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Calculating of Some Exhaust Emission Compounds of Diesel Engine Generators in Sulaimani City Using Energy-Based Approaches.

Karzan Q. Mohammed[1], Salih N. Majid[2*], Hunar B. Aziz[1], Aven R. Hamza[1], & Karzan S. Ismael[1],

1 Research Center, Sulaimani Polytechnic University, Kurdistan Region, IRAQ.
2 Natural Resources Department, College of Agricultural Engineering Sciences, University of Sulaimani, Sulaimani, Kurdistan Region, IRAQ.
**Corresponding author's e-mail: salih.majeed@univsul.edu.iq.*

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Abstract

In Kurdistan region of Iraq similar to developing countries, diesel engine generators (DEGs) have established themselves as reliable, durable and complementary suppliers to the main national grid of electric power for domestic, industrial, agriculture and commercial sectors. By domestic purpose, the generators are usually placed close to the residents in all the districts of the cities. However, diesel emissions contain numerous compounds that are evidenced to be a threat to humans and have the potential to cause adverse health effects. Furthermore, diesel emissions are particularly a significant hazard to the environment as well as they are significant contributors to global greenhouse gas (GHG) emissions. In view of the previous reasons, there was an urgent need to evaluate and quantify the exhaust emission of diesel generators by applying energy-based approaches.

Consequently, this study aimed to calculate the exhaust emission compounds of CO_2, CO, NOx, SO_2, and HC by applying energy-based approaches based on fuel consumption for the past three years of 2013, 2014 and 2015 in Sulaimani city, Kurdistan Region, IRAQ because no previous studies have yet been conducted for this issue.

Results indicated that the calculated amounts of the emitted gases had the following increasing trends; CO_2 > NOx > SO_2 > CO > HC. The percent of domestic source out of the total emission for all investigated gases was in the range of 90.95 to 98.13%. The amount of annual emission for all the investigate gases have increased obviously through the year's progression of 2013 to 2015 due to the increasing of DEGs numbers and more electric power consumption.

Introduction

For most of the developing countries, supplying electrical power from the main national grid to cover the demand of urban area was not acceptable and adequate, therefore installation of diesel generators as reliable and durable sources for power generation were the solution to meet domestic demand as well as the high-energy requirements for all other sectors in the urban areas. However, diesel generator principally belongs to the internal combustion engines that emit numerous organic, inorganic gases and particulate matters. In spite of the advantages of diesel engine generators, the disadvantages of internal combustion engines are evident because they are regarded among the most dominant anthropogenic pollutants all over the world [1]. Nonetheless, the increasing numbers of diesel-fueled engines become customary in heavily populated urban regions for electric generating and other purposes like private transportation. As a result, vast amounts of air pollutants will be emitted from the diesel exhaust engines, and this led to increasing health risks and environmental hazard.

Exhaust emission is the gaseous and organic particulates matters (PM) produced by any engine during internal combustion. The gases and particulates matters may vary markedly with fuel type (fuel composition), engine type (whether the engine is in locomotive, on-road or off-road vehicles, farm vehicle, marine vessel, or stationary generator), rate of consumption, operating conditions and speed of engine operation (lazing or at speed or under load) [2].

Diesel engine exhaust is a complex mixture containing hundreds of organic particle-phase, gas-phase, and semi-volatile components that are emitted through the combustion of diesel fuel [3 and 4]. Consequently, we are exposed daily in the city's urban to many airs borne toxics and pollutants which they are mainly interrelated to combustion in diesel engines [5 and 6].

Based on toxicological studies and satisfactory evidence, exposure to diesel exhaust is linked with an increased risk for lung cancer. For instance, during a nested case-control study in a cohort of 12315 workers by [7], their finding emphasized additional evidence that diesel exhaust exposure may cause lung cancer in humans and may represent a potential public health burden. [8] has also examined the possible health hazards associated with exposure for long and short-range to diesel engine exhaust, their assessment concluded that prolonged inhalation exposure is likely to damage the lung, as well as to pose a lung cancer hazard to humans depending on exposure duration, while short-range exposures can cause acute or chronic cell damage, irritants, and pathogen of a transient nature. Moreover, increasing the severity or violence of existing allergies and asthma symptoms could emerge variable across the population. For that reason, diesel exhaust has been classified as carcinogenic agent (Group 1) to humans [9 and 10].

According to the California Air Resources Board, diesel engines have a great environmental impact on air, water, and soil due to the release of a mass of risky compounds; for example black carbon particles (soot), sulfur oxides, heavy metals and other toxins found in diesel exhaust will be deposited on soil surface and cause soil, air and water [11]. As black carbon deposited on the topsoil, then it affects the ability of plants to take nutrients from the soil. Moreover, it affects the soil's ability to absorb and hold water [12]. Consequently, this can disturb the ability to cultivate important crops used as a food source or other purpose such as alternative fuels production.

Along with the substantial adverse effect of diesel fuel combustion on health and environment, there is much other weakness in diesel-generated electricity as compared with the other electric supply sources; the weakness include cost of diesel which is rapidly increasing (economic implication), social impact and noise pollution which can be disturbing in the vicinity of schools, health centers, requires a larger lubrication and cooling system too, and in quiet remote locations [13 and 14].

Several authors and studies such as; [1, 15 and16] have reported that the regulated emissions from internal diesel combustion engines are composed of the following chemical compounds; carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), numerous polycyclic aromatic hydrocarbons (PAH), volatile organic compounds (VOCs), nitrous oxides (NOx), sulphur oxides (SOx), heavy metals (HM) and particulate matter or black carbon (PM or BC) which will be released as basic components of deiseal engine exhaust and they have many implication on health and environment. As refereed by [17], diesel as a type of heavy oil fuel for an internal combustion engine is composed of about 25% aromatic hydrocarbons, and 75% saturated hydrocarbons.

