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Estimation of CO_2 emission factor for Power Industry Sector in Libya

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Abstract —This study is relevant to the efforts being made to support the Libyan state achieve its goal of reducing greenhouse gas emissions since Libya is one of the countries that ratified the Paris Agreement of 2015 and participated in the COP27 conference. Therefore, this research aims to estimate the amounts of CO_2 emitted from Libyan power industry sector. The results presented in this research is based on real measured data that had been collected over long periods of time series by monitoring and control systems of the considered power plants. Thus, the presented here CO_2 emission factors on different basis can be considered as an indicator to the environmental situation of the power industry sector of Libyan State. The methodology used in this study can be adopted to estimate other air pollutions emission factors in the power sector or even in other sectors. The results were also compared with emission inventories published by environmental agencies such as IPCC, EAA, EAI, and EEM, as well as the standards set by UNFCCC. This research sounds the alarm that the current environmental situation of the stations is much worse than all expectations, and therefore scientists and decision-makers must take immediate measures to reduce pollution in this sector.

Keywords — Air pollutants, carbon dioxide emission factor, pollution in electric power plants, cost of environmental damage, Libya

I. INTRODUCTION

There are growing concerns about the harmful effects of greenhouse gases worldwide, and climate change has arisen as a major concern, as was shown during the United Nations Conference on Environment and Development (UNCED) in June 1992. The Kyoto Protocol was followed in December 1997 by legal commitments to reduce greenhouse gas emissions to reduce global warming to less than 2 degrees Celsius. To reach net zero emissions by the middle of this century, emissions must be reduced as rapidly as possible [1].

The electrical generation system in Libya is based on 13 power plant stations. The total capacity is 8051 MW with the contribution of the steam stations of 20%, while 53% for gas plants and the share of the combined cycle plants is 27%. The energy produced from Libyan stations comes from combustion of heavy oil (20%), light oil (40%) and natural gas (40%). The total electricity generated in 2022 is 33,980 GWh with an average efficiency of 27% [2]. As a part of the scientific nation project being adopted by the Faculty of Engineering and the Faculty of Environment and Natural Resources of Wadi Alshatti University, this research aims to determine the CO_2 emission factors, as well as those for CO, NOx, and SO_2 from the gas-turbines based power. In order to conduct an environmental analysis of the Libyan electric power production system, data must first be collected from the all stations.

Despite the significance of this subject, there are few published scientific researches, which are as a result of the lack of information. For this reason, most of these studies had used databases of environmental organizations. However, these inventories were estimated by applying theoretical approaches (Tier 1), and this represents one of the uncertainty sources in the obtained results [3]. In this manner; the amounts of gases released from different air pollution sources in Libya were determined by Nassar et.al [4]. This study established a framework for any actions to lower air pollution. According to the study, electricity production was the most polluted of all other sectors with 33.9% followed by the transport sector with 30.7%. With commercially available carbon capture techniques, these emissions may have been reduced.

Youssef et al. conducted a theoretical investigation on the dispersion of pollutants, nitrogen oxides, sulfur dioxide and particulate matter, on four power plants in Libya, north Benghazi, south of Tripoli, Zueitina and Khoms. The first three stations are gas stations, while the last station is a combined station [5]. Iessa conducted a study using the life cycle assessment methodology to estimate the carbon dioxide emission factor in the Libyan energy production sector. The study monitored the CO_2 emissions from oil extraction from the oil fields, through the refinery processes, to the electricity generation power plant. In comparison to the traditional methodology, the method adopted in this investigation raised the CO_2 emission factor by 6.7% [6]. As a result, possibilities for fair competition for alternative technologies of electricity generation will be provided (such as renewable energy resources) [7]. In this context, many researches presented the costs of environmental damage caused by greenhouse gas emissions [8], [9], [10]. This procedure makes it possible to verify the impact of each type of service on the environment separately [11]. This research paved the way for further research to calculate the social and economic cost of all pollutants.

