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The Economics of Power Sector Decarbonization: A Case Study for Kuwait

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Abstract

In this research activity fuel energies were used to evaluate CO_2 emissions resulting from the power stations in Kuwait. Also, the calculated CO_2 emitted was used to perform economic valuation for using amine-based carbon capture technology to reduce the CO_2 emissions from the power stations. Linear regression model was used to predict CO_2 emissions using fuels energies used in the power stations. The dependent variable is total CO_2 emissions from the power stations while the independent variables are the fuels energies of the fuels used to generate electricity. Regression analysis results showed that the model has strong goodness of fit and regression coefficients have high significance level. The regression model indicated that Heavy fuel oil has the highest effect on the total CO_2 emitted. If the heavy fuel oil consumption increases with 1 BBTU this will lead to an increase in the total CO_2 emission of 0.0817 kton. The power stations with high dependence on Heavy fuel oil had higher emissions than other power stations. On the other hand, when Natural gas consumption increases with 1 BBTU this will increase the total CO_2 emissions with 0.0592 kton. Natural gas is the best fossil fuel to reduce emissions since it has less CO_2 emissions at any level of fuel energy compared to other fossil fuels. It was found that Alzour South, Sabiya, and Doha West power stations have the highest CO_2 emissions in the power sector. The preliminary economic valuation to use post combustion carbon capture technology was performed for the three power stations considering two modes of transportation which are pipelines and trucks. The results indicated that the total costs of CO_2 avoided for Alzour South are approximately USD 1.23 billion, and USD 1.58 billion for pipelines and trucks transport respectively while for Doha West are USD 738.5 million, and USD 945.9 million for pipelines and trucks transport respectively.

Keywords: Fossil Fuel, Carbon Capture, Emissions, Post Combustion, Linear Regression

1. Introduction

Carbon dioxide (CO_2) emissions are an unescapable consequence of today's modern civil and technological development. The environmental effects caused by high CO_2 emissions became tangible in modern days due to the accumulation over the previous decades and due to urban and industrial expansions, causing the rise in demand for electric power supply leading to an increase in green house effects and global temperature which cause severe and harmful effects on all kinds of living creatures. These effects are threatening the sustainability of the modern lifestyle, hence leading the international community to take necessary action to promote the usage of decarbonization processes. One of the agreements that undertook actions for climate change mitigation through the participating countries is the Paris Agreement signed in 2016, in which the State of Kuwait is a participant.

These actions include but not limited to CO_2 emission reduction from various sectors. The State of Kuwait, in the Nationally Determined Contribution Document issued in October 2021 by the Environmental Public Authority in Kuwait, declared to reduce carbon emissions by 7.4% of total emissions in the year 2035 by the deployment of energy efficiency technologies in power distribution, energy efficiency in buildings, renewable energy technologies, increasing the usage of combined cycle technologies in power generation, and implementing carbon capture and storage technologies.

This study presents a prediction model to forecast CO_2 emissions from the power sector in Kuwait using linear regression. The model will allow predicting total CO_2 emission resulting from the power sector in Kuwait. The various types of fuels utilized in the power stations to generate electricity are used to construct regression model and in predicting CO_2 emissions.

Cost estimate for installing amine-based absorption CO_2 capture units is presented in this report. The cost is evaluated based on rates in USD per tons of CO_2 emitted. Also, factors affecting and relevant to CO_2 capture in the power sector are presented and discussed.

1.1 Literature Review

Several technologies with promising prospects for carbon capture are presented, including amine-based technologies and polymer membrane. Amine-based absorption carbon capture is the more conventional application, specifically for large-scale power plants. However, this process is energy intensive. On the other hand, polymer membrane carbon capture still needs further developments for commercial use (He, 2018).

New processes and absorbents for amine-based carbon capture were developed, which have the potential to reduce the pressure needed to pump flue gasses from the power stations' stack to extract and capture the CO_2 emissions. Pressure reduction is carried out by a novel rotary wheel absorber and, consequently, the energy intensity for amine-based carbon capture technology is reduced (Gibson et al., 2016). The novel absorbents are new materials including zeolites, metal-organic framework (MOF), and other amine-functionalized materials. It is worth noting that these new materials and processes are still in the lab-scale testing phase and are not mature for commercial large-scale applications.

A review of carbon capture in power stations for conventional amine technology was considered using data for power plants in USA, Europe, and China. The results indicated that capital cost, operation and maintenance, and transportation vary in real-life projects (Finkenrath, 2012). In addition, the results provide a generic cost estimate since some factors such as the location of the power station effects significantly on the overall cost of CO_2 capture.

