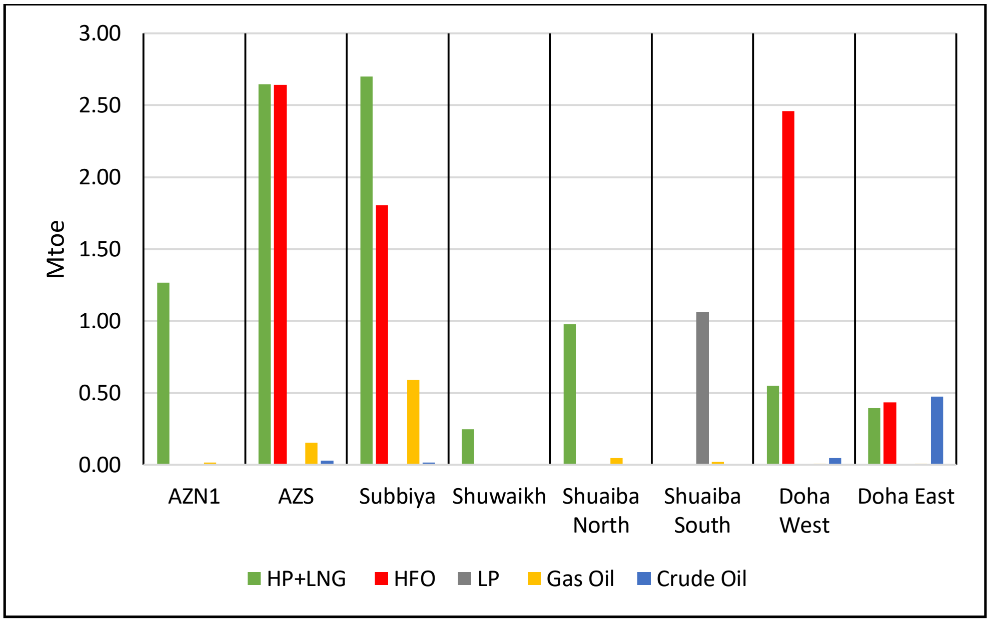


Figure 4. Fuel Consumption from Each Power Plant in Kuwait during 2016 (Mtoe) (Ministry of Electricity and Water, 2017)

The total fuel consumption in MEW power plants in 2016 was 18.57 Million tons of oil equivalent (Mtoe). Figure 3 indicates that natural gas and HFO were the significant fuels consumed by MEW power plants, while figure 4 presents the individual fuel consumption of each power plant. With respect to LP gas (low-pressure lean gas), it is used only in the Shuaiba South plant, while this fuel is incompatible with the other plants. Moreover, gas oil is scarcely used and is utilized only in emergencies as a backup fuel, which explains its low value in its overall fuel consumption and is used in power plants.

Part of Kuwait's MEW master plan by 2030 is to introduce six cogeneration plants to keep up with the forecasted demands for power and water (Ministry of Electricity and Water, 2018). The proposed power plants are designed to use natural gas as their primary fuel type and are shown in Figure 5. Additionally, the plan includes commissioning two renewable energy plants that provide up to 1.1 Giga Watts.

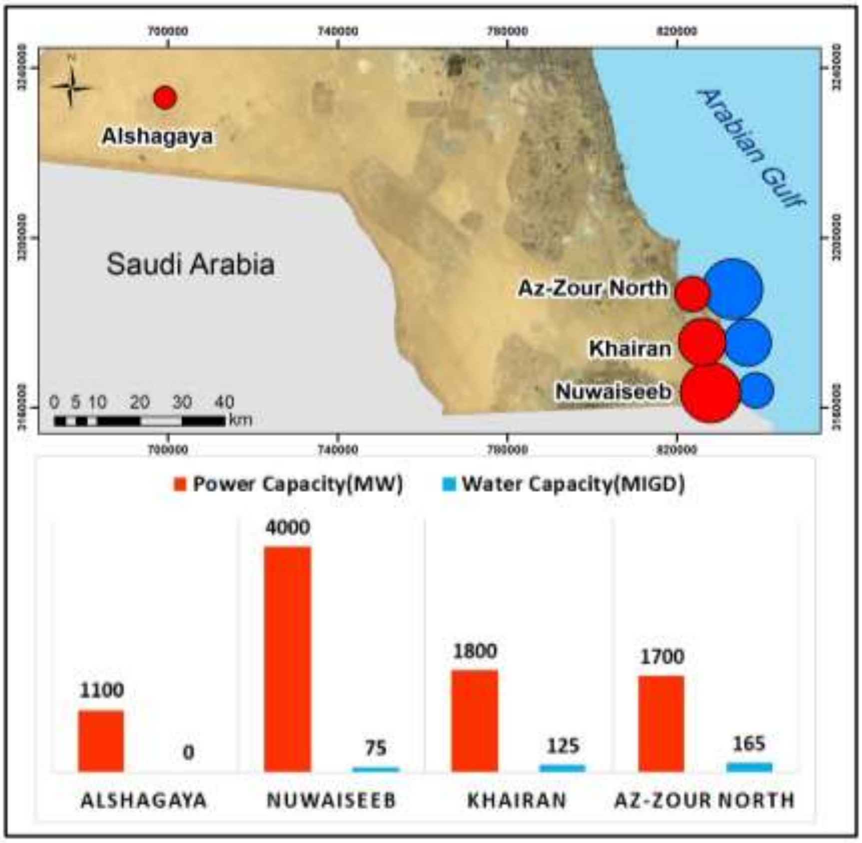


Figure 5. The Proposed 2030 Power Stations Plan.

This paper aims to model the current 2016 and proposed 2030 CO_2 emissions during peak times from Kuwait's energy sector using the USEPA Fuel Analysis methodology and estimate the ACI to determine Kuwait's CO_2 emission rates with respect to other countries. The 2030 CO_2 emissions are projected using five scenarios pertaining to possible fuel blends used to produce Kuwait's energy demands. Assessing the current CO_2 emissions produced from electricity generation and comparing it against the 2030 CO_2 emissions from the planned capacities of power plants and renewable plants allow creating a map showing the CO_2 levels. This map has the potential to be a valuable tool for policymakers who plan and apply mitigation measures. This study provides a brief of energy sector status in Kuwait associated with CO_2 emissions. It is important to use a comparative analysis model to forecast CO_2 emission and show the different parameters such as ACI, temperature, and energy consumption

METHODOLOGY

A power station emits carbon dioxide because of burning fossil fuels necessary to generate the steam for steam turbines and the heat for gas turbines. The demand determines the CO2 emissions of each power plant in Kuwait investigated using combustion equations. In this study, the scope focused on estimating CO2 emissions using the combustion equation. Two primary methodologies were the most dependent on inventorying GHGs. The Intergovernmental Panel for Climate Change (IPCC) and the USEPA provide their methodologies for the inventory process. While the methods are similar, each has its distinct features. The equation used to determine the CO2 emissions of each power plant in Kuwait was investigated using the Fuel Analysis USEPA equation (USEPA,2016). After calculating the carbon dioxide emissions, the ACI for each power station and ultimately all of Kuwait was compiled for 2016 and every 2030 scenarios.