Okasha et al. measured the NO_X SO_2 and PMs emissions emitted from Khoms power plants, measured their concentrations around and faraway from the power station, and estimated the impact of these emissions on the surrounding environment [12], [13], [14]. Hesham et al, proposed design modifications for Khoms steam power station in order to improve the overall efficiency, reduce gas emissions and lower operation and maintenance costs [15], [16].

The importance of this study lies in the fact that estimating the quantities of pollutants is necessary to know the social and economic impact of environmental damage and to estimate the carbon price or the tax on industrial activities, similar to the countries that preceded us in this field. In Libya, there is no study being conducted in this field.

In this research, the emission factors of three significant pollutants used in the calculation of greenhouse gases from two Libyan power plants the South Tripoli plant and Khoms gas-turbine power plants, which operate on natural gas and light fuel, were calculated. This is considered the main significance of the research. Neither natural gas emissions nor the effect of plant performance on these factors have been studied. The rest of the work is divided into three sections: The approach that follows for processing the data obtained from the power stations are included in chapter II. Some of the qualitative results obtained from the research are graphically depicted and discussed, in addition, it provided some comparisons with the standards included in the lists of international organizations as well as the emission factor of some other States and established the benchmarks set by UNFCCC for the country's overall environmental situation. The cost of environmental damage resulting from these emissions has also been also estimated and the potential of these budgets for construction of renewable energy plants in Libya. Finally, conclusions and some recommendations of this research are provided.

II. METHODOLOGY

Two paths were followed to accomplish the research's objective: The first was data collection, via field measurements and the collection of operational data for long operation hours. These data are; fuel consumption, electricity generation, over-all plant efficiency, and emissions monitoring data, quantity of exhaust gases. While, the second path is the analytical approach in order to process the data.

A. Research Data

Three different power stations were considered in the present research, South Tripoli, Khoms, and Musrata. This selection is perfect due to the different fuels used in each power station. The data provided by the monitoring and control chamber of the power stations are hourly time series monitoring data for selected days every month during the year of 2022. The following tables present the average values of the metrics

Table 1 listed the gas-turbine based power plants operate in the electricity generation system in Libya [2]. While the fuel consumption, exhaust gases rate, fuels' low heating values, Temperatures of exhaust gases and the electricity generated are tabulated in Table 2.

These data are obtained directly from the monitoring and control chambers in the considered power plants.

TABLE 1: POWER PLANTS, OPERATION AND PERFORMANCE INFORMATION

Power Station (operation year)	Capacity MW	Fuel	Efficiency %	Operation hours; h/year	Fuel consumption (10^3 m^3/year)	Energy generation GWh/year
Musrata (1990)	570	Heavy Fuel Oil	%20	4810	1,085.6	2,405.0
North Benghazi (1995)	570	NG	%25	5230	1,091,600	2,615.0
AbuKmash (1982)	45	Diesel	%11	3288	129.91	55.9
Khoms (1995)	600	NG	%23	4999	1,193,800	1,823.0
South Tripoli (1994)	500	Diesel	%18	3646	978.12	1,458.4
Azzawia (1994)	770	NG	%20	4290	1,512,000	2,145.0
AlKoofra (1982)	50	Diesel	%11	2870	126.0	-
West Mountain (2005)	780	Diesel	%24	5176	1,624.46	3,364.4
Musrata (2010)	570	NG	%23	4810	1,091,300	2,405.0
Alsareer (2010)	360	Diesel	%20	5120	890.06	1,280.0
Total	**4,815**		**21.6%**	**4424**	**4,893,534.15**	**17,551.7**

TABLE 2: OPERATION PARAMETERS FOR ONE GAS-TURBINE OF THE CONSIDERING POWER STATIONS.