Two scenarios were analyzed in (Psarras et al., 2020) the capture of CO_2 emissions in the US for natural gas-fired power plants. The first scenario considered pumping captured CO_2 into proper storage containers. While the second scenario studied injecting captured CO_2 emissions into oil reservoirs for enhanced oil recovery (EOR). Results indicated that with proper incentives, the cost of CO_2 capture with enhanced oil recovery was less than storing it in containers.

A cost analysis was conducted for natural gas fired combined-cycle power plants in (Rubin et al., 2012). Due to site-specific difficulties during retrofitting, the study found that installing a carbon capture system during the construction of a newly established plant is cheaper than retrofitting an existing plant. In general, the study also found that transport and storage costs could increase depending on plant location. Additionally, it found that financing costs could increase if the remaining life of the plant is short. Finally, if less efficient gas turbine plants with carbon capture units are operated at low load factors, the levelized cost of electricity (LCOE) would further increase due to the energy consumed by the carbon capture units. Thus, making it less economically feasible.

The power sector proved to be the predominant source of carbon dioxide (CO_2) emissions occupying 41.6% of total emissions (Al-Mutairi et al., 2017). The second and third sectors with high CO_2 emissions are the Chemicals and transportation with 25.5% and 16.6% respectively.

A process integration approach is considered to analyze the impact of the post-combustion CO_2 capture integration on the coal-fired power plant performance to provide design options for achieving better energy efficiency by (Oh et al., 2018). Four case design options were considered and modeled to investigate their energy efficiency effect and net CO_2 net efficiency penalty. The results indicated that the design of case three which is the installation of an additional turbine from Intermediate Pressure (IP)/Low Pressure (LP) crossover rendered the best energy efficiency by burning less coal and less CO_2 penalty.

2. Methods

The model used in this project to analyze and forecast CO_2 emissions is constructed through linear regression. The utilized linear regression technique is Ordinary Least Square (OLS) method. The data utilized in creating the model is monthly time series data for the fuels' energies used in the power stations. The power stations in Kuwait uses various types of fuel to generate electricity. The fuels' energies data were obtained from MEWRE annual statistical book, and the data used span from January 2014 to December 2021. CO_2 emissions were calculated from fuels' energies using IPCC standards [8]. It is worth mentioning that the fuels that are used to generate electricity in the power sector in Kuwait are crude oil, natural gas, fuel oil, and gas oil. The CO_2 emissions are calculated using the formula, $E=FE\times CF$, where E is CO_2 emissions, FE is fuel energy for the used fuel, and CF is conversion factor which identifies the amount of CO_2 emission per energy unit. The value of CF is obtained from IPCC standards (Intergovernmental Panel on Climate Change, 2006). The value of E is measured in kg of CO_2, FE in BTU, and CF in kg of CO_2 per TJ. Once the CO_2 emissions are found for each type of fuel, it is summed up to obtain the total CO_2 emission in the power sector in Kuwait. Table 1 indicates the values of CF used in this study to obtain the CO_2 emissions for each type of fuel. The unit of FE used is converted from BTU to TJ to match the unit of CF. The factor used is 1.0551×10^{-9} TJ/BTU. Also, the value of E is converted to tons using the factor 1000 kg/ton.

*Table 1. The CO_2 emissions for Different Fuel Types**

Fuel Type	CO_2 Emission per Energy (kg CO_2/TJ)
Natural Gas	56100
Crude Oil	73300
Gas Oil	74100
Heavy Fuel Oil	77400

**Source: IPCC Guidelines for National Greenhouse Gas Inventories; Intergovernmental Panel on Climate Change, 2006.*

The fuels' energies for all types of fuels and the total CO_2 emissions are fed into statistical software package STATA 15 to construct the linear regression model using OLS method. The regression model is the following:

$$TE = C + \alpha\, FE_{CRo} + \beta\, FE_{NG} + \gamma\, FE_{FO} + \delta\, FE_{GO} \quad (1)$$

Where, TE is total CO_2 emissions in tons, FE_{CRo} is fuel energy of crude oil, FE_{NG} is fuel energy of the natural gas, FE_{FO} is fuel energy of fuel oil, and FE_{GO} is fuel energy of gas oil. While C is regression constant, α, β, γ, and δ are regression coefficient. The fuel energies and total CO_2 emissions data are fed into STATA 15 statistical software package to calculate the optimal values for C, α, β, γ, and δ which make the model of equation (1) a reliable predictor for future CO_2 emissions.