About 99% (by volume) of diesel exhaust gases are non-toxic gases, and they consist mainly of carbon dioxide, nitrogen, water vapor, and oxygen (Figure 1). Although the rest of 1% by volume exhaust gases are present in a smaller fraction, it contains numerous organic compounds and still pose the biggest health threat to humans. The most important organic compounds in this smaller fraction of hazards group include small and large molecules of the following compounds; polynuclear aromatic hydrocarbons and their various functionalized derivatives, collectively referred to as PAHs, nitro-polyaromatic hydrocarbons (NPAHs) and heterocyclic aromatic compounds (HACs). Furthermore, the emitted organic gases from diesel exhaust contain; aldehydes, and selected other hydrocarbons and their derivatives. Several of these species in their pure state have been categorized as human carcinogens (e.g., chrysene, benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene, indeno[1,2,3-c,d]pyrene dibenzo[a,h]anthracene), benzo[k]fluoranthene, [1, 16, 18, 19, and 20].

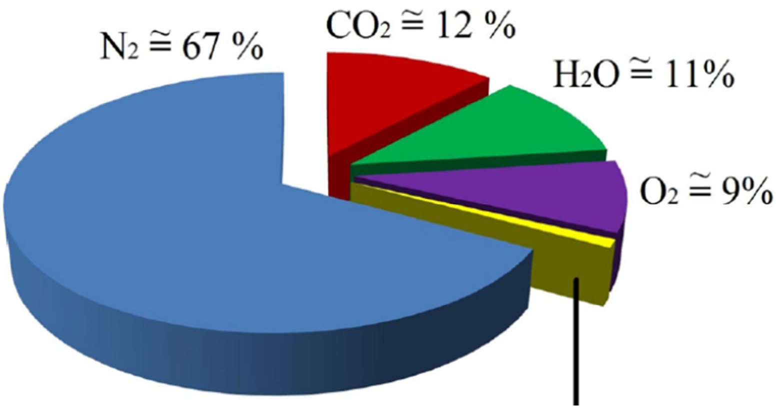

Figure 1: Approximate volume percent's of non-toxic chemical compounds which constitutes 99% of the total volume of diesel exhaust emissions [16].

On the other hand, diesel fuel types and air-fuel ratio (AFR) (standardized AFR for diesel engine is 14.7 air :1 fuel) effects significantly on the amount and type of the emitted gases from diesel engine exhaust as well as on the engine performance [21, 22 and 23].

Electric energy consumption has grown up dramatically in all cities of Iraqi Kurdistan region as well as the other Iraqi cities over the last three decades. Commonly, in Iraq, there is two main sources of power, one fossil fuels power which produces 81% of the demand of electric power, and the other rest of 19% is from renewable hydropower [24]. Accordingly, diesel engine generators (DEGs) in huge numbers were used as an alternative electricity source to cover the demand of all the residential districts and other activities of Sulaimani city and all the other Iraqi Kurdistan.

In this study, we have applied energy-based methods for measuring the amount of the emitted gases of CO_2, CO, NOx, SO_2, and HC from diesel exhaust of electric power generators based on the amount of consumed fuel. Hence, the current study aimed to assess the environmental impact of diesel exhaust through calculating the amount of the emitting gases of CO_2, CO, NOx, SO_2, and HC for the past three years of 2013, 2014 and 2015 in Sulaimani city, Kurdistan Region, IRAQ, because diesel fuel combustion is reasonably serious locally and globally over its contribution to global greenhouse gas (GHG) emissions. Moreover, the object of this study extended to predict the associated carbon footprint per capita per year for electric power consumption by diesel generators for domestic and commercial purposes. Finally, the study also intended to focus on the overall reviews about the health and environmental effects of diesel exhausts as well as the chemical composition of diesel fuel because no considerable attention has been previously given to this hazardous exhaust of diesel engine in Sulaimani city.

Data and Methodology

I. Study area

Sulaimani city is located in northeastern of Iraq; near to the Iranian border with a longitude of 44.50 to 46.16 East and latitude of 35.04 to 36.30 North, it has an elevation of 895 m above sea level (Fig 2), [25]. it is regarded as one of the main and most populated cities in Iraqi Kurdistan region with an estimated 2015 population of 656100 [26].

The climate of Sulaimani governorate is semi-arid continental: very hot and dry in the summer months from June to September; mean highs are 39°C to 43°C. Winter months are cold and wet, particularly in the high mountains; mean winter high temperature is 7 to 13oC; mean lows are 2°C to7°C. The mean range of spring season is from 13°C to 32°C, while for autumn season ranges from 24°C to 29°C [27].

II. Chemistry of diesel fuel

Diesel fuel is a liquid byproduct of the petroleum and mainly made of carbon and hydrogen. Diesel fuel contains about 75% of saturated hydrocarbons (primarily cycloparaffins and n, isoparaffin), and contains

25% aromatic hydrocarbons (including alkylbenzenes and naphthalenes a). The average chemical formula for collective diesel fuel has the chemical formula of $C_{12}H_{24}$, ranging approximately from $C_{10}H_{20}$ to $C_{15}H_{28}$ [28]. This variation in carbon content might be due to the differences of fossil oil source and the addressed quality standard among the countries; for example, the diesel fuel of European countries characterized by higher; Cetane number, density, and hydrogen content but lower sulfur content as compared to Iraqi diesel fuel (Table 1). Usually, the higher sulfur amount in diesel fuel could lead to emitting more sulfur oxides in specific internal combustion.

