

AMERICAN UNIVERSITY OF BEIRUT

ASSESSING THE ENVIRONMENTAL IMPACT OF THE
ENERGY CRISIS ON GREATER BEIRUT AREA AND
LEBANON IN GENERAL

by
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To my father, though you are no longer with me in the physical sense, your presence continues to guide and inspire me every day. I will always work to make you proud.

ABSTRACT

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The deterioration of air quality in Lebanon is a growing environmental concern as it negatively impacts the public health, and the environment in general. According to the World Health Organization (WHO) 4.2 million premature deaths were caused by the degradation of ambient air quality worldwide in 2019. In Lebanon, the estimated average number of deaths is 4 per 10,000 people because of air pollution in 2018 and this is one of the highest rates in the MENA region alongside Egypt. Lebanon heavily depends on fossil fuels, primarily within unregulated power generation units and an unsustainable transport sector, leading to the emission of Sulfur dioxide (SO₂), Particulate Matter (PM_{2.5} and PM₁₀), Carbon dioxide (CO₂), and Nitrogen Oxide (NO_x). The energy sector in Lebanon has undergone a dramatic transformation after the economic crisis of 2019. Prior to this crisis, Beirut benefited from 22 hours of uninterrupted supply of electricity from Electricity Du Liban (EDL); however, after the crisis in 2019, these hours were cut into almost 2 hours increasing the reliance on the private diesel generators. In this work, the Gaussian model for area source was used to estimate the emissions of SO₂ and PM from private diesel generators in Greater Beirut Area (GBA). The particulate matter concentration in Beirut is exceeding established international air quality standards; however, even with the increase in the sulfur dioxide concentration, it remains in the limit outlined by WHO. Moreover, the point source Gaussian model depends on logarithmic graphs to determine the dispersion coefficients. A software program was developed depending on an iterative process to determine the emission concentration in a more accurate and precise way. This tool was incorporated in a user-friendly platform to optimize stack height, find the maximum ground concentration, and the concentration from area source. It is aimed to support in air quality assessment for Lebanon and other developing countries that lacks advanced monitoring techniques.

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CHAPTER I

INTRODUCTION

A. Motivation and Problem Definition

The deterioration of air quality in Lebanon, like in many nations worldwide, is a growing environmental concern as it negatively impacts the public health, and the environment in general. According to the World Health Organization (WHO) 4.2 million premature deaths were caused by the deterioration of ambient air pollution worldwide in 2019 [1]. In Lebanon, the estimated average number of deaths is 4 per 10,000 people because of air pollution due to fossil fuels in 2018 and this is one of the highest rates in the MENA region along with Egypt [2]. In the WHO 2016 report, the organization presented stricter guidelines and standards for what hazardous emissions cause air pollution, with the aim to save millions of lives from air pollution [3]. Due to the impact of air pollution on the climate and the temperature increase of Earth, different global organizations, under the umbrella of the United Nations, have worked on developing and implementing the sustainable development goals (SDGs) for better health and environment including (SDG) 13 related to climate action. The new guidelines for air quality will not only protect health but also will support in tackling climate change.

The pollutants found in the atmosphere are of two types: primary that are emitted from various emissions sources directly from the source, and secondary that result from further reactions between primary pollutants. For example, oxides of nitrogen (NO_x) are a primary source emitted from combustion processes as well as carbon monoxide (CO); however, when both NO_x and CO react, they create Ozone (O₃) which is marked as a

secondary pollutant [4], see Table 1 where samples of primary and secondary pollutants are listed.