The cost of avoided CO_2 is the cost associated with installing carbon capture units that captures the emitted CO_2 gas that would be released to the atmosphere. The cost of avoided CO_2 consists of two main components which are the CAPEX and OPEX. The CAPEX is the sum of capture facility capital, fees, interests, contingency, etc. The capture facility contains direct contact cooler, flue gas blower, CO_2 stripper, heat exchangers, circulation pumps, solvent regenerator, reboiler, steam extractor, solvent reclaimer, processing unit, and drying and compression unit. The OPEX includes material replacement costs, electricity, water, CO_2 transport and sequestration, and total fixed costs (Psarras et al., 2020). The average values used in this project are as per reference (Psarras et al., 2020) where the avoided CO_2 capture cost combines the CAPEX and OPEX items. The items are averaged and combined under CO_2 capture cost except the compression, transport, and injection. The reason to set some items under exception is due to the considerable cost variability for different implementation modes.

The following formulas are used to estimate the avoided CO_2 cost:

$$CapC = CO_2\ Capture\ Rate\left(\frac{USD}{ton\ CO_2}\right) \times ATE \tag{2}$$

$$TC = Transport\ Rate\left(\frac{USD}{ton\ CO_2}\right) \times ATE \tag{3}$$

$$IC = Injection\ Rate\left(\frac{USD}{ton\ CO_2}\right) \times ATE \tag{4}$$

$$CompC = Compression\ Rate\left(\frac{USD}{ton\ CO_2}\right) \times ATE \tag{5}$$

$$TACC = CapC + TC + IC + CompC \tag{6}$$

Where, *CapC* is capture cost, *TC* is transport cost, *IC* is injection cost, *CompC* is compression cost, *ATE* is average total annual CO_2 emission, and *TACC* is total avoided CO_2 capture cost. All cost units are in USD. The value of *ATE* is found using the following formula:

$$ATE = {(TE_{14} + TE_{15} + TE_{16} + TE_{17} + TE_{18} + TE_{19} + TE_{20} + TE_{21})}/{8} \tag{7}$$

Where, TE_{14} to TE_{21} is the total emission for each year of 2014 to 2021 measured in tons of CO_2. The costs' rates of CO_2 capture, transport, injection, compression, and total cost of avoided CO_2 are illustrated in Table 2 as per reference (Psarras et al., 2020). Table 2 indicates the costs rates considering two transportation modes of the captured CO_2 gas. The first mode is transportation through pipelines while the second is using trucks.

Table 2. Costs Rates and Components Data for CO_2 Capture

Item	Pipeline transport cost (US$ / ton of CO_2)	Trucks transport cost (US$ / ton of CO_2)
Cost of CO_2 capture	53	53
Cost of transport and sequestration	15	43
Injection cost	11	11
Compression cost	10	7
Total Cost of CO_2 avoided	89	114

3. Results and Discussion

Several analyses were performed to study CO_2 emissions from the power sector in the Kuwait and evaluate the usage of the carbon capture technology in power sector.

3.1 Regression Analysis

The monthly time series data of the fuel energies and total CO_2 emissions were fed into STATA 15 software. The units of the fuel energies were in BBTU while the units of the CO_2 emissions were in kton. The regression coefficients were found and the model in equation (1) becomes the following:

$$TE = 0.0000276 + 0.0773\, FE_{CRo} + \; 0.0592\, FE_{NG} + 0.0817\; \; FE_{FO} + 0.0782\, FE_{GO} \qquad (8)$$

The regression model in equation (8) helps to predict the future CO_2 emission from the power sector. The regression coefficients explain the effect of the fuel used on the total CO_2 emissions. It can be stated from the regression model that an increase in crude oil consumption of 1 BBTU will increase total CO_2 emission with 0.0773 kton. An increase in natural gas consumption with 1 BBTU will increase the total CO_2 emissions with 0.0592 kton. If the heavy fuel oil consumption increases with 1 BBTU this will lead to an increase in the total CO_2 emission of 0.0817 kton. When the consumption of gas oil increases with 1 BBTU this leads to an increase in CO_2 total emissions with 0.0782 kton. It can be stated that heavy fuel oil has the highest impact on the total CO_2 emissions while natural gas has the least impact. Hence, it is important to increase the use of natural gas as a fuel to produce electricity due to its low CO_2 emissions.

It is worth mentioning that the regression model has strong predictive power since the goodness of fit R^2 = 1. The t-statistics is very high of the regression coefficient which indicates high significance level of the regression coefficients. The t-statistics values for FE_{CRo}, FE_{NG}, FE_{FO}, FE_{GO} are 9.7×10^6, 1.7×10^7, 1.1×10^7, 4.5×10^6 respectively. These results indicate the strong relation between the fuels energies and the CO_2 emissions from the power stations.