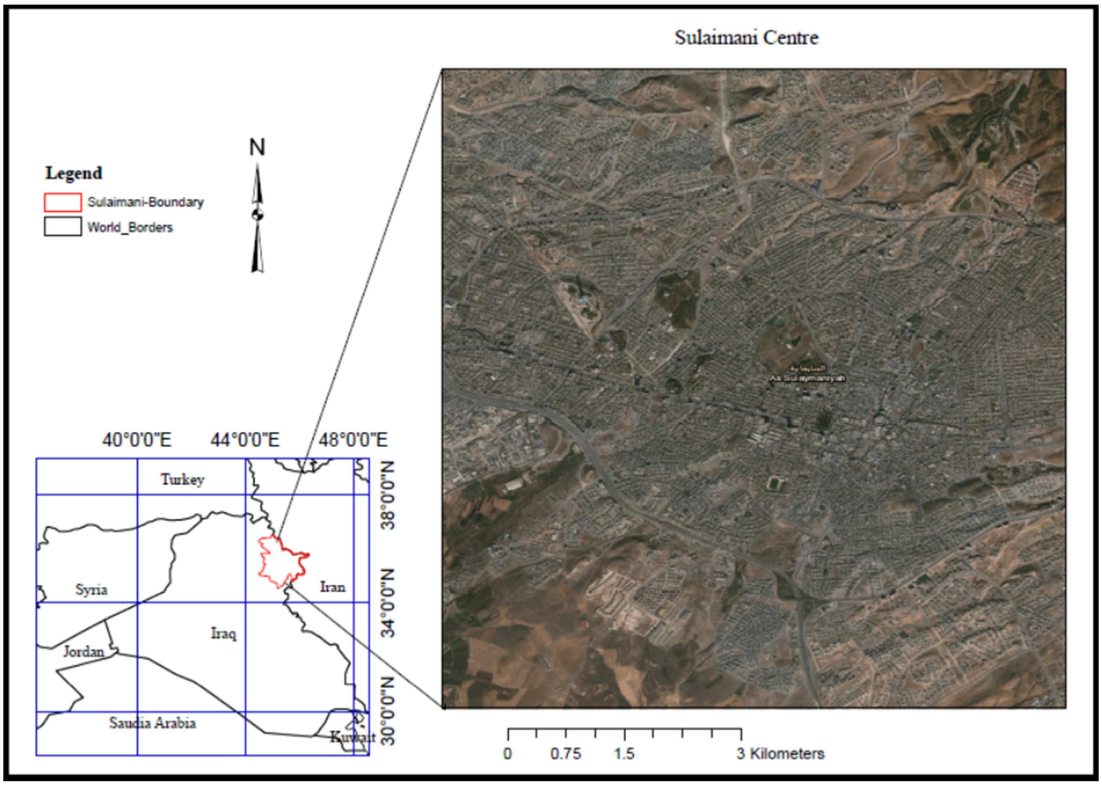

Figure 2: Sulaimani city (Google Earth)

III. Applied models for calculating the investigated diesel exhaust gases.

A-Fuel analysis approach for estimating CO_2 emissions:

The energy-based approach is an accurate and preferable method to estimate GHG emissions and other pollutants gases which are emitted from the exhaust of diesel internal combustions engine [29]. In this study, equation (1) as the energy-based approach was applied to measure the amount of the emitted CO_2 from diesel-powered generators in Sulaimani city [30 and 31]. Having a total volume of fuel consumption (fuel-based method) could be useful for measuring the total amount of carbon dioxide equivalent (CO_2e) in kilotons or metric tons if this will be included by the temperature control and the empty return for the diesel engine. Usually, there is for each fuel type given emission factors which are multiplied with the total volume in liters or mass in a kilogram of fuel consumption for any internal-combustion diesel engine [32 and 33].

Table1: Chemistry and properties of Euro and Iraqi diesel fuel.

Properties	Euro Diesel: Source [34].	Iraq Diesel: Source [35].
Density (kg/m^3)	840	820
Cetane number (CN)	56.5	48.5
Lower Heating Value (MJ/kg)	42.74	42.31
C%	86	86
H%	14	12.935
S%	< 0.5	1
N%	-	0.065
O%	0	-

Emission Factor (FE) is a quantity to indicate the rate of emission per unit of energy use. For example, combustion-related CO_2 emissions are calculated through multiplying with the related fuel data, as obtained from statistics, by the valid emission factors. The emission factors for this purpose depend principally on the net calorific value and carbon content of the involved fuel [36].

A quantity of any greenhouse gases (GHGs) can be expressed as carbon dioxide equivalent (CO_2e) by multiplying the amount of the GHG by its global warming potential [37].

Ordinarily, all CO_2 emissions from diesel-electric generators are energy-related, the simplest and most accurate way of calculating these emissions is energy-based approach via recording energy consumption and using standard emission factors to convert energy values into CO_2. The unit of fuel energy will typically be a liter of fuel for the internal combustion diesel engine. Fortunately, the best occasion in Sulaimani city was the availability of data about the fuel consumption related to the back-up diesel-electric generators for the years 2013, 2014 and 2015. Thus, based on the available data in Tables (2, 3 and 4), we used firstly equation (1) according to [30] as the approach to assessing the amount of CO_2 emission rate in a kilogram. However, equation (1) as an approach for estimating CO_2 emissions is as follows:

$$\mathbf{CO_2\ emission} = \sum_{k=1}^{n} \mathbf{Fuel_k} \times \mathbf{HC_k} \times \mathbf{C_k} \times \mathbf{FO_k} \times \frac{\mathbf{CO_2(m.v)}}{\mathbf{C(m.v)}} \qquad \textbf{[1]}$$

Where:

$Fuel_k$= Mass or volume of fuel type k combusted.

HC_k= Heat content of fuel type k ($\frac{\text{energy}}{\text{volume of fuel}}$).

C_k= Carbon content of fuel type k ($\frac{\text{mass}}{\text{energy}}$).