The data necessary for the calculations were compiled from 3 main sources: the IPCC dataset, USEPA manuals, and MEW. The acquired data included the following: chemical properties of fuels supplied by the oil sector, emission factors and carbon contents of fuel, calorific values, power generation, and fuel consumption per power station.

The mechanism of this study compares the CO2 level and its impact on climate change between the two statuses of 2016 and 2030. After successfully calculating the current 2016 CO2 levels, then we projected CO2 2030 levels. The evaluation for CO2 emissions in 2030 considers the business-as-usual approach, where it is assumed that the electricity consumption habits by the consumer will remain relatively unchanged by 2030. The percent utilization rates of the available power were applied since it was business as usual, and the total power consumption in 2030 was approximated. This approach allowed several blends for the fuel consumed to generate power. Moreover, the intervention of renewable energy calculates the offset CO2 by the proposed scenarios with traditional Combined Cycle Gas Turbines (CCGT) and compares it with renewable energy displacement. The necessary carbon dioxide emission factors for each fuel type were provided from the USEPA dataset.

The CO2 calculation was carried out for each power station by assessing each power station's unique fuel allocation profile, the total power generated, and the chemical properties of the four fuel types. The fuel consumption profile for each power plant was constructed using power generation and fuel consumption data acquired from the MEW (2017) statistics book.

The examining fuel consumption profile of the power plants is dependent on the supply operations from the oil sector in Kuwait. The fuel consumption rates vary monthly and yearly, according to the availability of local Kuwait gas, imported LNG, and energy demand requirements. This process somewhat restricts the generalization of the fuel profile.

Looking to the 2030 strategic plan of MEW and ultimately Kuwait, a new updated energy vision is forming. There is a target of 30% renewable energy, and the goal is to switch the fuel from HFO to low sulfur fuel oil (LSFO), which will be imported via the KIPIC refinery (Kuwait News Agency, 2018).

The total load consumption profile for 2030 was projected as the following: first, the monthly power generation data for 2016 were used to calculate the percent utilization of availability. The utilization percentages represent the ratio of actual power generated against the peak available power. These percentages were then applied to the power availability in 2030, which resulted in an approximate power consumption profile for 2030.

Next, the offset CO2 in 2030 was calculated by assuming that the full load was generated using traditional CCGT, and each scenario was considered with its proposed fuel blend. After that, we deduced the renewable energy availability, which was approximated to be 51.5 GWHr by the MEW (Ministry of Electricity and Water, 2018). This method allowed to calculate the total CO2 in the year 2030, both with and without the addition of renewable energy. The five scenarios provide an envelope of possible CO2 emission levels as follows:

1) Scenario 1: 100% Natural Gas (Ideal case)
2) Scenario 2: 80% Natural Gas – 20% Gas Oil
3) Scenario 3: 70% Natural Gas – 30% Gas Oil
4) Scenario 4: 60% Natural Gas – 40% Gas Oil
5) Scenario 5: 60% Natural Gas – 40% LSFO, with no renewable energy in the grid (Worst case).

The average plant efficiency for MEW plants in 2030 was assumed to be approximately 41.66%, which was achieved by assessing a current plant in 2016 with CCGT technology. By assuming a heat rate of 8,640 kJ/kW-hr, the efficiency was derived by dividing the heat rate by the conversion factor of 3,600 kJ/kW-hr. After completing the above, the total available installed capacity in 2030 (according to the latest forecast from the MEW) was divided by efficiency. Based on the resulting figures, the total projected CO_2 in 2030 was calculated.

The USEPA Fuel Analysis methodology was applied to calculate the CO_2 quantities. In general, GHG emissions are calculated by multiplying the volumes of combusted fuel by the respective emission factor for each fuel type. The USEPA provides three different sets of equations for calculating GHG emissions from fossil fuel combustion. In this study, the 2nd set of the equation used to comply with the available data depends on the emission factor variables (USEPA, 2016). The MEW kindly provided the monthly gross calorific values for all fuel types. The equation used is detailed as follows:

$$CO_2 = Q_{mass} * GCV * \ EF * F \qquad (1)$$

where CO_2: Carbon dioxide emissions (tons), Q_{mass}: Quantity of fuel combusted (tons), EF: Emission factor (Carbon/bbl or Carbon/SCF), GCV: Gross calorific value (Btu/bbl or Btu/SCF), and F: Oxidation factor, assumed = 1 (100% combustion of carbon).

The USEPA uses the gross calorific value, adding to the assumption of 100% oxidation. The emission factors for HFO are 72.93 kgCO2/MMBtu, and Crude Oil is 74.54 kgCO2/MMBtu, Gas Oil is 74.92 kgCO2/MMBtu, and natural Gas is 53.06 kgCO2/MMBtu cited from the USEPA (United States Environmental Protection Agency, 2013).

The data for fuel quantities ('Q') acquired from the MEW statistics book have units of barrel of oil (bbl) or standard cubic feet of gas (SCF). In the interest of unit consistency, the following conversion is used to convert the quantity from volume to mass:

$$Q_{mass} = Q_{volume} \ * \frac{1}{\rho} \qquad (2)$$

where Q_{mass}: mass of fuel combusted, Q_{volume}: volume of fuel combusted, and r: specific density (ton/bbl, or ton/SCF).

Aggregate Carbon Intensity of Power and Desalination Plants

ACI is defined as the ratio of the total CO_2 emissions mass from fossil fuel combustion in electricity production to the total electricity produced. After calculating the CO_2 emissions, the ACI is computed by the following equation:

$$ACI = \frac{CO_2}{MWhr} * 10^6 \quad (3)$$

where ACI: aggregate carbon intensity (kgCO2/kW-hr); CO_2: carbon dioxide emission quantity (kgCO2); and MWhr: power generation (MWhr).