3.2 Power Stations Fuels and CO_2 Emissions

The installed capacity for some power stations changed over the years while other remained constant during the time span considered in this study. Figure 1 illustrates the installed capacities of the active power stations in Kuwait. It can be seen that Sabiya and Alzour South power stations have the highest installed capacities while Shuwaikh power station has the lowest installed capacity. The power stations have stable and consistent capacities except Sabiya power station which its installed capacity increased from 4866.7 MW to 7046.7 MW in the period from 2014 to 2021. The installed capacity of Alzour North power station increased gradually until 2015 reaching 1540 MW. It is expected that the CO_2 emissions increase as the installed capacity increases.

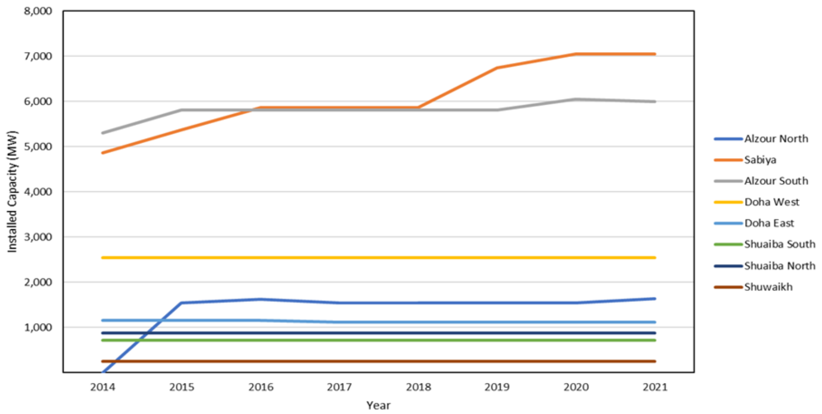

Figure 1. Annual Installed Capacities of the Power Stations.

Figures 2 shows the monthly consumed fuels energies in the power stations in Kuwait. Natural gas had the highest usage in the power sector while gas oil had the least usage. During summer season the consumed fuels energies increase to generate the needed electricity to meet the power demand by air conditioning systems. The crude oil usage had minor occasional increases in the power stations during the summers of 2014, 2017, and 2018. But in the summer of 2020, during COVID-19 pandemic, the consumption of crude oil for electricity generation spiked to reach approximately 31000 BBTU. This unusual increase was due to the sever decrease in demand for crude oil by the international market since lockdown procedures were applied globally. The heavy oil dropped to 4900 BBTU in the summer of 2020 during COVID-19 pandemic. This decrease was due to the reduced production of heavy oil from the refineries during lockdown periods.

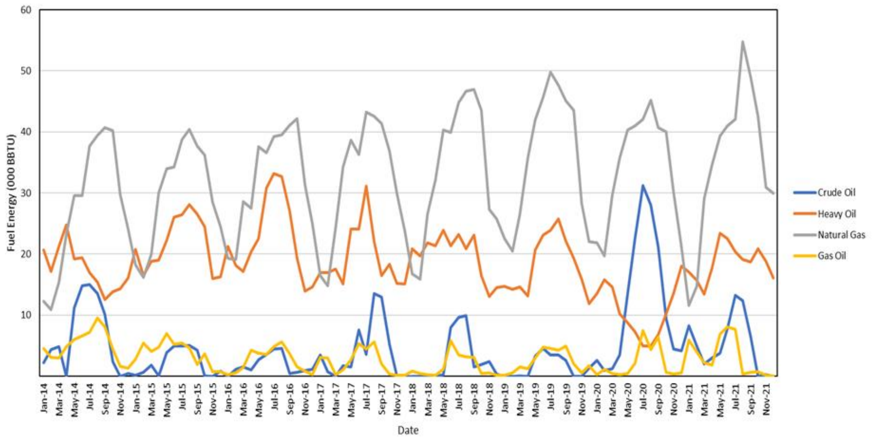

Figure 2: Consumed monthly fuels energies for different types of fuels in the power stations.

Figure 3 shows CO_2 emissions resulted from fuel energies in each type of fuel for electricity generation at the power stations in Kuwait. Natural gas has the least CO_2 emissions compared to the other fuels used to generate electricity. On the other hand, heavy oil has the highest CO_2 emissions when burned to produce electricity. This confirms the values of CO_2 contents in each type of fuel in Table 1. Hence, usage of natural gas in electricity generation is highly recommended due to its lowest CO_2 emissions within the energy content compared to the other used fuels.