FO_k= Fraction oxidized of fuel type k.

$CO_2(m.v)$ = Molecular weight of CO_2.

C (m.w) = Molecular weight of Carbon.

B- Approaches for estimating CO, HC, NOx and SO_2 :

In addition to the greenhouse gases, internal combustion diesel engines produce also damaging inorganic and organic gases including carbon monoxide (CO), nitrogen oxides (NO_x) sulfur dioxide (SO_2) and Hydrocarbons (HC). Accordingly, based on the equations for medium and slow-speed diesel engine (kg/hours) and fuel consumption for engine data in Annex 1 and 2 the total amounts of CO, HC, NOx, SO_2 pollutants were calculated in kilograms for medium speed auxiliary engines and slow speed conditions according to [30].

Annex 1: Emission rates for medium and slow speed auxiliary engines (kg/hours)

Gases	Medium speed	Slow Speed
CO	$15.32 \times 10^{-3} \times P^{0.68} \times N$	$0.68 \times 10^{-3} \times P^{1.08} \times N$
HC	$4.86 \times 10^{-3} \times P^{0.69} \times N$	$0.28 \times 10^{-3} \times P \times N$
NOx	$4.25 \times 10^{-3} \times P^{1.15} \times N$	$17.50 \times 10^{-3} \times P \times N$
*SO_2	$2.31 \times 10^{-3} \times P \times N$	--
**SO_2	$12.47 \times 10^{-3} \times P \times N$	$11.34 \times 10^{-3} \times P \times N$

Where,

P is the engine power (kW) x engine load (85% MCR),

N is the number of engines

* valid for engines < 2000 kW , ** valid for engines ≥ 2000 kW

(Source; [38]).

Annex 2: Fuel consumption for engine

Fuel System	Load %	RPM	1500
Prime power Specific Fuel consumption (SFC)	25	g/kWh	227
	50	g/kWh	203
	75	g/kWh	198
	100	g/kWh	200

Source; [30].

Results and DIscussion

Carbon dioxide (CO_2) emission:

The level of CO_2 varies spatially and temporally due to the increase in overall human-caused CO_2 emissions (anthropogenic activity) and seasonal plant growth; concentrations of carbon dioxide fall during the northern spring and summer as plants consume CO_2 gas, and rise during the northern autumn and winter as plants go dormant, die and decay [25].

CO_2 is a chemically most stable non-condensing greenhouse gas and transmits visible light but absorbs the infrared and near-infrared spectrum strongly. Hence, CO_2 acts as a critical "climate control knob" [39]. Carbon dioxide contributes to the most substantial rate among the other greenhouse gases; hence, it is the main reason for global warming. The global emission of carbon dioxide has reached 34 billion tons, with an increase of 3 % in 2011 [40]. Currently, on a global scale, carbon dioxide emissions are about 35,000 million metric tons per year, and the emissions will be projected to rise to 41,000 million metric tons per year in the 2020 if the urgent policies and international action plane do not come into achievement [16]. Besides to the fact of attributing CO_2 to global warming effect due to raising its concentration in the atmosphere, CO_2 will also lead to ocean acidification because of dissolutions in the oceanic aquatic system [41].
For that reason, controlling and monitoring of the atmospheric carbon dioxide levels and sources of emission became a hot topic for everyone to consider it.

As shown in Table (2), fuel consumption for back-up generators (domestic and commercial use) and production hours of apparent power has increased significantly year after year from 2013 to the end of 2015. In 2015 alone a total volume of 82870489 liters (equivalent to 70439916 kilograms) of diesel fuel was used to produce over 185946 kilowatts of apparent power in Sulaimani city by diesel generators in order to support government electricity; this volume was corresponding to 3334 hrs of production power in 2015 or more than 9 hrs and 8 minutes in the whole 24 hrs of electric generation for both commercial and domestic purposes. The main disquiet and risks of working those electric generators are the geographical location because they were installed among residents in urban areas of the districts [42]. Pollutants emissions from diesel generators operating in urban areas have a damaging effect on air quality and negative impacts on the life quality of resident's people living in the vicinity of the diesel generators. Thus, using the available data in Tables (2, 3, and 4), we used equation (1) as the approach to assessing the amount of CO_2 emission rate in kilograms.

Table 2: Fuel consumption and production hours for the back-up generators (domestic and commercial use) in the year 2013, 2014 and 2015 (Source; [42].

Years	Working hours	Total power capacity (kW)	Fuel consumption (Liters)	Fuel consumption (Kilograms)
		Commercial		
2013	949	7500	1657866	1409186
2014	1122	7743	202,640	1720094
2015	1399	7551	2460580	2091493
		Domestic		
2013	1160	166628	44927536	38188406
2014	1500	181104	63279765	53787800
2015	1935	178395	80409909	68348423
		Total		
2013	2109	174128	46585402	39597592
2014	2622	188847	65303405	55507894
2015	3334	185946	82870489	70439916

Table 3: Typical density and net heating value of different Fuels. (Source: [43].

Fuel	Density g/cm³ at 15°C	Net Heating Value			
		Btu/Ib	Btu/gal	kJ/kg	kJ/L
Regular Gasoline	0.735	18630	114200	43330	31830
Premium Gasoline	0.755	18440	116200	42890	32390
Jet Fuel	0.795	18420	122200	42850	34060

Diesel Fuel	0.850	18330	130000	42640	36240

With Density of HSD = 0.85 kg/L
1 Barrel = 159 liter = 135.15 kg
For instance fuel consumption in 2013 for commercial purpose is as follows: 1657866 Liter = 1409186 kg = 10426.8 barrel

Table 4. Default factors for calculation of CO_2 emissions (Source: [31].