Table 1: Categories of pollutants

Primary	Secondary
Gaseous Pollutants	
Nitrogen Oxides NO _x , Sulfur Oxides SO _x , Carbon Oxides CO _x , Hydrocarbons (HC), Volatile Organic Compounds (VOC), CFCs and HCFCs	Nitrogen Dioxide (NO ₂), Ground level Ozone (O ₃)
Aerosol, Particles or Particulate Matter (PM)	
PM ₁₀ (with an aerodynamic diameter “ad” of 10 μm or less)	PM _{2.5} (ad ≤ 2.5 μm), PM ₁ (ad ≤ 1 μm), PM _{0.1} (ad ≤ 0.1 μm)

Human activities release more carbon dioxide emissions than the natural processes can remove. Thus, the global average carbon dioxide (CO₂) set a very high record of around 414 parts per million (ppm) in 2021 which is an increase of around 50% from 1960 level of 280 ppm [5]. Figure 1 shows the increase in the atmospheric carbon dioxide from 1960 till 2021.

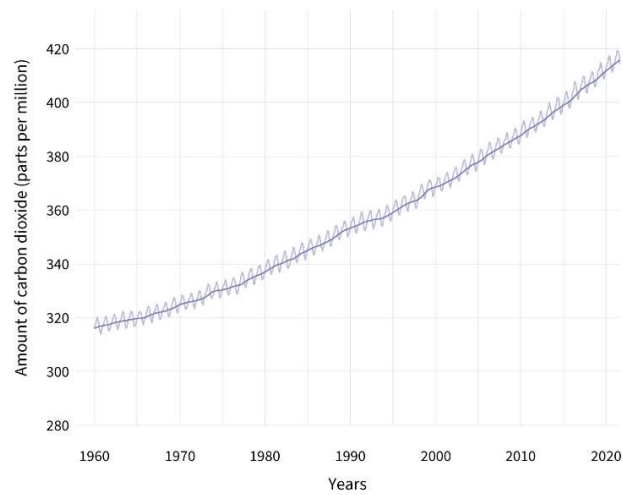


Figure 1: Atmospheric Carbon Dioxide from 1960-2021 [5]

According to the World Bank data, CO₂ emissions from Lebanon have increased drastically from 5.6 million metric tons in the 1990 to 27.401 million metric tons in 2018. This quantity of CO₂ decreased in 2020 to reach 21.4 million metric tons. This decline can be explained by the electricity production outage, the COVID 19 pandemic and the shift to remote work through years 2019 and 2020. The graph of Figure 2 shows the amount of CO₂ over the years in Lebanon [6].

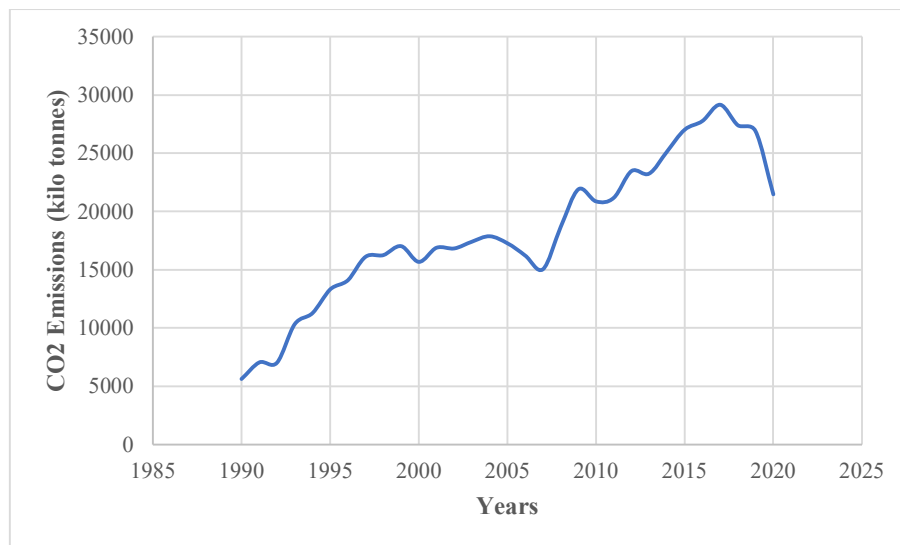


Figure 2: CO2 emissions in Lebanon [6]

More than 80% of CO₂ emissions in Lebanon comes from the energy sector which includes electricity production, heat production, and transportation. Figure 3 shows the percentage of CO₂ emission by sector in 2012 where electricity (57%) and transportation (25%) sectors hold the highest percentages of emissions [7].