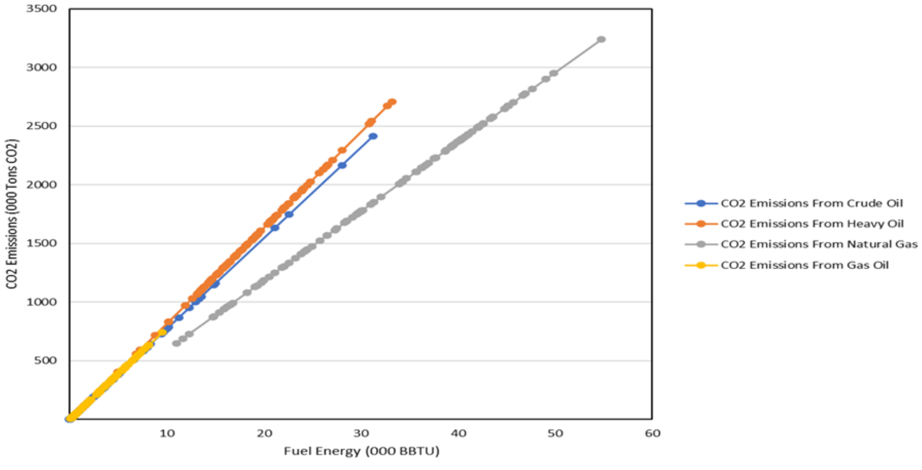

Figure 3: CO_2 emissions for each fuel type used in the power stations.

The CO_2 emissions from the fuel mix used in the power station is illustrated in Figure 4. It is clear that natural gas and heavy oil are the dominant fuels used in electricity generation. The total annual CO_2 emissions dropped approximately by 4.3% from 2016 to 2019, but it increased by 8.3% from 2020 to 2021 as per Figure 5. The drop in CO_2 emissions happened because of the annual increase in using natural gas and decrease in heavy oil usage for electricity production. On the other hand, the increase in CO_2 emissions was due to the excessive usage of crude oil during COVID-19 pandemic period and the return of using heavy oil along with plenty of natural gas after revoking lockdown and restoring normal activities. The CO_2 emissions from crude oil increased in 2020 due to high usage during COVID-19 period in electricity generation while the CO_2 emissions from heavy oil decreased since the refineries decreased the production during the lockdown.

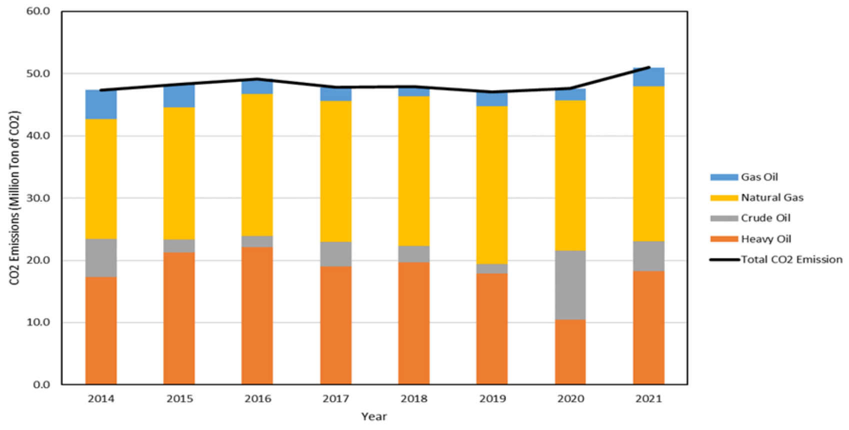

Figure 4: Total annual CO2 emissions from the power sector from each fuel type used in the power sector.

Figure 5 illustrates the CO_2 emissions from each power station in Kuwait. Sabiya and Alzour South power stations have the highest CO_2 emissions while Shuwaikh power station has the lowest. Between 2014 and 2021 the CO_2 emission at Sabiya power station dropped approximately 6.9%. The emissions at Alzour South dropped approximately 30% between 2014 and 2019 and increased approximately with 42.4 between 2019 and 2021. The third highest CO_2 emissions came from Doha West power station where the emissions had minor fluctuations.