The fuel quantities converted to their thermal energy equivalent, MMBtu, and consequently converted to a ton of oil equivalent (toe) to maintain unit consistency when comparing the fuel consumption rates. This conversion process allows the correct approach to compare the fuel consumption percentages.

$$MMBtu = Q_{volume} * CV \quad (4)$$

$$Mtoe = MMBtu * 2.52\text{x}10^{-08} \quad (5)$$

where Q_{volume}: volume of fuel consumed; and CV: calorific value of fuel (from the USEPA).

RESULTS & DISCUSSION

The comprehensive analysis of CO_2 emissions and the energy profile contained the following parameters: emission factors, heating values, conversions, and energy generation data. Then, each power plant's CO_2 emissions are calculated by using the respective fuel combustion data from MEW's statistics book. The resulting masses of CO_2 were summed to produce the total CO_2 emission levels from Kuwait's energy sector in 2016. The ACI for each power plant was calculated for each month, and the 2016 total ACI for Kuwait was obtained by dividing the total CO_2 by the total power generation. Moreover, every power plant's fuel consumption profile was created by converting the fuel consumption quantities into million tons of oil equivalent (Mtoe) by using equations 4 and 5.

This study aimed to establish a model to calculate the CO_2 emissions from the energy sector in Kuwait and provide an energy-emissions profile. The total CO_2 emitted from the energy sector in Kuwait in 2016, as calculated by the USEPA equations, was 48.6 $MtCO_2$. MEW's report indicated the estimation of CO_2 emissions to be approximately 44.6 Megatons (MEW, 2017). By comparing this figure with the USEPA equation's results, the value of 48.6 $MtCO_2$ is within the acceptable 10% error range, which validates and confirms the accuracy of the USEPA equation model.

Looking at the results of examining the fuel profile of Kuwait's energy sector in 2016, natural gas consumption dominated the other fuel types, comprising approximately 47% of the total fuel combusted in 2016. Additionally, HFO combustion represented approximately 40% of the total fuel combusted. Figure 6 summarizes the CO_2 emissions estimated for each power plant.

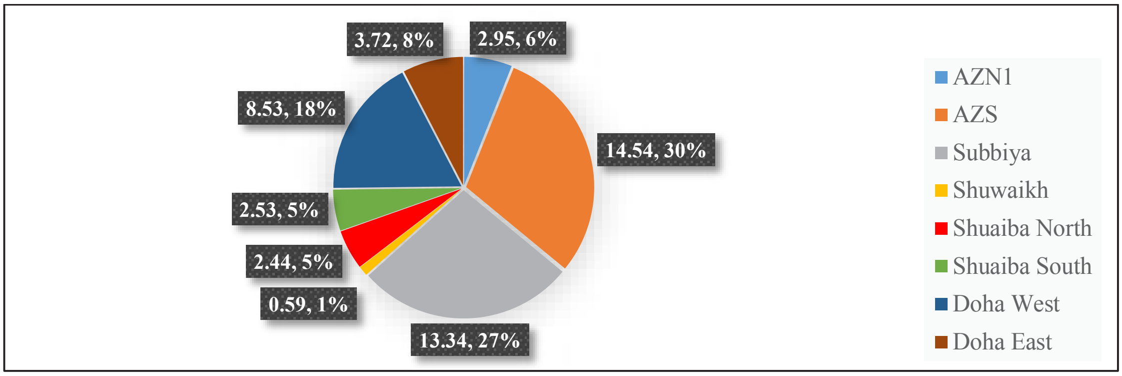


Figure 6. Total CO2 Emissions from the Kuwait Energy Sector in 2016 ($MtCO_2$).

The USEPA equation provided excellent CO_2 emission outcomes and is in line with the MEW data (MEW, 2017) and IEA (IEA, 2017) measurements of approximately 44 MtCO2 and 42.4 MtCO2, respectively. The factor that contributed to the highly accurate results was that the calorific value data used in the USEPA equation were actual monthly values.

The total ACI of Kuwait in 2016 was calculated to be 0.69 $kgCO_2/kWhr$, and the ACI value for each power plant is shown in Figure 7. The result matches well with the ACI reported by the IEA (0.651 $KgCO_2/kW\text{-}hr$) (Internation Energy Agency, 2017).

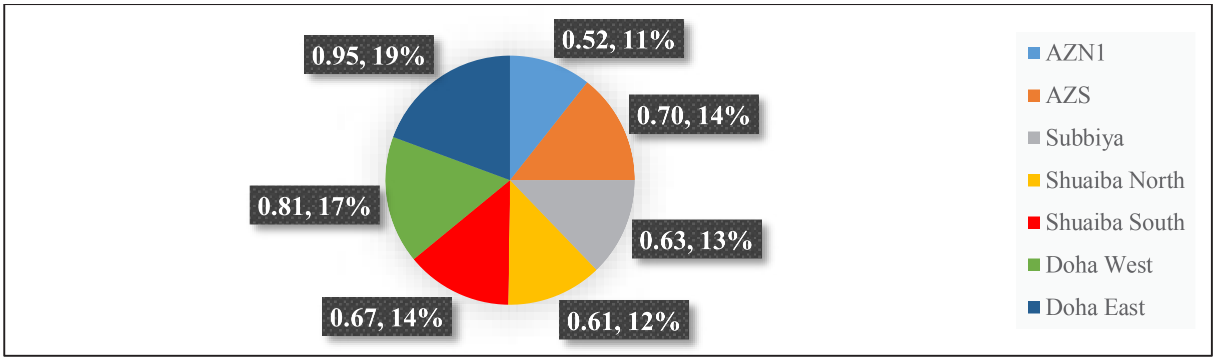


Figure 7. ACI Per Power Plant in 2016 ($kgCO_2/kWhr$).

Several factors must be considered by looking at the value of ACI's Doha East plant with the highest carbon dioxide emission intensity for 2016. The plant relied more on combusting HFO and crude oil than on combusting natural gas and the age and degradation level of the units. Az-Zour North 1 is the lowest carbon dioxide emission-intensive plant (Figure 7) for the following reasons: the new plant (commissioned in November 2016) utilizes CCGT technology (combined cycle). It relies entirely on natural gas (except for minor gas oil used as backup).