Power Station (operation year)	Fuel	Fuel rate kg/s	Fuel HV. MJ/kg	Exhaust gas kg/s	Exhaust Temp. °C	CO_2 % volume	Electricity G. kWh
Musrata (1990)	Heavy Fuel Oil	6.46	44.56	378.8	513	3.7	83,235
Khoms (1995)	NG	7.67	35.42	378.8	492	2.7	94,770
South Tripoli (1994)	Diesel	7.65	41.56	378.8	496	3.7	95,330

B. Research Assumptions

In order to estimate the quantity of CO_2 emissions from the considered power stations, the following assumptions have been adopted:

1. Normal operating conditions.
2. The calculations were made on the basis of the monthly reports
3. Adoption of one analysis certificate for each fuel type.

C. Emission factors calculations EF_{CO_2}

The CO_2 emission factors can be calculated on the basis of many indicators by means of the following expressions [17]:

$$EF_{CO_2}(kg\ CO_2/MWh) = \frac{1}{24} \times \rho_{CO_2} \times \sum_{h=1}^{24} \frac{Q_{CO_2} \times V_{fg}}{E_p} \quad (1)$$

$$EF_{CO_2}(kg\ CO_2/kg\ fuel) = \frac{1}{24} \times \rho_{CO_2} \times \sum_{h=1}^{24} \frac{Q_{CO_2} \times V_{fg}}{m_f} \quad (2)$$

$$EF_{CO_2}(kg\ CO_2/m^3\ fuel) = \frac{1}{24} \times \rho_{CO_2} \times \rho_{fuel} \times \sum_{h=1}^{24} \frac{Q_{CO_2} \times V_{fg}}{m_f} \quad (3)$$

$$EF_{CO_2}(kg\ CO_2/MJ) = \frac{1}{24} \times \rho_{CO_2} \times \sum_{h=1}^{24} \frac{Q_{CO_2} \times V_{fg}}{m_f \times HV} \quad (4)$$

Whereas, ρ_{CO_2} is the CO_2 density ($1.2605\ kg/m^3$), ρ_{fuel} states for fuel's density ($\rho_{NG} = 0.7801$, $\rho_{Diesel} = 913$ and $\rho_{HFO} = 927\ kg/m^3$), Q_{CO_2} is the volumetric ratio of CO_2 continents in the exhaust gases, V_{fg} is the volumetric flow rate of exhaust gases m^3/hr, E_p is the hourly electrical energy produced MWh, m_f is the fuel mass flow rate kg/hr, HV represents the low heating value of the fuel $MJ/kg\ fuel$.

D. Ecoenvironmental aspects

This section aims to predict the cost of the damages caused by the CO_2 that emitted from the electricity generation system in Libya which depending almost 100% on fossil fuels. The US Energy Institute reveals that the CO_2 causes over three times as much damage in dollar terms as the figure currently used by the US government, $51 per ton. The new study shows $185 per ton of CO_2 as the Social Cost of Carbon (SCC) [18]. Recently, at COP27 in Sharm El-Sheikh, Egypt, which was held in November 2022, a Carbon Tax (CTax) was set at about $75 per ton CO_2 to meet goals set under the Paris climate agreement [19].

In general, this approach enables countries can know their environmental obligations to the international and local community. Using eq. (2) or (3) and the knowledge of quantities and types of fuels consumed in the local market, whether it is for electricity generation, transportation, industry, etc. Accordingly the total annual Carbon Cost (CC) can be predicted as follows:

$$CC\ (\$) = 260 \times \sum_{i=1}^{n} \left(EF_{CO_2} \times m_f\right)_i \quad (5)$$

Where *i* denoted to type of fuel.

Recently, many of those interested in promoting renewable energies' market; insist on including the carbon cost in the economic calculations of environmental friendly energy systems as a value subtracted from the cost of operation and maintenance, and this in turn supports competition in favor of renewables in the global energy market [20], [21], [22].

III. Results and Discussions

An MS Excel worksheet has been prepared to process the data in order to compute the CO_2 emission factors by using the previous mentioned four equations. The obtained results are graphically depicted, discussed and compared with other references.