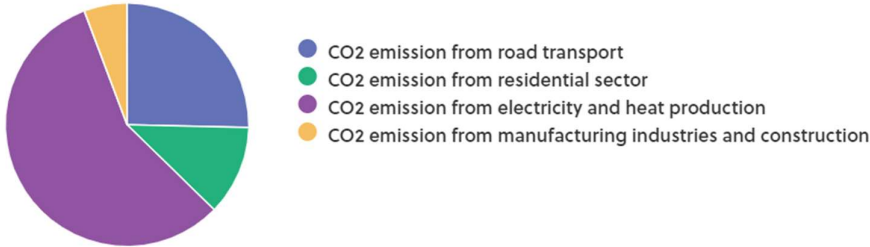


Figure 3: CO₂ emissions by sector in Lebanon 2012 [7]

Moreover, in 2019 the Greenhouse gas emissions in Lebanon were mainly produced by the electricity and heat sectors; producing around 15 million tons of CO₂ equivalent, followed by the transport and the industry sectors [8].

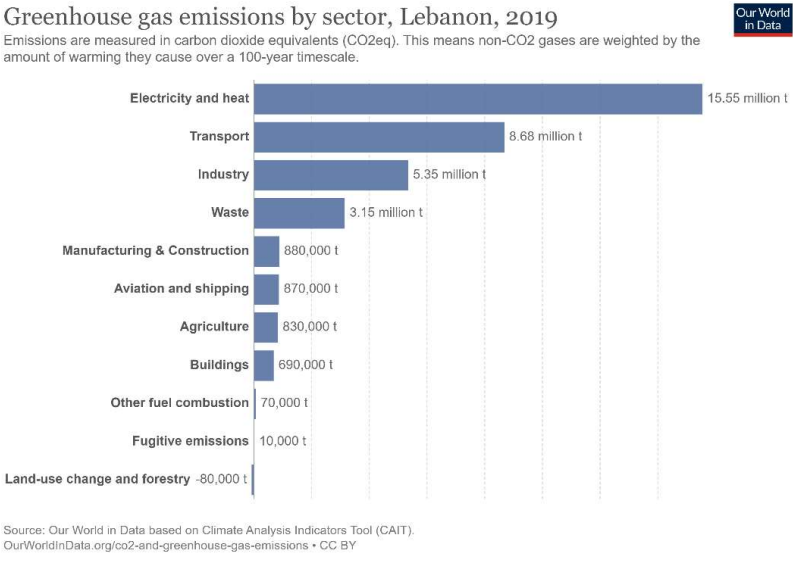


Figure 4: Greenhouse gas emissions in Lebanon by sector [8]

B. Energy Resources in Lebanon

Lebanon depends mainly on fossil fuels of different forms to produce its energy. According to the policy paper submitted by the Ministry of Energy and Water, Lebanon has effective supply capacity of 2,403 MW in 2018 of electric power coming from the different generation units in Lebanon [9]. The installed capacity is 3,259 MW, but the reduction in the capacity is due to the aging power plants and the losses in the grid transmission system. Moreover, the significant power supply that comes from clean and renewable energy accounts to 88 MW capacity of the hydro power plants. Table 2 shows the effective capacity of each generation unit [10]. In addition, the Lebanese Center of Energy Conservation (LCEC) assumes an emission factor of 650 grams of CO₂ per kWh produced. However, since the power utility of Lebanon, Electricity du Liban (EDL), doesn't support 24 hours continuous power in Lebanon in 2018, private generation units of diesel generators are deployed over all the country. Private generators accounted to supply 23% of demand in 2010, and the household connection to private diesel generators has increased to 65% all over Lebanon according to UNHCR findings in 2021 [11, 12].