Fossil Fuel (Petroleum)	Heat Content (HHV) (MMBtu /Barrel)	Carbon Content Coefficients kg C/MMBtu	Fraction Oxidized
Distillate Fuel Oil	5.825	19.95	1
Residual Fuel	6.287	21.49	1

For example, in 2013 and for a commercial purpose; the volume of fuel consumption was 1657866 liters, and this equivalent to 1409186 kilograms.

$$\mathbf{CO_2\ emission} = \sum_{k=1}^{n} \mathbf{Fuel_k} \times \mathbf{HC_k} \times \mathbf{C_k} \times \mathbf{FO_k} \times \frac{\mathbf{CO_2(m.v)}}{\mathbf{C(m.v)}} \qquad \textbf{[1]}$$

Where:
$Fuel_k$= Mass or volume of fuel type k combusted.
HC_k= Heat content of fuel type k ($\frac{\text{energy}}{\text{volume of fuel}}$).
Heat content of fuel per barrel = 5.8250 MMBtu /Barrel
But, heat content of fuel per kilogram = 5.8250 MMBtu / 135.15kg = 0.0431 MMBtu /kg.
Since 1 barrel = 135.15 kilogram (kg).
C_k= Carbon content of fuel type k ($\frac{\text{mass}}{\text{energy}}$).
Hence carbon content coefficient = 19.95 kg C/MMBtu .
FO_k= Fraction oxidized of fuel type k, thus fraction oxidized = 1.0.
$CO_2(m.v)$ = Molecular weight of CO_2 = 44 g/mol.
C (m.w) = Molecular weight of carbon =12 g/mol.
Thus, CO_2 emissions $= 1409186 \text{ kg x } 0.0431 \text{ MMBtu /kg x} 19.95 \text{ kgC/MMBtu x } 1{,}0 \text{ x } (44/12)$
CO_2 Emissions $= 4442832$ kg CO_2 $= 4442.83$ tons.
Similarly, equation (1) was applied to calculate the amount of CO_2 emission for both the commercial and domestic sources over the investigated years of 2013, 2014 and 2015; and the results are presented in Table (5).
Results in Table (5) revealed that the total amount (commercial + domestic) of CO_2 emission ranged between 124841900 to 222080501 kilograms for 2013 and 2015, respectively, with an average of 173975249 kg. From 2013 to 2014 CO_2 emissions has increased from 124841900 to 175003348 kg; this increment rate of CO_2 emissions between 2013 and 2014 made an equivalent percentage increase of 28.66%. Whereas from 2014 to 2015 total CO_2 emissions have increased from 175003348 to 222080501 kg, and this increment rate of CO_2 emissions between 2014 and 2015 made an equivalent percentage increase of 21.20% (Table 6). This means that the percentage increase in CO_2 emissions from 2013 to 2014 was higher than the percentage increase from 2014 to 2015. In general, the increment rate of total CO_2 emissions in years progress might be attributed to the additional and rapid population growth rate and then time increasing of electric power demand.
Table (5) also showed that the amount of CO_2 emission from the domestic source was 27.1; 31.3 and 32.68 times higher than the amount of CO_2 emission from a commercial source in 2013, 2014 and 2015 respectively. This can be attributed to the fact that domestic demand for electric energy consumption was much higher than electrical energy consumption or demand for commercial activities. Incidentally, the percent of CO_2 from domestic source out of the total amount of emitted CO_2 was 96.44, 96.90, and 97.03 % for 2013, 2014 and 2015 respectively.

According to [26], the estimated 2015 population of Sulaimani city was 656100 population. Hence, the mean amount of total emitted CO_2 from diesel engine generators in kilogram per capita per year in Sulaimani city due to the electric power production for both domestic and commercial purposes = 173975249 / 656100 = 265.17 kg per capita per year for electric power generation during the years of 2013, 2014 and 2015 (Table 5). Whereas [44] has pointed out that the total amount of emitted CO_2 in Iraq was 1.13 tons per capita per year in 1960, but it increased to 4.81 tons in 2014 for all sources and activities such as breathing, vehicles, industrial, agriculture, commercial sources, etc.

Our findings in 2015 for total annual CO_2 emissions from DEGs (222080501 kg which equivalent to 222080.5 tons) is much lower than the result of the authors [45] who reported that Nigeria produces about 29 million metric tons of CO_2 emission annually because Nigeria is Africa's largest importer of diesel generators. The authors also pointed out that pollution issues in Nigeria are largely ignored and the environment is not protected from harmful pollutants, so is the case in our Kurdistan region and Iraq as a whole.

Conversely, our findings were much higher than the results found by [11] in a quantifying emissions study for diesel generators used to power the global system of mobile telecommunication GSM base station sites in Nigeria, their results showed that the amount of emissions were as follow; 105.96 tons of carbon dioxide (CO_2), 0.26 tons of carbon monoxide (CO), 0.03 tons of hydrocarbons (HC), 2.33 tons of nitrogen oxides (NOx), 0.21 tons of sulfur dioxide (SO_2), and 0.02 tons of particulate matter (PM) . Moreover, the authors concluded that the use of diesel generators to power GSM base station sites had a significant environmental impact.

Table 5: Amount of annual emissions for the investigated gases of the selected sources during the three years of the study.