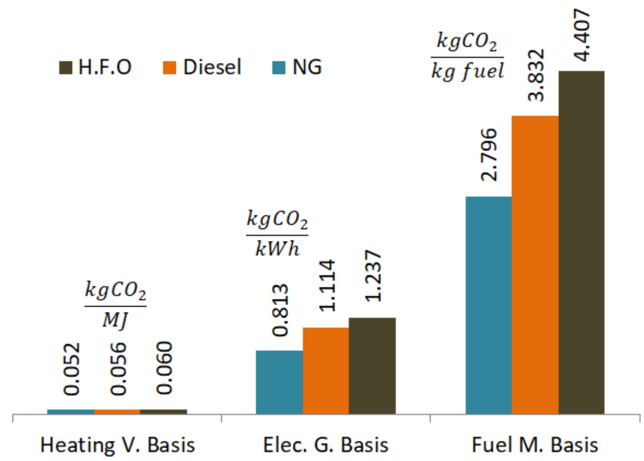

Fig. 1: CO_2 emission factors on different basses

Thus, EF_{CO_2} for 50% of the power generation system of Libya can be estimated by using the weights of electricity production and fuel consumption for each station and each fuel type, as listed in Table 3.

TABLE 3: CO_2 EMISSION FACTORS EF_{CO_2}

$kg\ CO_2/MWh$	$kg\ CO_2/GJ$
967.35	52.76

To recognize the environmental situation of the country's power industry sector, a comparison was made with some countries in the region, and the results were represented graphically in the form of clustered bars, as in Fig. 2.

It is clear from Fig.2, that Libya has the largest emission factor among all countries; the reason for this –in the first place - is due to the low efficiency of the power stations, due to the old age of these stations.

In the same manner, a comparison of CO_2 emission factors on the heating value basis with several European countries and organizations in [$kg\ CO_2/GJ$] is illustrated in Fig. 3.

Fig. 3 shows that the fuels used in power stations have good characteristics in terms of the heating values.

Fig. 3 supports - without doubt - what was analyzed due to the high emission factor based on the electrical energy produced: despite the quality of the fuel operating the stations, the electrical energy produced is low, and this is due to the lack of operating efficiency.

Figs. 4 and 5 present comparison between EF_{CO_2} on the basis of fuel mass which obtained in the present study with other countries, environmental agencies and biodiesel (B100).