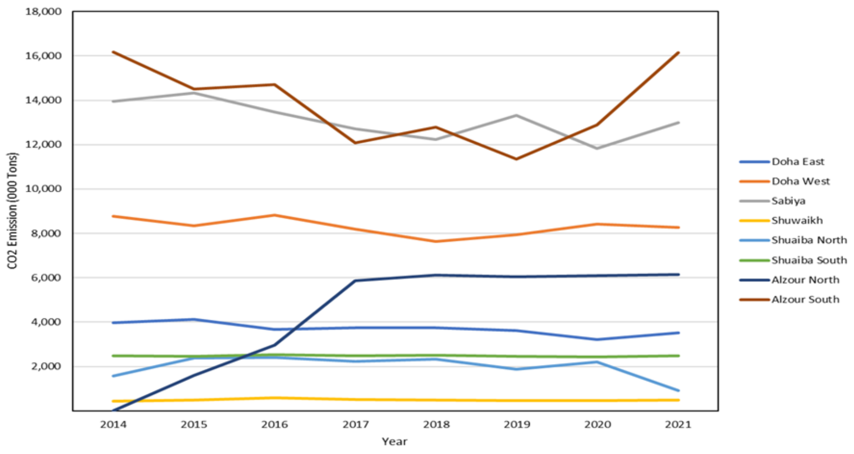

Figure 5: Annual CO2 Emissions from the Power Stations.

The fuel mix used to generate electricity was analyzed for the two power stations with the highest CO_2 emissions (i.e. Sabiya and Alzour South power stations). As per Figure 6, crude oil had minimal usage at Alzour South power station. On the other hand, natural gas and heavy oil had the biggest usage share in electricity generation. Sabiya power station mainly depends on natural gas and heavy oil for electricity generation (see Figure 7). But higher amounts of gas oil are used at Sabiya power station compared to Alzour South.

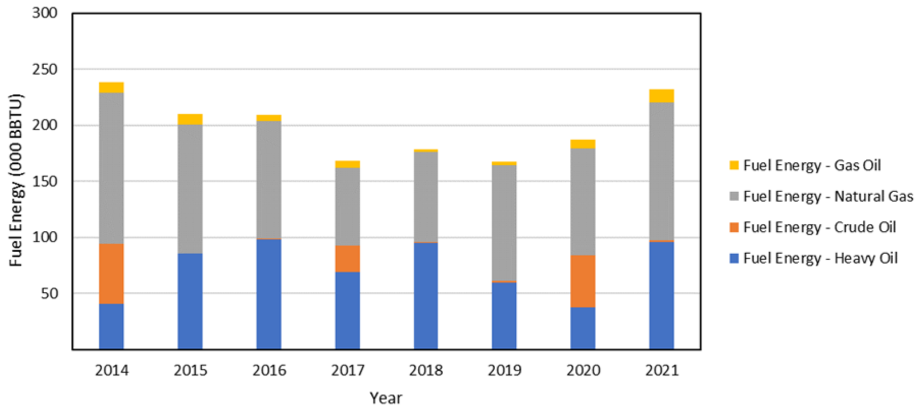

Figure 6: Annual fuel energy mix usage at Alzour South power station.

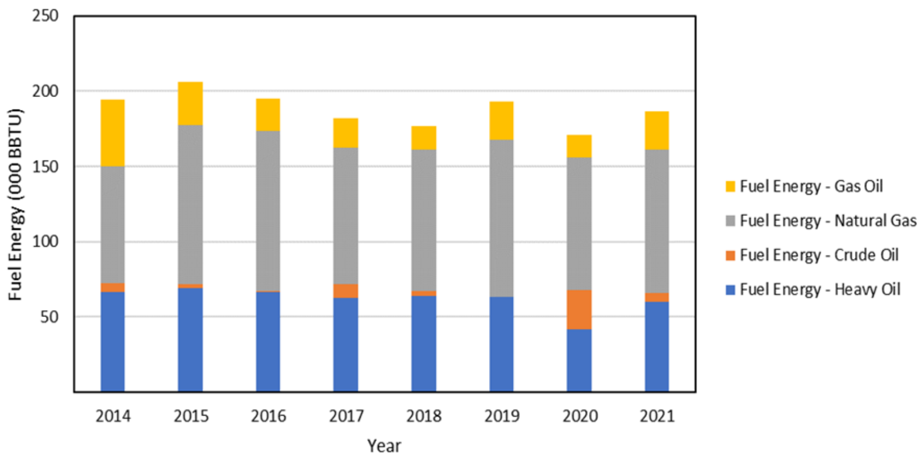

Figure 7: Annual fuel energy mix usage at Sabiya power station.