Table 2: Effective capacity of all generation units in Lebanon [10]

Name of the Power Plant	Installed Capacity (MW)	Effective Capacity 2018 (MW)
Existing EDL		
Zouk 1 Thermal Power Plant	607	440
Jieh 1 Thermal Power Plant	343	180
Zouk 2 ICE Power Plant	198	157
Jieh 2 ICE Power Plant	78	63
Zahrani I CCPP	469	420
Deir Ammar I CCPP	464	430
Baalbeck Open Cycle GT	64	57
Tyr Open Cycle GT	72	56
Richmaya-Safa Hydro	13	3
Naameh (Landfill Gas)	7	7
Rented Barges		
Power Barge Zouk	187	195
Power Barge Jiyeh	187	195
Existing IPP's		
Litani Hydro	199	47
Nahr Ibrahim Hydro	32	17
Bared Hydro	17	6
Kadisha Hydro	21	15
Hrayche Thermal Power Plant	35	46
Power Wheeling		
Imports from Syria	276	69
Total	3269	2357

Lebanon in 2020 had a maximum electricity-generation capacity of 2000 MW, far less than the summer peak demand of 3400 MW [13].

Combustion of different fuel types has led to emission rates presented in table 3 [14]. So, in order to precisely identify carbon emissions from electricity produced, we will depend on the fuel type emission rates.

Table 3: Emission rates of different fuel types [14]

Fuel Type	CO2 Emissions (g/kWh)
Lignite	1140.1
Coal	915.8
Oil	755.6
Natural Gas	420.1

The road transport in Lebanon mainly consists of road-motorized vehicles only since there is no proper infrastructure for trains, and even for bicycles and scooters. The vehicles are mainly passenger cars, light-duty vehicles, heavy-duty vehicles, and motorcycles. The total number of vehicles in 2012 was 1.58 million registered vehicles which increased to 1.75 million registered cards in 2015 according to the Ministry of Interior and Municipalities. The transportation sector as shown above is responsible for more than 25% of carbon emissions in Lebanon. In 2011, the emissions from road transport in Lebanon were 51.79 Gg NO_x, 358.37 Gg CO, 72.34 Gg Non-Methane Volatile Organic Compounds (NMVOCs) and 5.34 Gg SO₂. The figure below shows the increase of greenhouse gases (GHG) emissions from road transport in Lebanon from 1994 till 2011 [15].

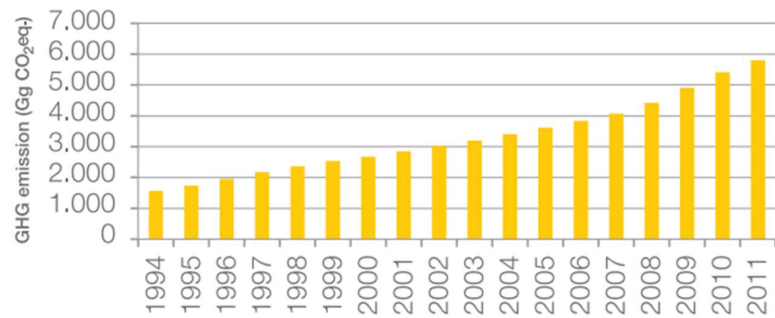


Figure 5: GHG emission from 1994 to 2011 from road transport [11]

The high CO₂ emission from both electric power generation and transport sectors is alarming, especially in economically disabled country like Lebanon. With the fixed tariff rate and the economic crisis after 2019 in Lebanon and astronomical increase in fuels prices due to the currency deterioration, EDL is not able to support the demand, and in fact, in 2022, the EDL was almost shut down with an average of one hour of electricity provided on daily basis. Hence, private diesel generators are taking over in production of electricity especially in Greater Beirut Area (GBA) where the use of solar photovoltaic systems is very restricted due to the limited area available of rooftops of buildings. This has been accomplished by much heavier reliance on diesel for private power generation. The diesel engines are scattered almost in every street of the main cities, with very low stacks to exit the emissions.

The main objective of this thesis is to assess how the economic and energy crisis in Lebanon, affected reliance on various fuels for electricity generation and hence the emissions concentration in GBA. To carry out this task, use will be made of air quality concentration models such as Gaussian Dispersion model for emission prediction. Also, the noise levels due to the operation of standby generators is measures and assessed. In what follows is a preview of existing dispersion models, and the main features of the Gaussian models.