Years	Calculated amount of annual emissions kilogram per year (kg $year^{-1}$).				
	CO_2	**CO**	**HC**	**NO_x**	**SO_2**
	Amount of commercial source				
2013	4442832	6274	2176	115331	16441
2014	5423053	7581	2630	141452	20068
2015	6593986	9292	3223	171347	24401
	Amount of domestic source				
2013	120399068	63076	22566	4974810	445531
2014	169580295	86445	30953	7097357	627524
2015	215486515	110377	39516	8998282	797398
	Total amounts				
2013	124841900	69350	24742	5090141	461972
2014	175003348	94026	33583	7238809	647592
2015	222080501	119699	42739	9169,629	821799
mean of the total amounts	173975249	94358	33688	7166193	643787
Kg $capita^{-1}$ $year^{-1}$	265.17 kg	0.144	0.051	10.922	0.981

Undoubtedly, carbon monoxide (CO), hydrocarbon (HC), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) are the principal toxic gases found in diesel exhaust; and the toxic characteristics of those compounds have been examined for years, and they are relatively well understood. Therefore likewise CO_2 and based on the fuel data in Table (2), the equations in Annex (1) as well as to the information in Annex (2); the quantity of the air pollutants; CO, HC, NOx and SO_2 which have been emitted into the atmosphere from the diesel generators were calculated in Sulaimani city in kilogram during 2013, 2014 and 2015 for both commercial and domestic sources.

However, a sample application for commercial purpose in 2013 has been carried out for calculating the quantity of the air pollutants; CO, HC, NOx, and SO_2 as follows when medium and auxiliary engines were being undertaken in the calculation:

The total volume of fuel consumption in 2013 for commercial purpose = 1657866 liter.

Thus, mass of fuel consumption = 1657866 x 0.85 = 1409186 kg = 1409186000 g

Total productivity = 949 hour

With specific fuel consumption (SFC) and estimated (75 %), grams of emissions that an engine can produce per kWh = 198 g/kWh.

kilowatt hour Energy = 1409186000 g fuel / 198 g/kWh = 7117101 kWh

Power (P) in kilowatt = Energy / total hour productivity = 7117101 kWh/ 949 h=7499.6 kW

$CO = 15.32 \times 10^{-3} \times P^{0.68} \times N = 15.32 \times 10^{-3} \times (7499.6)^{0.68} \times 1$. (from Annex 1)

Kilogram CO emission per hour = 0.01532 x 431.54 = 6.611 kg CO per hour.

Thus, total CO emission in kilogram = 6.61 x 949 = 6274 kg CO.

$HC = 4.86 \times 10^{-3} \times P^{0.69} \times N$ (from Annex 1)

$HC = 4.86 \times 10^{-3} \times (7499.6)^{0.69} \times 1$

HC = 0.00486 x 471.8= 2.29 kg per hour HC.

Thus, total HC emission in kilogram Total HC emission = 2.29 x 949 = 2176 kg HC

$NOx = 4.25 \times 10^{-3} \times P^{1.15} \times N$ (from Annex 1)

$NOx = 4.25 \times 10^{-3} \times (7499.6)^{1.15} \times 1$

NOx = 0.00425 x 28595 = 121.5 kg per hour NOx.

Thus, total NOx emission in kilogram = 121.5 x 949 = 115331 kg NOx

$SO_2 = 2.31 \times 10^{-3} \times P \times N$ (from Annex 1)

$SO_2 = 2.31 \times 10^{-3} \times 7499.6 \times 1$= 17.32 kg per hour SO_2.

Thus, total SO_2 emission in kilogram = 17.32 x 949 = 16441 kg SO_2

Similarly, the amounts of pollutants emission of CO, HC, NOx, SO_2 from diesel generator were calculated in kilogram for the other cases of commercial and domestic sources during 2013, 2014 and 2015.

Table 6: Ratios and percent of some related parameters to the domestic and commercial amount for the investigate gases during the years of study.

Years	D/C ratio: Domestic to commercial amount of the emitted gases ratios				
	CO_2	CO	HC	NO_x	SO_2
2013	27.1	10.05	10.37	43.14	27.10
2014	31.3	11.40	11.77	50.18	31.26
2015	32.68	11.88	12.26	52.51	32.68
	Percent of the domestic emission out of the total amount				
2013	96.44	90.95	91.21	97.73	96.44
2014	96.90	91.94	92.17	98.04	96.90
2015	97.03	92.21	92.46	98.13	97.03
	% Percent of increased total gases emission with years progress				
From 2013 to 2014	28.66	26.24	26.33	29.68	28.66
From 2014 to 2015	21.20	21.45	21.42	21.06	21.20

Carbon monoxide (CO) emission:

CO is a non-irritating, odorless, colorless, tasteless and criteria toxic air pollutants; it results mainly from the incomplete combustion of carbon-containing fuels (carbonaceous fuels) while the oxidation process does not take place completely [46].

The natural carbon monoxide level in atmospheric air composition is 0.1 ppmv or ppm on volume bases [47]. The author [25] has detected a range of 0.1 to 32.8 ppmv CO in ambient air of 17 selected locations in Sulaimani city during 31.9.2009 to 13.7.2010. The current National Ambient Air Quality Standards (NAAQS) guideline values for CO by [48] are as follow; for averaging time 1-hour the permissible level is

35 ppm (40 mg m^{-3}), while for averaging time 8-hour the concentration of CO is 9 ppm (10 mg m^{-3}), in both cases the maximum should not be exceeded more than once in a year.

As it is revealed in Table (5) the amount of total CO emission in the current study varied between 69350 to 119699 kg for 2013 and 2015, respectively, with an average of 94358 kg. As shown in Table (6), CO from domestic source were 10.05; 11.40 and 11.88 times higher than the amount of CO emission from commercial source in 2013, 2014 and 2015 respectively. This might be due the same reason mentioned by carbon dioxide because CO also showed similar trend to CO_2 in amount of emission by commercial and domestic source except that CO had the lowest ratios for domestic/ commercial ratios as compared to the ratios of CO_2, NOx, and SO_2 particularly, and the ratios for CO were 10.05; 11.40 and 11.88 for 2013, 2014 and 2015 respectively.