Table 2 details all calculated CO2 emissions per power plant in 2016 using the USEPA model. Kuwait Power plants CO_2 footprint is shown in figure 8, where the plant with the highest CO_2 emissions was the Az-Zour South plant (14.54 $MtCO_2$), while the lowest CO_2 emissions were the Shuwaikh power plant (0.59 $MtCO_2$). These results can be attributed to the generation levels of each respective plant, as Az-Zour South is one of the largest generators of power and desalinated water in Kuwait, whereas Shuwaikh is the smallest generator of power. It is also important to note that Shuwaikh's water production uses external power sources and is not supplied with auxiliary power from within the plants' power generation. Az-Zour South CO_2 emissions are driven by the combustion of large amounts of HFO (7.65 Mtoe), and this plant was the largest consumer of HFO in Kuwait out of the 8 power plants in 2016.

Table 2. Total Monthly CO2 Emissions for 2016 from Each Power Plant (MtCO2).

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
AZN1	0.29	0.29	0.30	0.07	0.10	0.10	0.11	0.22	0.16	0.51	0.27	0.51	2.95
AZS	0.67	0.60	0.77	1.06	1.42	1.78	2.23	1.86	1.57	1.19	1.07	0.32	14.54
Subbiya	0.67	0.73	0.94	1.22	1.28	1.43	1.74	1.63	1.39	1.02	0.58	0.72	13.34
Shuwaikh	0.00	0.04	0.05	0.05	0.06	0.06	0.08	0.05	0.05	0.05	0.05	0.05	0.59
Shuaiba North	0.14	0.16	0.19	0.18	0.21	0.28	0.34	0.25	0.21	0.23	0.19	0.06	2.44
Shuaiba South	0.19	0.17	0.22	0.19	0.23	0.23	0.26	0.26	0.23	0.22	0.17	0.15	2.53
Doha West	0.59	0.58	0.61	0.62	0.81	0.87	0.95	0.93	0.81	0.64	0.54	0.60	8.53
Doha East	0.28	0.17	0.17	0.25	0.40	0.40	0.48	0.46	0.34	0.26	0.25	0.27	3.72
$MtCO_2$/month	**2.82**	**2.73**	**3.25**	**3.64**	**4.50**	**5.15**	**6.20**	**5.66**	**4.75**	**4.12**	**3.12**	**2.69**	**48.63**

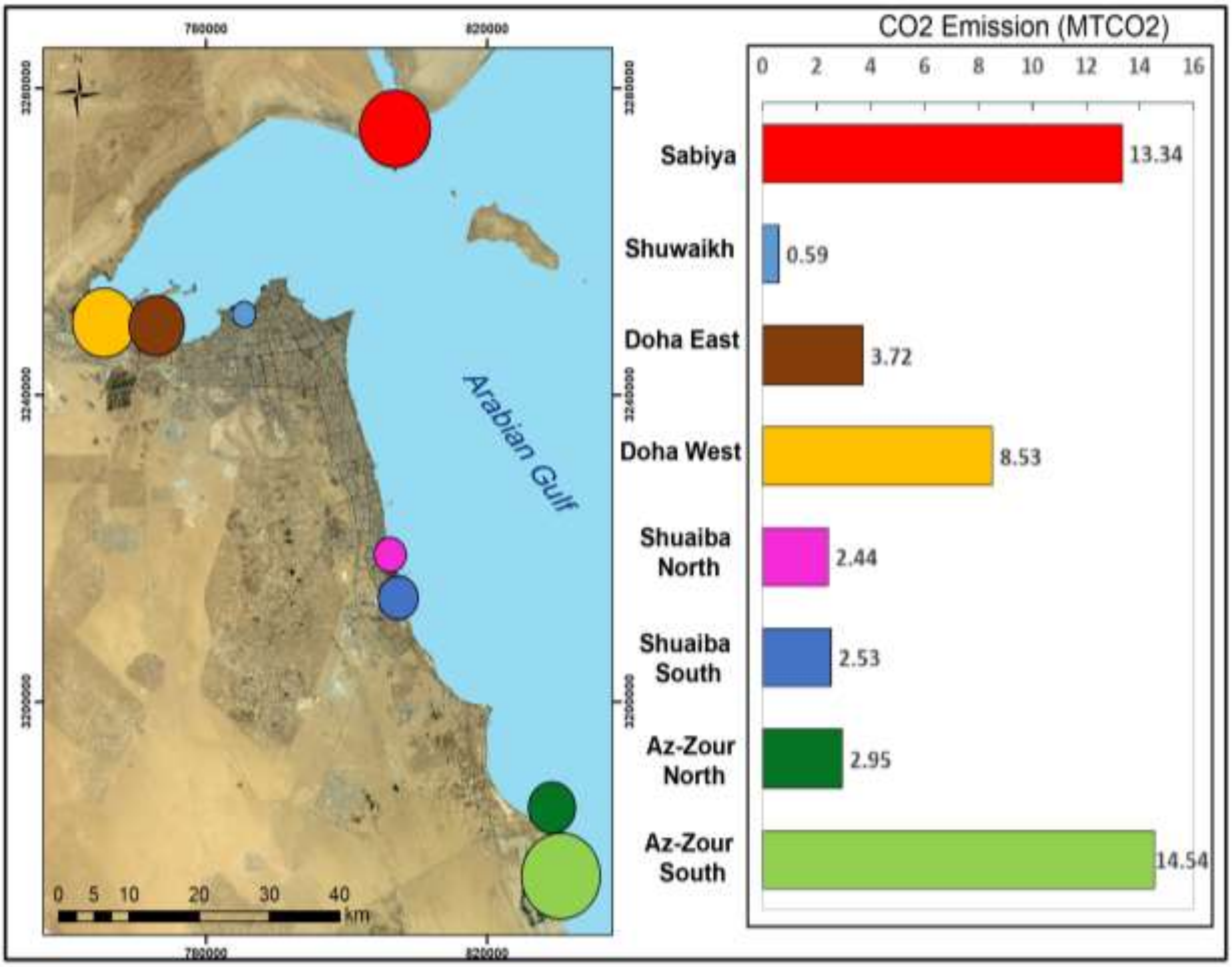


Figure 8. Kuwait Power Plants CO_2 Footprint in 2016.