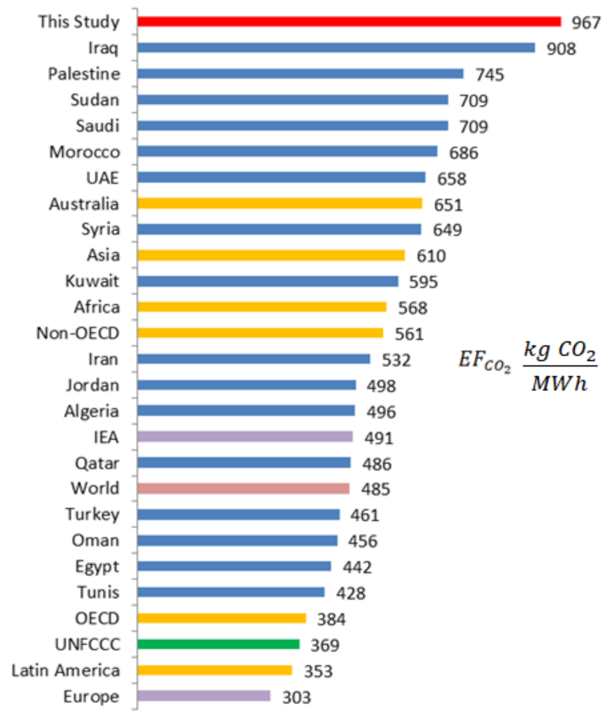

Fig.2. Electricity generation basis CO_2 emission factors comparison

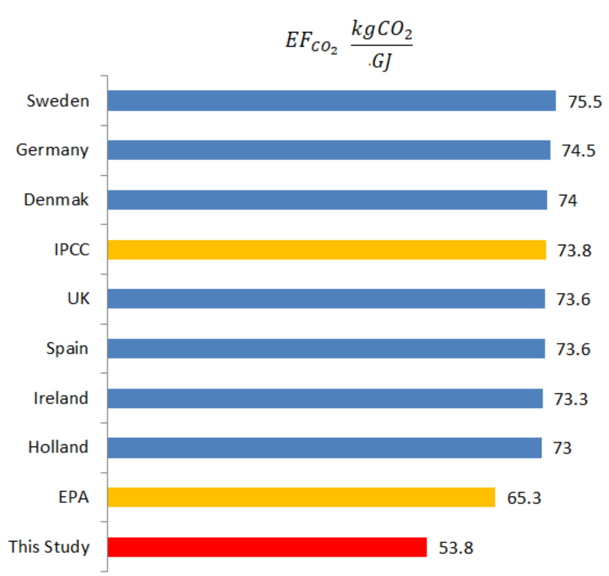

Fig.3. Heating value basis CO_2 emission factors comparison

Despite the low operation efficiency - the first reason for the increase in coefficients - the Libyan natural gas index showed progress over the rest of the countries. The reason for this is due to the high quality of Libyan natural gas, which contains a high percentage of methane gas CH4 (87%), as indicated by the results of the analysis of natural gas used in power stations.

Fig. 6 demonstrates the variation in CO_2 emission factor on the basis of electricity generation. This is considered as a source of uncertainties in the results.

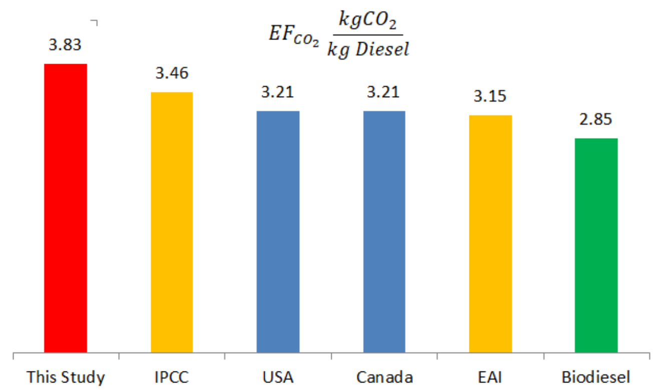

Fig.4: Comparison of CO2 emission factors on the basis of fuel mass [kgCO2/kg Diesel]

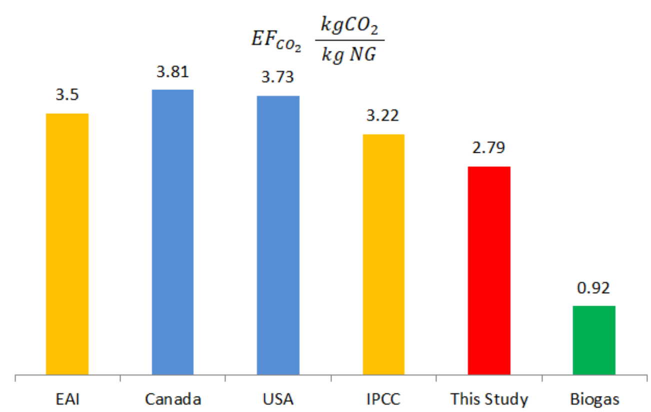

Fig.5: Comparison of CO_2 emission factors on the basis of fuel mass [$kgCO_2$/kg NG]

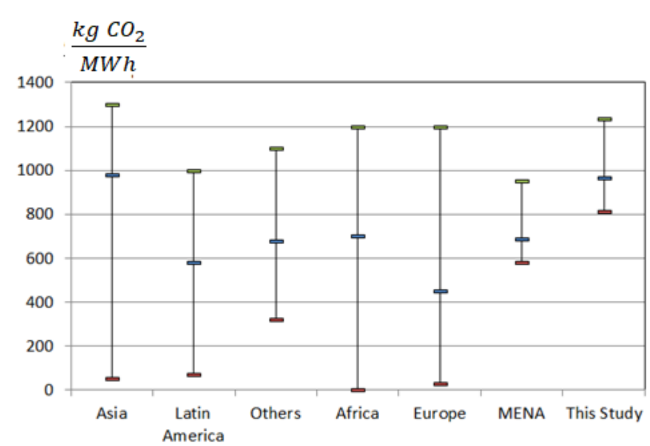

Fig. 6: Comparison of the maximum, minimum and average regional CO_2 emission factors on the basis of the electricity generation index [$kgCO_2$/MWh]