By the way, the percent of CO from the domestic source out of the total amount of emitted CO was 90.95, 91.94, and 92.21 % for 2013, 2014 and 2015 respectively. Additionally, the percent increase of total CO emissions from 2013 to 2014 was 26.24%, while, the increment rate of total CO emissions from 2014 to 2015 denoted a percentage increase of 21.45% (Table 6). This exposes that the percent increase of total CO emissions from 2013 to 2014 was higher than the percent increase from 2014 to 2015.

Generally, diesel engines (compression-ignition) are lean combustion engines and have a consistently high air-fuel ratio (k factor is more than1.0). So, the formation of CO is minimal in diesel engines as compared to a gasoline engine [16]. Also, [49] have indicated that diesel engines have an outstanding exhaust emission behavior, and its exhaust contains the least amounts of CO and HC.

Regarding the impact of CO on human health, CO causes reducing oxygen (O_2) transport by hemoglobin when breathed in high concentrations because it has a high affinity (more than 200 times greater than does O_2) to bind with hemoglobin to form carboxyhemoglobin (COHb). Moreover, carboxyhemoglobin concentrations in blood are cumulative over time [46]. As pointed out by [50], it has been reported in many countries that CO harming is responsible for the death of more than 50% of the fatal poisonings. The severity of CO poisoning is dependent on concentration, length of exposure, and the general underlying health status of the exposed individual.

Hydrocarbons (HC)

Hydrocarbons are organic compounds consisting entirely of hydrogen and carbon, and they are ordinarily identified in terms of equivalent methane CH_4 content [51]. Diesel engines ordinarily emit low levels of HC, and the emissions happen chiefly at light loads [16].

Table (5) illustrates the amount of variation in HC emission according to the investigated sources (commercial and domestic) as well as the years of study (2013, 2014 and 2015). It was observed that the total amount of HC from both commercial and domestic source was in the range of 24742 to 42739 kg for 2013 and 2015 respectively. HC had the smallest average amount (33688 kg) of emission as compared to the averages of the other studied gases of CO_2, NOx, SO_2 and CO, because diesel engines typically emit relatively low amount of HC and CO and the emissions happen chiefly at light loads [16], while diesel engines represent a significant emitter of particulate matters (PM) and NOx [52].

From Table (6) we could conclude that HC also showed a similar trend to CO because close-ratio values (10.37, 11.77 and 12.26) were obtained for domestic/commercial ratios through the studied years and domestic source represented the main source of the total HC emission. The percent of domestic emission out of the total amount were 91.21; 92.17 and 92.46% for 2013, 2014 and 2015 respectively. Moreover, the percentage increase of total HC emissions between 2013 and 2014 was 26.33%, while, the increment rate of total HC emissions represented a percentage of 21.42% from 2014 to 2015 (Table: 6). This interprets that the percent of increment rate of total HC emissions from 2013 to 2014 was higher than the percentage of increment rate from 2014 to 2015.

Hydrocarbons have detrimental effects on human health and might cause respiratory tract irritation and cancer. Furthermore, hydrocarbon contamination in the environment is a very serious problem because it plays a significant role in the formation of smog and ground-level ozone (tropospheric ozone), [25 and 53].

Nitrogen oxides: (NOx):

The most atmospheric constituents of nitrogen oxides are; nitric oxide (NO); nitrous oxide (N_2O); and nitrogen dioxide (NO_2), [25 and 54]. Nitrogen dioxide has been addressed as one of the standards criteria for air quality elements by many local and international standard guidelines of air quality such as WHO, NAAQS criteria air pollutants by US EPA and European Union (EU) air quality guidelines. The amount of emitted NOx from the diesel engine is depending on the maximum temperature of the cylinder, oxygen level, and residence time [16].

As presented in Table (5), NOx matched the greatest quantity of air pollutants emission among the four other investigated toxic trace gases and its total emitted amount varied between 5091141 and 9169629 kg for 2013 and 2015 respectively with an average of 7166193 kg, and this is due to the fact that diesel engines represent a substantial emitter and dominant exhaust source of NOx as well as particulate matters (PM), [52 and 55]. Moreover, diesel engines produce about 85% of all the NOx emissions and mainly in the form of NO [56]. NOx also exhibited an increasing trend within the ongoing years, and the percentage increase of total NO_X emissions between 2013 and 2014 was equivalent to a percentage increase of 29.68%, while, the percentage increase of total NOx emissions from 2014 to 2015 was 21.06% (Table: 6). This explains that the percentage increase in total NOx emissions from 2013 to 2014 was higher than the percentage increase from 2014 to 2015.

NOx emission from the domestic source was 43.14; 50.18 and 52.51 times higher than the total amount of NOx emission from a commercial source in 2013, 2014 and 2015 respectively; this might be due to increasing population growth rate and increasing of electric power demand at Sulaimani city. NOx had the highest ratios for domestic/ commercial, and they were 43.14; 50.18 and 52.51 for 2013, 2014 and 2015 respectively. The percent of domestic NOx emission out of the total amount were 97.73; 98.04 and 98.13% for 2013, 2014 and 2015 respectively.

NOx emissions from diesel engines can cause health and environmental problems. For example, smog and ozone formation, acidification of rainwater, and nutrient enrichment as well as haze-forming pollutants which causes visual pollution and became a substantial phenomenon in most cities in the world due to the increasing level of NOx in the atmosphere through photochemical reactions [25, 57 and 58].

Numerous studies have found that NOx is harmful to human health and there are many adverse health effects associated with it [59]; as an example [60] have found in a medium-sized Brazilian city that exposure to nitrogen oxides pollutants were significantly associated with mortality owing to respiratory and lung diseases because NO and NO_2 are considered as toxic pollutants; while NO_2 has a level of toxicity that is five times greater than that of NO. Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infection (such as influenza). Based on individualized exposure assessments during a study by [61] in a large cohort of California, it has been found that NO_2, O_3, and fine PM (less than 2.5 mm in diameter, PM2.5) have positive associations with mortality risk of adults. Their study also stated that traffic pollution was related to premature death.