CHAPTER II

LITERATURE REVIEW

A. Air Quality of Lebanon

Lebanon suffers from low air quality due to the dependence on fossil fuels. Several work has been done to assess the air quality of Lebanon; however, the scarcity of data about power generation units, the transport sector and the industries in Lebanon was limiting a precise and accurate emissions concentrations calculation. Baayoun et al. presented the air pollution emission inventory for the two major emission sources in Lebanon. Diesel generators were estimated to use 1.6 million tons of fuel in 2016 if the private diesel generators where on for 3 hours per day and emitted about 2 Gg of particulate matter. Moreover, the light duty vehicles, one of the main transport methods in Lebanon, emitted around 0.75 Gg of PM and 3.27 Gg of SO₂ in 2015. Figure 6 shows the emissions trend from 2009 till 2016 from diesel generators. It shows the increase of SO₂ emissions from 1.4 Gg in 2009 to 3.3 Gg in 2016. In addition, figure 7 shows the annual emissions from light duty vehicles depending on gasoline and diesel [16].

Annual Emissions of CO₂, NO_x, CO, SO₂ and PM_{2.5} in Gg from diesel generators.

	2009	2010	2011	2012	2013	2014	2016	7-year average
CO ₂	2136.1	2071.5	3013.6	4837.5	4322.6	3273.2	5032.0	3526.6
NO _x	27.2	26.3	38.3	61.5	55.0	41.6	64.0	44.8
CO	3.75	3.63	5.29	8.49	7.58	5.74	8.83	6.19
SO ₂	1.4	1.3	2.0	3.1	2.8	2.1	3.3	2.3
PM _{2.5}	0.87	0.84	1.2	2.0	1.8	1.3	2.0	1.4

Figure 6: Annual emissions from diesel generators [16]

Annual emissions of CO₂, CO, NO_x, SO₂, and PM_{2.5} in Gg from light duty vehicles.

		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CO ₂	Gasoline	3560	3400	3630	4050	4750	4760	4800	4630	4570	4890	5780
	Diesel	743	645	532	747	1120	968	1060	1160	1280	1320	1400
	Total	4303	4045	4162	4797	5870	5728	5860	5790	5850	6210	7180
CO	Gasoline	38	35	37	40	46	45	44	42	41	43	50
	Diesel	5.9	5.0	3.9	5.0	6.8	5.6	6.0	6.4	6.9	7.1	7.4
	Total	43.9	40.0	40.9	45.0	52.8	50.6	50.0	48.4	47.9	50.1	57.4
NO _x	Gasoline	1.8	1.7	1.8	2.0	2.3	2.3	2.3	2.2	2.1	2.2	2.6
	Diesel	1.2	1.0	0.80	1.2	1.8	1.5	1.6	1.7	1.9	1.9	2.0
	Total	3.0	2.7	2.6	3.2	4.1	3.8	3.9	3.9	4.0	4.1	4.6
SO ₂	Gasoline	1.27	1.20	1.27	1.40	1.62	1.60	1.60	1.53	1.51	1.60	1.88
	Diesel	0.675	0.660	0.540	0.750	1.11	0.960	1.05	1.15	1.27	1.31	1.39
	Total	1.95	1.86	1.81	2.15	2.73	2.56	2.65	2.68	2.78	2.91	3.27
PM _{2.5}	Gasoline	0.37	0.35	0.36	0.38	0.42	0.40	0.39	0.37	0.35	0.36	0.42
	Diesel	0.29	0.24	0.19	0.25	0.34	0.28	0.29	0.30	0.32	0.32	0.33
	Total	0.66	0.59	0.55	0.63	0.76	0.68	0.68	0.67	0.67	0.68	0.75

Figure 7: Annual emissions from light duty vehicles [16]