CO2 Emissions, Climate Change, and Energy Profile

It is evident when comparing Figures 9 and 10 that there is a direct relationship between energy production and peak average temperature with CO2 emissions level. As the generated power increases, the accompanying CO2 emissions also increase. Furthermore, the peak generation is associated with the peak CO2 amounts. CO2 emissions peaked in July due to the hot arid weather in that month (average temperature was 37 degrees Celsius). However, it must be stated that the overall fuel blend of each month has a direct effect on CO2 emissions. When comparing the CO_2 contribution from each power plant, it was observed that most CO_2 emissions were from the following fuel oils: HFO, crude oil, and gas oil.

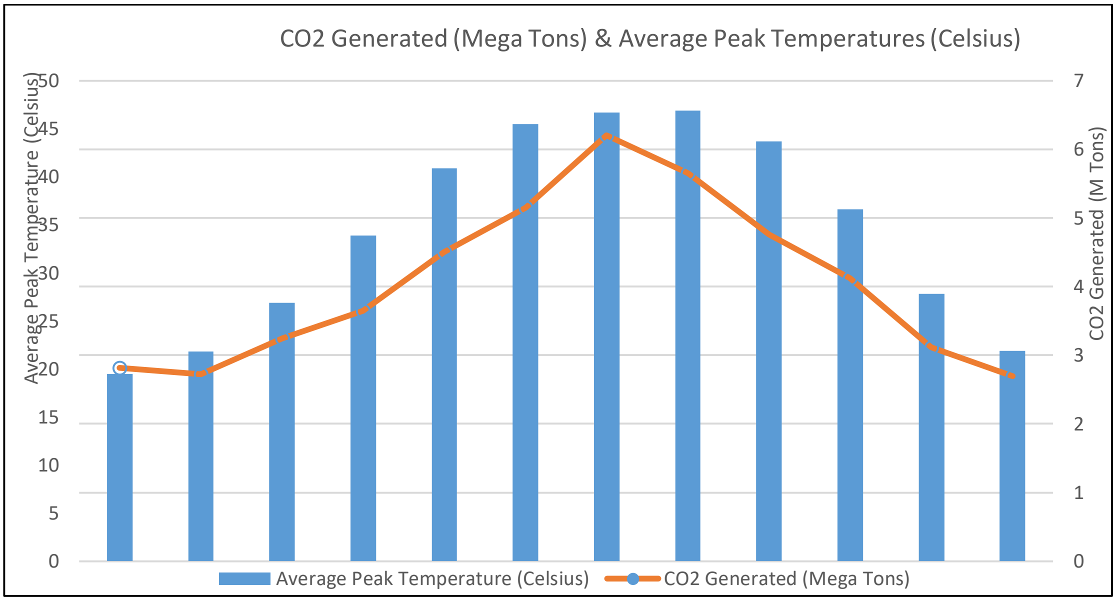


Figure 9. CO2 Generated CO2 and Average Peak Temperatures in year 2016.

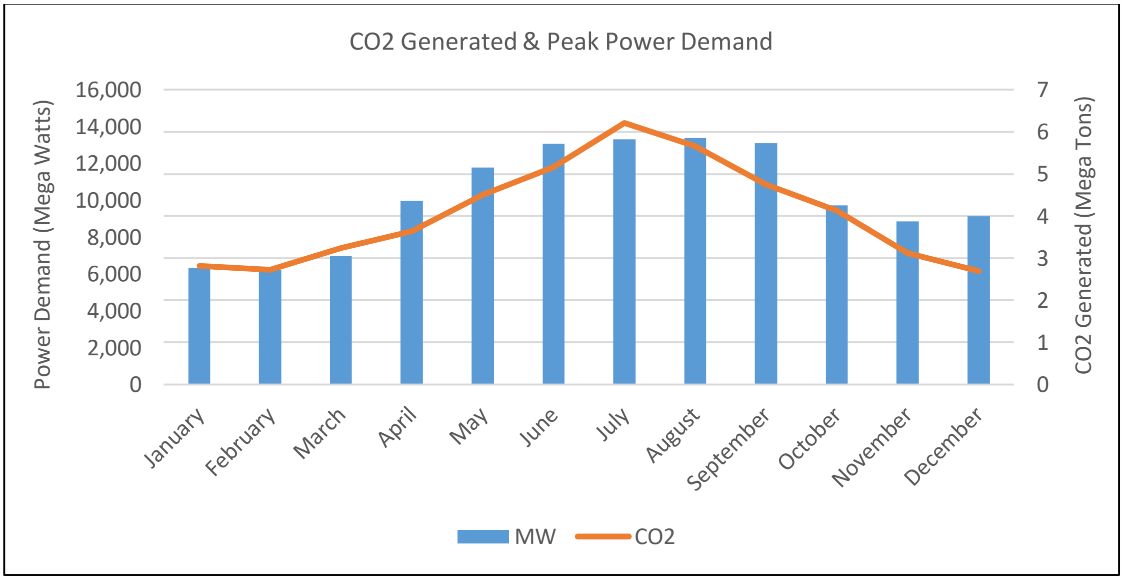


Figure 10. Generated CO2 and Peak Power Demand in 2016.

The electricity consumption in Kuwait for each sector is as presented in figure 11. Using the percentages provided by MEW, the CO_2 levels contributed from each sector were obtained. It found that the residential sector in Kuwait was the highest consumer of power; therefore, it was responsible for the largest share of CO_2, which was almost 20 $MtCO_2$. A lack of public awareness, governmental subsidies, thermal insulation, and consumer behavior are factors that contribute to the residential sector producing 41% of the CO_2 emissions.

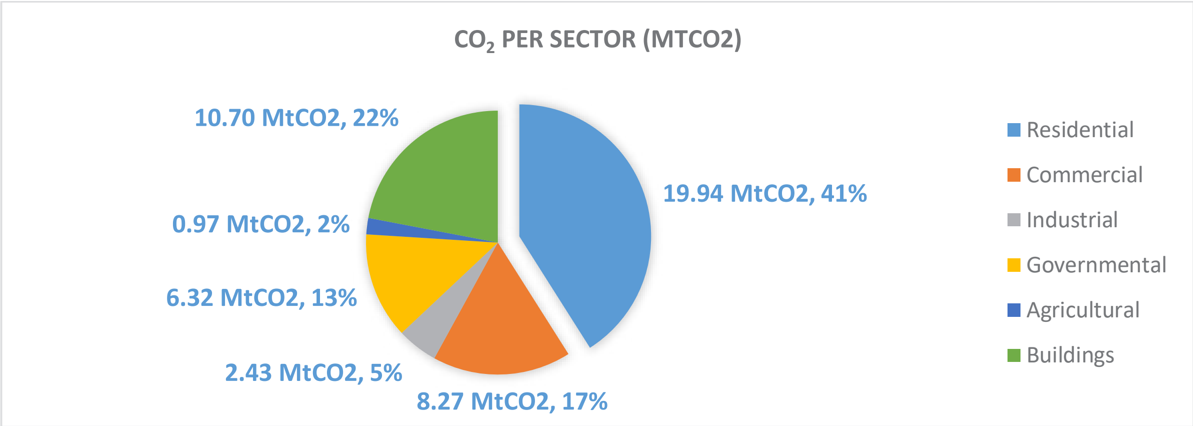


Figure 11. CO2 Emissions per Sector.