The fuel mix used at Doha West power station in Figure 8 indicates that the dominant fuel used is heavy oil followed by crude oil. In spite the fact that Doha West used mainly heavy oil, which has the highest carbon content, for electricity generation but its CO_2 emissions were less than Sabiya and Alzour South power stations. This is due to the fact that the installed capacity of Doha West (i.e. 2541 MW) is smaller than the installed capacities of Sabiya and Alzour South which each exceeds 5000 MW.

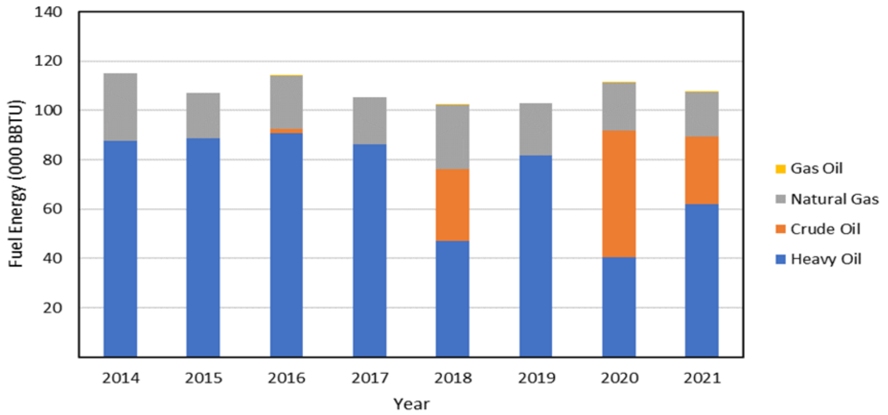

Figure 8: Annual fuel energy mix usage at Doha West power station.

3.3 Economic Valuation and Analysis

Economic valuation was performed based on the average CO_2 emissions for the period from 2014 to 2021. Cost rates in Table 2 are used to find the total cost for installation of carbon capture units and cost of CO_2 avoided. The cost of avoided CO_2 is the cost for reducing the quantity of CO_2 emitted to the atmosphere as a result of the implementation of human interventions such as the installation of carbon capture systems. The cost rates are based on the absorption technology in reference [2]. The economic valuation in this study considers two modes of transportation for the captured CO_2 including pipelines and trucks.

In Tables 3 – 4, the average annual CO_2 emitted from Doha West is less than Alzour South and Sabiya. This is because Doha West has smaller installed capacity than Alzour South and Sabiya. The average annual CO_2 emissions from 2014 to 2021 are approximately 8.3, 13.8, and 13.1 million tons from Doha West, Alzour South, and Sabiya respectively. It can be seen that the cost of facility and injection cost are constant for all power station including the two transportation modes. The cost of transport using trucks is higher than pipelines approximately by 187% for Doha West, Alzour South, and Sabiya. On the other hand, compression cost for pipelines is higher than that of trucks approximately by 43.9% for the three power stations.

The costs of CO_2 avoided using pipelines transport were found approximately to be USD 738.5 million, USD 1,230.8 million, USD 1,166.4 million for Doha West, Alzour South, and Sabiya power stations respectively. Regarding the cost of CO_2 avoided using trucks were found approximately to be USD 945.9 million, USD 1,576.6 million, USD 1,494 million for Doha West, Alzour South, and Sabiya power stations respectively. The total cost of CO_2 avoided is higher for trucks than pipelines approximately by 28% for the three power stations.

*Table 3. Economic Valuation Results of CO_2 Capture with Pipelines Transport**

Item	Doha West	Alzour South	Sabiya
Average CO_2 emission (tons of CO_2)	8,297,787.26	13,829,632.07	13,105,635.74
Cost of facility for CO_2 capture (US$)	439,782,724.60	732,970,499.46	694,598,694.38
Cost of transport and sequestration (US$)	124,466,808.85	207,444,480.98	196,584,536.15
Injection cost (US$)	91,275,659.82	152,125,952.72	144,161,993.17
Compression cost (US$)	82,977,872.57	138,296,320.65	131,056,357.43
Total cost of CO_2 avoided (US$)	738,503,065.83	1,230,837,253.81	1,166,401,581.13

* *Based on average annual CO_2 emissions from 2014 to 2021.*

It is worth mentioning that, for the three power stations, the percentage costs of facility, transport, injection, and compression from total cost of CO_2 avoided are approximately 59.5%, 17%, 12.4%, and 11.2% respectively for pipelines transport. While the percentage costs of facility, transport, injection, and compression from total cost of CO_2 avoided are approximately 46.5%, 38%, 9.7%, and 6% respectively for trucks transport. It is observed that the highest change in the percentages is for the transport mode used to deliver the captured CO_2 gas. A cost sensitivity analysis was conducted for cost of transport since the cost of facility is constant for both types of transportation modes and cost of transport occupies the second highest share.