Sulfur dioxide (SO_2) Emission

Sulfur dioxide belongs to the group of sulfur oxide (SOx) gases, and high concentrations of SO_2 affects human health, ecosystems, agriculture as well as global and regional climate. SO_2 is emitted by burning fossil fuels, coal, oil, and diesel, or other materials that contain sulfur [62 and 63]. Sources of SO_2 emission include metals processing, smelting facilities, and internal-combustion diesel engines. The most significant sources of SO_2 emissions are from fossil fuel combustion at power plants, which represent 73% of the total SO_2 emissions, while other industrial facilities emit 20% SO_2. Smaller sources of SO_2 emissions include industrial processes [64]. Moreover, sulfur dioxide is also a natural byproduct of volcanic activity [65 and 66].

From Table (5) we also can see the total amount of SO_2 emission and be between 461972 to 821799 kg for 2013 and 2015 respectively with an average of 643799 kg, and SO_2 took the second rank after NOx in higher degree for the amount of emission. The domestic/ commercial ratios of SO_2 were 27.10; 31.26 and

32.68 for 2013, 2014 and 2015 respectively. However, the percent of domestic SO_2 emission out of the total amount were 96.44; 96.90 and 97.03% for 2013, 2014, and 2015 respectively (Table 6). This indicated that the majority of diesel engine generators (DEGs) in Sulaimani city were used to cover the domestic demand for electricity power rather than the commercial purpose. Likewise, the other investigated air pollutants, the percent of SO_2 has increased with the ongoing years from 2013 to 2015, and the increment rate was as follow; from 2013 to 2014 the percentage increase of total SO_2 emissions was 28.66%, while from 2014 to 2015 the percentage increase of total SO_2 emissions was 21.20%. Moreover, a similar trend to the other air pollutants was occurred by the percentage increase of SO_2 in the ongoing years of this study.

Once SO_2 released into the air, it plays like nitrogen dioxide as a precursor agent to create secondary pollutants such as; aerosols, particulate matter, acid rain and secondary sulfates like sulfuric acid, which is a stronger irritant than SO_2 for the elderly and persons with cardiovascular and respiratory illnesses [67].

The researcher [25] has detected a range of 27.1 to 270.6 ppbv SO_2 in ambient air at Sulaimani city during 31.9.2009 to 13.7.2010 in 17 studied locations. Whereas, according to [68], the annual averages environmental concentrations of SO_2 in Canada ranged from below the detection limit to 8.6 ppb. But, the 24-h averages of urban residential sites had the concentration from below the detection limit to 56 ppb, and for the 1-h averages fluctuated from below the detection limit to 314 ppb knowing that the majority of National Air Pollution Surveillance (NAPS) monitors did not detect SO_2 regularly.

Currently, China becomes the highest emitter of SO_2 in the world due to its dependence on coal for energy generation [72].

In a quantifying emissions study by [11] relating to diesel generators used to power the global system of mobile telecommunication GSM base station sites, results showed that the amount of the studied gases emissions were much lower than our findings and their outcomes were as follow; 105.96 tons of carbon dioxide (CO_2), 0.02 tons of particulate matter (PM), 0.26 tons of carbon monoxide (CO), 0.03 tons of unburned hydrocarbons (UHC), 0.21 tons of sulfur dioxide (SO_2), and 2.33 tons of nitrogen oxides (NOx).

Finally, the averages of total emission quantity (domestic + commercial) of the studied gases during 2013 to 2014 showed the following decreasing trend; 173975249, CO_2 > 7166193, NOx > 643787, SO_2 > 94358, CO >33688, HC kilogram per year (kg year $^{-1}$). However, the averages of the total amount of the studied gases per capita per year due to diesel-electric generators for domestic and commercial purposes were; 265.17 CO_2; 10.92 NOx; 0.98 SO_2; 0.14 CO and 0.05 HC kg per capita per year.

Conclusion and Recommendations

The study concluded that the fuel consumption and the amount of investigated gases were increased in the ongoing years from 2013 to 2015 and this led to widespread more diesel generators throughout the city; diesel generator numbers and diesel fuel consumption will probably grow for the anticipatable future.

From the results that were obtained in this study, we also concluded that using of diesel fuels generators will lead to emitting a higher amount of the toxic gases of NOx then SO_2 rather than CO and HC as well as greenhouse gas of CO_2. Moreover, domestic sources were the main cause of emitting the investigated gases because the demand for electric power was many times greater than for commercial purposes.

Although diesel engines offer abundant advantages for the new community, they are also significant sources of hazardous air pollutants that affect the environment and public health on a large scale. Therefore, using energetic approach studies are useful to quantify the amount of emissions from diesel generators power and other internal combustions sources to evaluate the environmental impact of internal combustions emissions. We, therefore, recommend those in a position of authority to place a mandatory price on the emissions of greenhouse gases and other air pollutants by the internal combustion engines to reduce diesel emission and its consequent environmental and health impact.

Renewable energy sources such as; wind, hydro and solar radiation (solar resource) mainly are highly recommended for providing electrical power in Sulaimani city rather than the diesel engine generators (DEGs) sources, because sufficient amount of solar resource is available for a long time over the seasons in the city except winter.

Highly effective emissions and control systems such as diesel oxidation catalyst (DOC), diesel particulate filter (PDF), selective catalytic reduction (SCR), hybrid diesel power as well as exhaust gas recirculation (EGR) and diesel blended base fuel are recommended to use comprehensively with DEGs. At the same time, the legal legislation and restrictions on exhaust-gas emissions should be applied or entered into force soon.

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