Furthermore, the air quality report issued by the Ministry of Energy and Water (MEW) with the support of UNHCR, UNICEF and UNDP discussed the emissions sources in Lebanon affecting the quality of ambient air. They compared the pollutants concentration to WHO standards. The average observed annual concentration of SO₂ is 10.5 µg/m³ which is relatively low compared to WHO daily SO₂ standard of 20 µg/m³ and lower than the national annual standard of 80 µg/m³. Moreover, the PM mass concentrations measured between 2003 and 2010 at various sites in Beirut varied between 19.7 and 521.2 µg/ m³ for PM₁₀ and 8.4 and 72.2 µg/ m³ for PM_{2.5} which exceeded the WHO standards of 50 µg/ m³ 24-hour standard for PM₁₀ and 25 µg/ m³ for 24-hour standard for PM_{2.5}. Mitigation solutions were suggested to decrease PM in greater Beirut area by supplying 24/7 electricity to reduce PM_{2.5} by 30% and a newer vehicle fleet would decrease the emissions from vehicles by 50%. This suggestion will reduce attributable cases of death from air pollution from 11,233 to 2,604 cases per year in GBA alone and would represent economic savings of around 1.2 billion USD [17].

El Fadel et al. studied the air quality of GBA due to traffic congestions. GBA of 1.5 million passenger trips per day occurring with a weak public transportation system, and without regulation enforcement has major impact on air quality. Measurements were

done to define existing pollutants exposure levels and the concentration of CO, NO₂ and PM were shown to exceed the standards [18]. Al Shami et al. presented the different national inventories responsible for pollutants emissions in Lebanon and compared the results to previous studies and the Emissions Database for Global Atmospheric Research (EDGAR). The road transport especially the light duty vehicles and diesel generators are the major contributors to the total emissions of pollutants in Lebanon [19]. In addition, a study in 2008 by Afif et al. was done to measure SO₂ in Beirut over 18 months. The values observed were under the WHO limits indicating that Beirut does not suffer from pollution due to SO₂. Also, one should note that 50% of SO₂ concentrations within Beirut is due to the transport sector; this could support in working towards SO₂ emission reduction [20].

B. Air Quality Dispersion Models

With the increase in air pollution and the emissions in the atmosphere, it is very important to identify the sources of emissions, and the environment of dispersion, to develop computer-based models to predict emissions concentration based on mass conservation flows and to assess the level of concentration of various pollutants to be able to put mitigation measures to reduce level of emissions. Air pollution dispersion models are a great tool to support in assessing environmental projects and help in visualizing emissions concentrations for effective mitigation planning. Air pollution modelling is a set of mathematical equation which simulates the natural atmospheric conditions. According to Aggarwal and Haritash, the models are designed to produce outputs that describe the number of primary pollutants in the atmosphere and sometimes the secondary pollutants knowing the meteorological data and source information like emission rates and stack heights [21]. The models show how air pollutants disperse in the

ambient atmosphere. They are used to predict the downwind concentration of emissions from point sources such as generation power plants, or line sources such as vehicular traffic [21].

Air quality models depend on the following inputs:

- 1- Emission Parameters: type of source, emission rate, location, height, temperature
- 2- Topography: Rural or Urban city, terrain elevation, obstruction, and receiver details.
- 3- Meteorological Condition: wind speed and direction, atmospheric temperature and stability and other environmental information [21].

Karroum et al. discussed different methods of air pollution estimation techniques based on the availability of datasets and computing resources [22]. Land-use regression (LUR) is a technique that develops stochastic models to predict pollutant concentration by utilizing the predictor variables as the surrounding, traffic, physical environment, and population. This technique can be used to explain air pollution conditions depending on seasonal variations of human activities. Moreover, the authors showed that machine learning also is a very great tool to use in predicting emissions concentrations depending in previous data recorded over time with different factors may affect this concentration. Support vector machine (SVM) and artificial neural network (ANN) are approaches used to predict the particulate matter ($PM_{2.5}$) in the atmosphere [22]. Moreover, they showed that hybrid models depending on algorithms of air quality prediction models with machine learning are more powerful to predict accurate results reducing the variance and enhancing the reliability of the model [22].