The Results of CO2 based on 2030 Scenarios

The outcomes of CO_2 levels in 2030 were determined based on five scenarios. First, the monthly power generation data were used to calculate the percent utilization of availability. The utilization percentages represent the ratio of actual power generated against the peak available power. In 2030, the only data available concerned the maximum availability. Historically, the month of July is when the most power is generated, so that the peak annual demand in that month can be met. The utilization percentages from 2016 were used to simulate a 'business-as-usual' scenario, where the utilization percentages were the same as those used for 2030. This approach assumes that consumer behavior will remain unchanged. The power generation data for each month were reverse-engineered using the utilization percentages. Figure 12 presents the 2016 and 2030 (scenario 2) power generation results in Gigawatt hours.

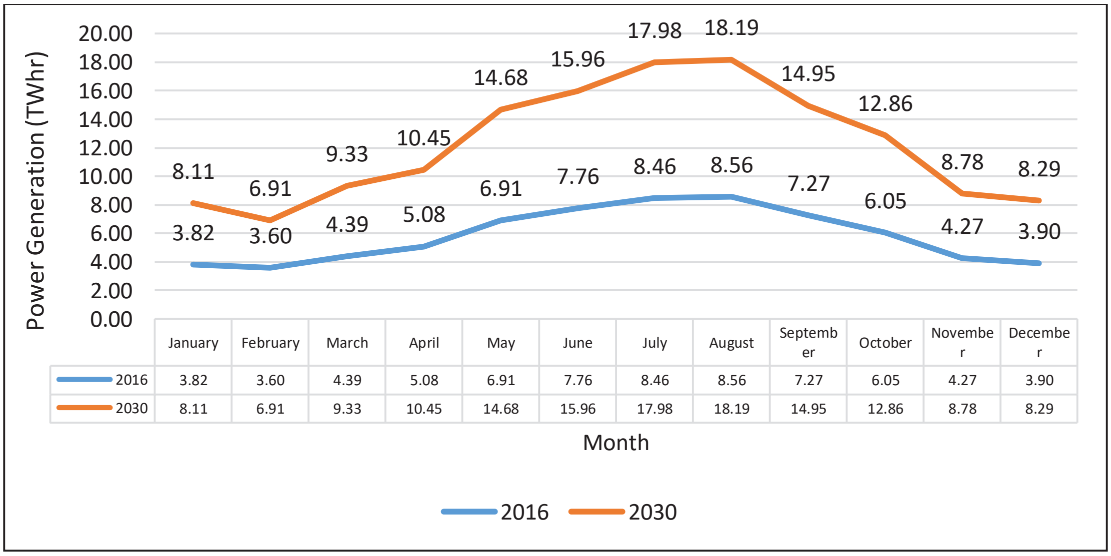


Figure 12. Energy Generation for 2016 vs 2030 ((Scenario 2, TWHr).

After estimating the monthly power generation in 2030, the CO2 levels were calculated using the USEPA's Fuel Analysis method. The proposed five scenarios apply several fuel consumption blends, ranging from 100% natural gas to 60%-40% natural gas to LSFO. Moreover, renewable energy availability is considered 'offset' CO2, as renewable energy does not produce CO2 emissions. Figure 13 summarizes the results of the five scenarios.