*Table 4. Economic Valuation Results of CO_2 Capture with Trucks Transport**

Item	Doha West	Alzour South	Sabiya
Average CO_2 Emission (tons of CO_2)	8,297,787.26	13,829,632.07	13,105,635.74
Cost of facility for CO_2 capture (US$)	439,782,724.60	732,970,499.46	694,598,694.38
Cost of transport and sequestration (US$)	356,804,852.03	594,674,178.81	563,542,336.95
Injection cost (US$)	91,275,659.82	152,125,952.72	144,161,993.17
Compression cost (US$)	58,084,510.80	96,807,424.46	91,739,450.20
Total Cost of CO_2 avoided (US$)	945,947,747.25	1,576,578,055.44	1,494,042,474.71

**Based on average annual CO_2 emissions from 2014 to 2021.*

3.4 Qualitative Discussion of Energy Efficiency

In this section a qualitative discussion is outlined for the installation of carbon capture units in the power stations. It was found in the literature that Amine-based carbon capture technology, which is commercially applicable, is energy intensive since it consumes some amount of energy during the process of capturing and compressing CO_2 gas in the power stations. The energy consumed by the carbon capture units is provided from the power stations connected to the units. This reduce the efficiency of the power stations since the desired output is not achieved. It recommended in the future to study, quantify, and analyze the decrease in energy efficiency of the power stations in Kuwait after installing carbon capture units. It is important to investigate potential and promising carbon capture technologies that do not consume a lot of energy from the power stations to maximize power output.

In spite of the fact that the installed capacity of Sabiya power station increased over Alzour South power station after year 2018 (see Figure 1), the CO_2 emissions from Alzour South were higher than Sabiya (see Figure 5). Specifically, the installed capacity of the Sabiya was higher than Alzour South approximately by 16.4%, and 17.6% in years 2020, and 2021 respectively. But the CO2 emissions from Alzour South were higher than Sabiya approximately by 9%, and 24.3% in years 2020, and 2021 respectively. Comparing fuel consumptions by the two power stations in Figure 7 – 8, Alzour South consumed more fuel than Sabiya. This is an indication of issues in energy efficiency that need attention at Alzour South power station. The issues are raised by the high fuel consumption in low installed capacity power station. In other words, the fuel energy is not fully utilized when the fuel is burned at Alzour South power station leading to more CO_2 emissions.

4. Conclusion

In this study analyses were performed for power station's fuels consumption and CO_2 emissions. Also, economic valuation for using carbon capture technology were performed for utilization at the power sector in Kuwait. The conducted analyses covered the period from 2014 to 2021 and it used fuel energies data as a basis for the CO_2 emissions calculations.

Regression analysis was conducted to predict CO_2 emissions based on the fuel types used to in the power stations to generate electricity. Also, the analysis showed the fuel type that has the highest impact on CO_2 emissions. The results of regression coefficients showed that heavy fuel oil has the highest impact on total CO_2 emissions in the power sector. If the heavy fuel oil increases with 1 BBTU this will lead to an increase in the total CO_2 emission of 0.0817 kton in the power sector.

The power stations with the highest installed capacities are Sabiya, Alzour South, and Doha West. This indicates that these power stations have the greatest level of CO_2 emissions in the power sector. The average annual CO_2 emissions from Sabiya, Alzour South, and Doha West power stations approximately are 13.1, 13.8, and 8.3 million tons respectively. In these power stations it was found that heavy fuel oil has been used with considerable amounts leading to substantial increase in CO_2 emissions.

Economic valuation was performed for using amine-based carbon capture technology in Sabiya, Alzour South, and Doha West power stations. The economic valuation considered two modes of transportation which are pipelines and trucks. The total cost of CO_2 avoided was the highest for Alzour South for the two modes of transportation while Doha West had the least for both transport modes. The total costs of CO_2 avoided for Alzour South are approximately USD 1.23 billion, and USD 1.58 billion for pipelines and trucks transport respectively. On the other hand, the total costs of CO_2 for Doha West are USD 738.5 million, and USD 945.9 million for pipelines and trucks transport respectively.

Since the current commercial CO_2 capture technologies are energy intensive it is recommended to consider potential future technologies that are less energy intensive to be used in the power sector. Using less energy intensive technologies will help improve and sustain the power output of the power stations.

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