C. Types of Air Dispersion Models

Various air dispersion models have been or are being used under different scenarios.

1. Gaussian models.
2. Statistical models.
3. Numerical models.

The Gaussian models are used for predicting the dispersion of a continuous air pollution plumes originating from the ground level or elevated sources. The statistical model is to form a relationship between different variables as inputs and correlate it to concentration of emission as output through mathematical equations [14]. It describes how can one variable or more affect the concentration of emissions. Numerical models are expressed in mathematical formulas that are solved on computers and it can show time dependence in generating results. Gaussian models are the mostly adopted models being used in different applications [14].

A Gaussian plume model was analyzed and implemented by Brusca et al. through a tunnel experiment to study the dispersion of PM_{10} in small scale system. The model showed an error less than 7% in all configurations of the experiment. The main conditions of the experiment were maintaining constant wind speed, wind direction, and temperature [15].

Johansson et al. developed an operational urban air quality modelling system by combining two models of Gaussian puff and Gaussian plume modelling. It showed reasonable accuracy in urban areas where detailed emissions inventories would not be available [16].

D. The Gaussian Model

This model is one of the important models to predict the emissions in air. Throughout this section the mathematical background of the model is discussed. Based on the assumption of the flux of matter per unit area and per unit time, Fick's first law for molecular diffusion is used as follows:

$$J = -K \frac{\partial C}{\partial x}$$

where:

J = Mass flux of the pollutant ($\text{Kg.m}^{-2} \cdot \text{s}^{-1}$).

∂C = Concentration variation of the pollutant (kg/m^3).

∂x = Distance variation (m).

K = diffusion coefficient (m^2/s).

The material balance assumes the following:

$$\frac{\partial C}{\partial t} = K \frac{\partial^2 C}{\partial x^2}$$

The solution of this one-dimensional equation is:

$$C(x, t) = \frac{M_0}{2(\pi t K)^{1/2}} e^{-\left(\frac{1}{4t}\right)\left(\frac{x^2}{K}\right)}$$

where M_0 is the mass deposited at $t = 0$.

The following formula is used, where σ_x is the turbulent dispersion coefficient (L).

$$\sigma_x = (2Kt)^{1/2}$$

It follows that:

$$C(x) = \frac{M_0}{(2\pi)^{1/2} \sigma_x} e^{-\left(\frac{x^2}{2\sigma_x^2}\right)}$$

In this one-dimensional equation, the concentration C is in units of mass per unit length (M/L).

The mass Mo can be determined by the relationship:

$$M_0 = Q/\mu$$

where:

Q = emission rate of the gaseous pollutant (Kg/s).

μ = average wind speed (m/s).

➤ **The form of the Gaussian point source model in 3D form is:**

$$C(x, y, z) = \frac{Q}{2\pi\mu\sigma_y\sigma_z} \cdot \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \cdot \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \right]$$

Where, in reference to Figure 8:

C is the pollutant concentration at a point of coordinates (x,y,z), [kg/m³],

Q is the rate of emission of the point source, [kg/s],

H is the effective plume height, [m],

μ is the average wind speed at effective height H, [m/s],

y is the horizontal distance from the plume centreline, [m],

z is the vertical distance, or height, from the ground level, [m],

σ_y is the horizontal dispersion coefficient in the y- direction, [m],

σ_z is the vertical dispersion coefficient in the z- direction, [m].

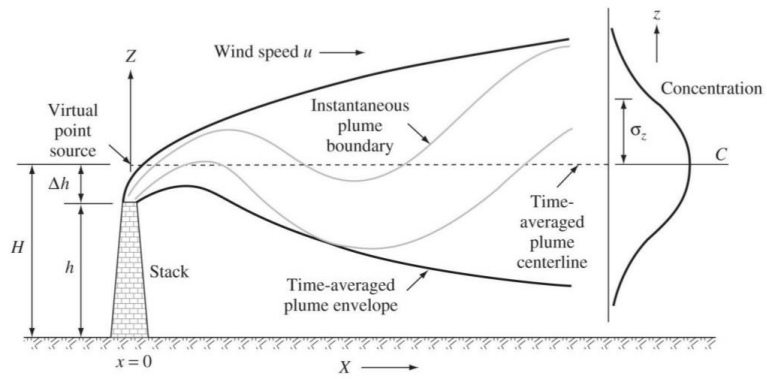


Figure 8: Gaussian plume modeling.