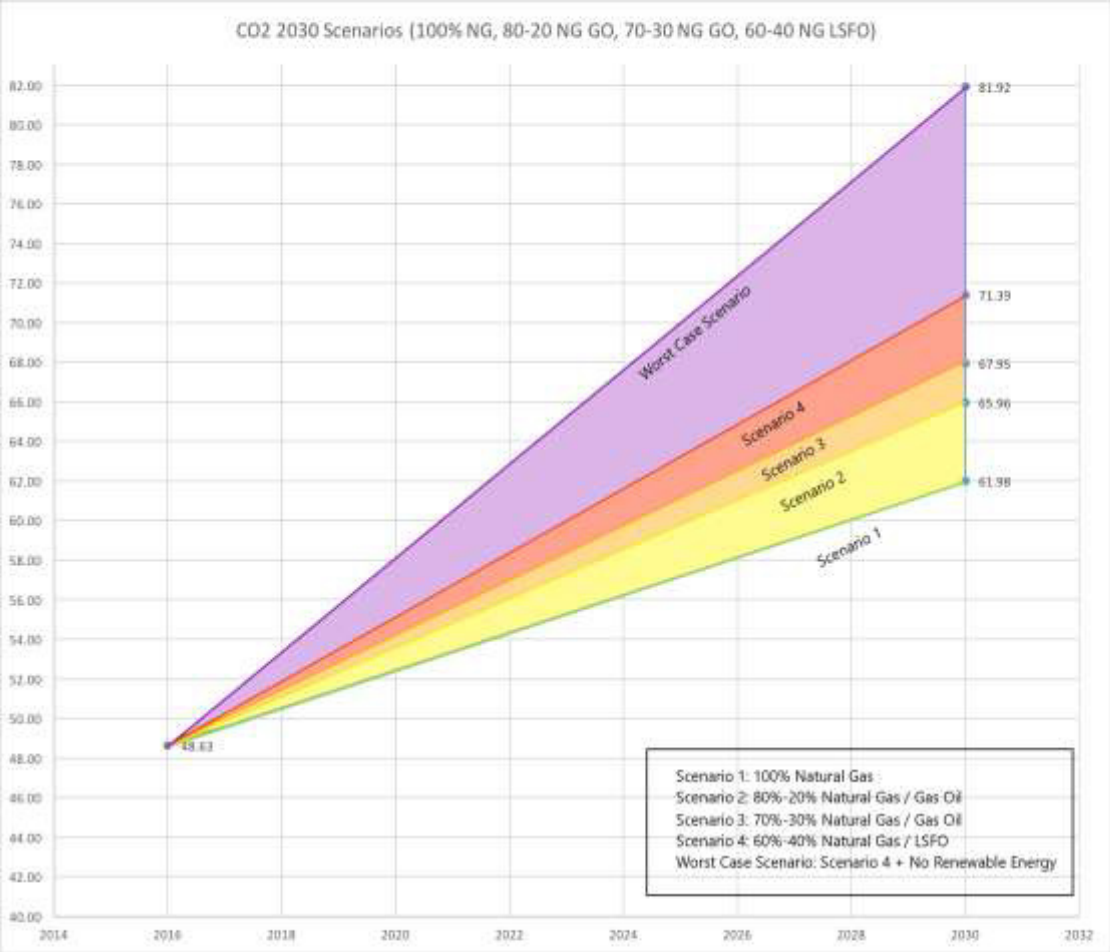
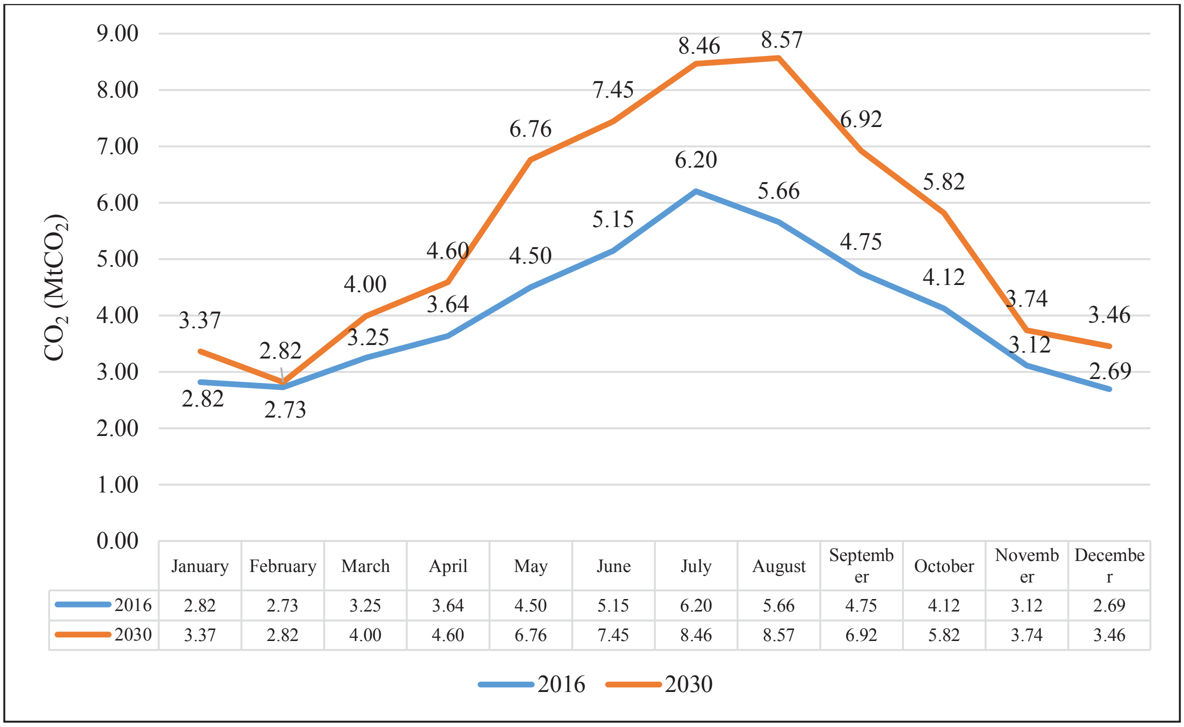


Figure 13. 2030 CO2 Estimations ($MtCO_2$).

Starting with scenario 1, a significant finding that was using 100% natural gas yielded the lowest CO_2 levels (~62 MtCO2). However, it is challenging to actualize this scenario due to the logistics of supplying natural gas in such large quantities. The worst-case scenario (60% natural gas and 40% LSFO, no renewable energy) showed a significant amount of CO_2 produced due to not generating 15% of power from renewables (~82 $MtCO_2$). This number is staggering, and all efforts must be put forth to avoid it. The worst-case scenario implies that Kuwait is taking the correct action by signing the Paris Agreement.

The 2nd scenario assumes 80% natural gas and 20% gas oil, resulting in approximately 66 Mt of CO2 value. This value is a well-rounded result and will be used to compare with the current 2016 CO_2 levels. Compared with the 2016 CO_2 levels, the CO_2 levels will increase by approximately 26.4%. This result is a good indicator of the efforts made to offset CO_2, especially when considering the power generation amount is going to be twice that in the year 2016. Moreover, when comparing the results from the second scenario and worst case, a major finding emphasizes cleaner fuels (natural gas and gas oil) with the addition of renewable energy, and utilizing energy-efficient technologies (MEDs, CCGTs) assists in mitigating CO_2 levels.



	January	February	March	April	May	June	July	August	September	October	November	December
2016	2.82	2.73	3.25	3.64	4.50	5.15	6.20	5.66	4.75	4.12	3.12	2.69
2030	3.37	2.82	4.00	4.60	6.76	7.45	8.46	8.57	6.92	5.82	3.74	3.46

Figure 14 CO2 Comparison: 2016 vs. 2030 CO2 Emissions (Scenario 2, $MtCO_2$).