This wide variation in CO_2 emission factors is attributed to the use of different sources of energy such as: nuclear, hydroelectric or renewable energy in generating a fraction of the electrical energy in some countries. While others use fossil fuels (coal, natural gas, diesel oil, heavy fuel oil, or crude oil), in such cases the CO_2 emission factor is higher according to the type of fuel, so it is highest in the case of using coal, and it is relatively lower in the case of using natural gas.

After knowing the CO_2 emission factor, we are now enabling to estimate the total annual carbon cost by using eq. 5.

Calculations revealed that the amount of CO_2 emitted from the chimneys of electric power plants operating on gas turbine technology is estimated at about 28,146,133 tons annually. Thus, the total cost of CO2 is $7,318M.

Fig. 7 represents the percentage consumption of each type of fuel in electric power generation using gas-turbine technology.

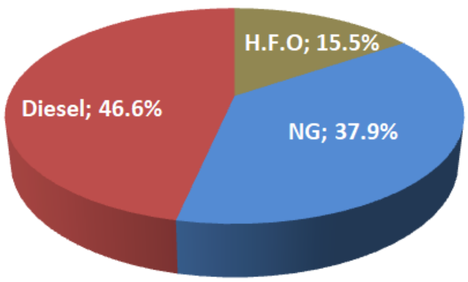

Fig. 7: The share of each fuel's type in electrical generation

While Fig. 8 represents the percentage contribution of each type of fuel to air pollution due to electricity generation using gas-turbine technology.

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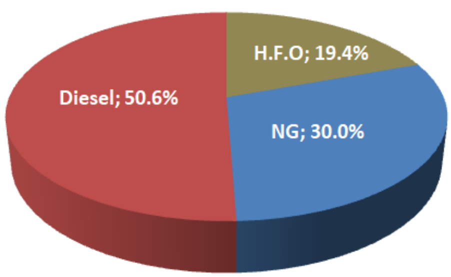

Fig.8: The share of each fuel's type in the air pollution

It is evident from Figs. 7 and 8; the air pollution resulting from the use of liquid fuels (heavy and light fuel oils) are emitted from more pollution than natural gas.

It is necessary to point out here that, the obtained results in this research did not represent the emission factor of Libya's electric power industry, but it represents only 50% of the generation system. Whoever, the situation will get worse because the steam plants operating in Libya, which represent 20% of the total generation, are of lower efficiency, and while the combined-cycle stations have higher efficiency, the generation rate does not exceed 27%. Thus, the results obtained in this research can be considered as an indicator to the environmental status of the energy industry sector in Libya.

IV. CONCLUSIONS

It was found through the results obtained from this study, which is based on real information measured from several electric power plants and for several types of fuels in the country, that the environmental situation of the electric power industry in Libya is more harmful to the environment than all estimations that use inventories' emission factors for the environmental agencies or even to other countries.

Accordingly, the technical course of this sector must be corrected so that the Libyan state can fulfill its obligations in mitigating climate change.

V. RECOMMENDATIONS

To improve the environmental situation in Libya's electric power plants, two strategies can be implemented.

A. The short strategy

1. The rapid change to using natural gas instead of diesel oil to generate electric power is a fast solution to reduce environmental degradation and mitigate the environmental damage.
2. The use of carbon captures.
3. Issuing legislation to encourage investment in the field of environmentally friendly energies

B. The long strategy

1. Improve the performance of working stations by using the most efficient techniques such as combined-cycles technology.
2. Developing a roadmap for the rapid transition to generation using environmentally friendly energies

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