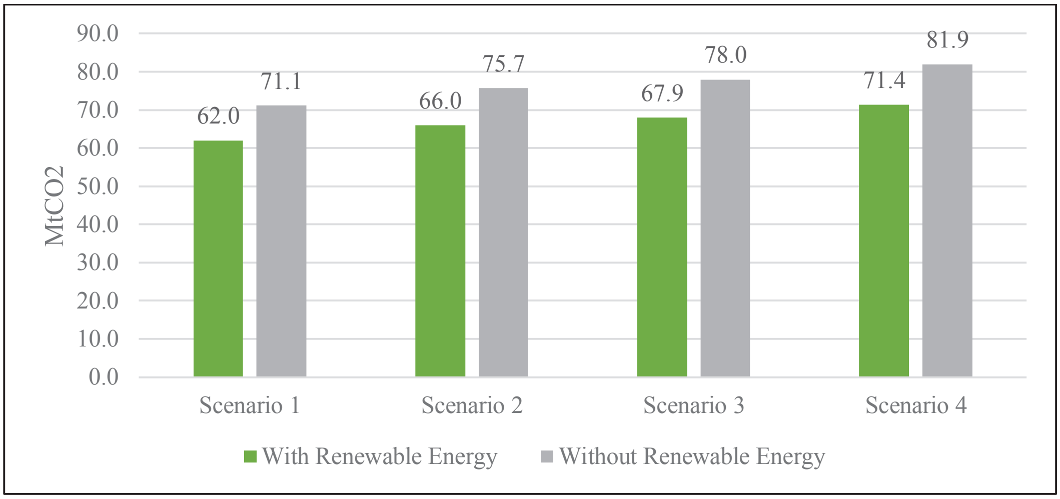


Figure 15. CO2 Renewable Energy Offset Comparison (MtCO2).

Referring to Figure 15, a comparison was made between CO_2 levels with and without the addition of renewable energy in the generating profile. The figure shows that the expansion of renewables can offset CO_2 up to approximately 13%. Adding to the offset CO_2, fossil fuel savings would be an economic bonus for the country.

Another matter to consider in 2030 is the ACI of each scenario, and this value should be compared against the historical ACI data (provided by the IEA) for Kuwait. Figure 16 presents the historical ACI, with the possible 2030 values according to the calculations obtained using this study model.

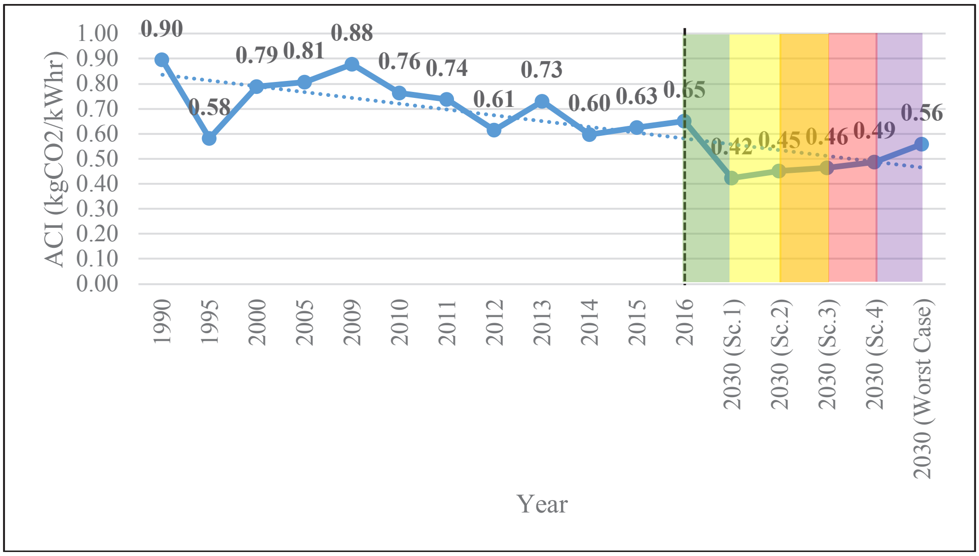


Figure 16. ACI Historical Trend & 2030 Estimations (kgCO2/kWhr) (Internation Energy Agency, 2017) the overall historical trend of the ACI (Internation Energy Agency, 2017) decreases.

The fluctuation in ACI values can be mainly attributed to the fuel blend used in a year. Notably, as the efficiency of the plants (CCGT *vs.* thermal) increases, the ACI decreases. Additionally, even though the worst-case 2030 scenario yields considerable CO_2, the ACI is still less than that in 2016. This result illustrates the causal relationship between switching carbon-intensive fuel (such as fuel oils) to less carbon-intensive fuel (such as natural gas).

The 2016 CO_2 results obtained in this study (48.6 $MtCO_2$) are in good agreement with the IEA estimates (42.4 $MtCO_2$) (Internation Energy Agency, 2017) although the IEA's latest estimate is for 2015. Additionally, the ACI calculated in this study for 2016 (0.694 kgCO2/kW-hr) is in line with the IEA's ACI for 2015 (0.651 $kgCO_2$/kW-hr) (Internation Energy Agency, 2017). The consistency in the results supports and validates this study's methodology and work.

CONCLUSION AND RECOMMENDATIONS

The CO_2 emissions from the energy sector (power and desalination plants) in Kuwait for 2016 were analyzed and examined, and values were predicted for 2030. The equation of the USEPA's Fuel Analysis method was applied and found that the total CO_2 emissions for 2016 were approximately 48.6 $MtCO_2$. The ACI of Kuwait was calculated to be 0.69 $kgCO_2$/kW-hr.

Some possible sources of deviations in the model are as follows: the upcoming plants to be commissioned by 2030 have not completed the design phase, and potential changes in fuel type and generation capacity could be made in the future. The analysis does not consider the unit efficiency, combustion efficiency, and overall age and maintenance status of the units.

When comparing ACI, it must be noted that Kuwait's power plants are cogeneration plants (power and water); thus, this factor should be considered when conducting comparisons with power plants that are not cogeneration plants. However, it should be noted that the efficiency of the units and their degradation were influential factors that were beyond the scope of this study.

This study developed a complete analysis of the CO2 emissions-energy profile for each power plant in Kuwait. After simulating the energy demand in 2030 using a business-as-usual approach (United States Environmental Protection Agency, 2013) and applying five scenarios with various fuel blends, it was found that the renewable energy contribution successfully reduced CO2 emissions up to 15%. The results of the scenarios indicated that using an 80% natural gas and 20% gas oil fuel blend stabilized the CO2 at approximately 66 MtCO2, with an ACI of 0.45 kgCO2/kWhr, which was reasonable when considering that the power availability will be twice as high in 2030 than it was in 2016 (48.6 MtCO2). The CO2 offset by renewable energy is, on average, almost 13%. This study provides a basis to evaluate CO_2 emissions from the energy sector using the ACI, which is used as an indicator of CO_2 for most sources. An additional benefit of deriving from the ACI is precisely calculating the CO_2' cost' or emission for any activity. Consumers' awareness of these values may reflect positively on their usual everyday practices by being more conscious of their electrical consumption habits and environmental impact.

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