For computational analysis, the following equations are used to avoid the need for more complicated curves method as in Figure 9:

$$\sigma_y = a \cdot x^{0.894}$$

$$\sigma_z = c \cdot x^d + f$$

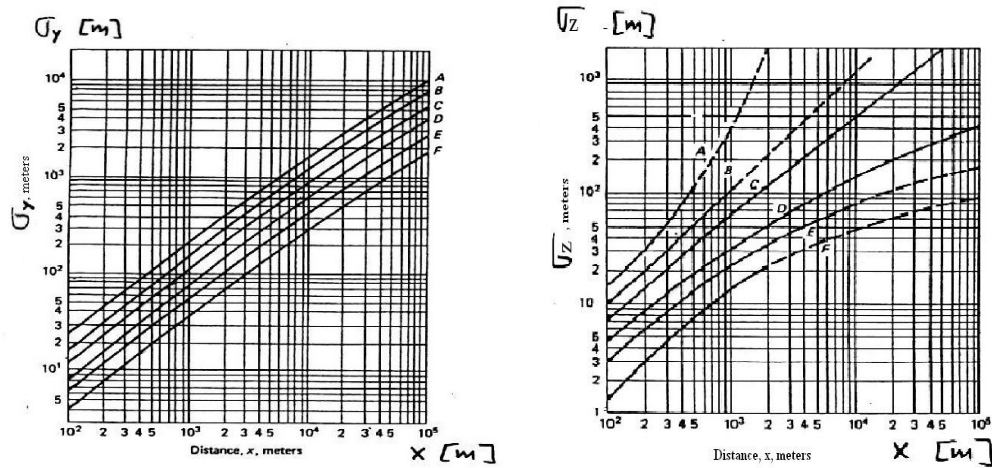


Figure 9: Dispersion coefficients w.r.t distance x and stability classes

To obtain the dispersion coefficients σ_y and σ_z that are dependent on the atmospheric stability category (ASC), Table 4 shows the different value for each stability class.

Table 4: Dispersion coefficients for different stability classes

Stability	$x \leq 1 \text{ Km}$				$x \geq 1 \text{ Km}$		
	a	c	d	f	c	d	f
A	213	440.8	1.941	9.27	459.7	2.094	-9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68	33.2	0.725	-1.7	44.5	0.516	-13.0
E	50.5	22.8	0.678	-1.3	55.4	0.305	-34.0
F	34	14.35	0.740	-0.35	62.6	0.180	-48.6

Moreover, wind speed varies with height, so to account for this variation use the following equation:

$$\mu_1 = \mu_2 \cdot \left(\frac{z_1}{z_2} \right)^n$$

Where μ_1 and μ_2 are wind speeds at high and low elevations z_1 and z_2 respectively, n is a dimensionless parameter, known as the wind exponent, that varies with atmospheric stability, as shown in Table 5.

Table 5: Wind exponent vs atmospheric stability

Stability Class	Wind exponent 'n'
A	0.15
B	0.15
C	0.2
D	0.25
E	0.4
F	0.6

➤ **Incremental Height (ΔH) Estimation**

The incremental stack height (plume rise height), that accounts for the vertical momentum of the emitted pollutants right at the stack opening, can be approximated using several techniques. One of which is the set of equations developed by **Moses and Carsons** that depends on the existing climatic conditions such that:

$$\text{Super adiabatic} \quad : \quad \Delta h = [3.47V_s d + 5.15Q_h^{0.5}] \cdot \frac{1}{\mu}$$

$$\text{Neutral} \quad : \quad \Delta h = [0.35V_s d + 2.64Q_h^{0.5}] \cdot \frac{1}{\mu}$$

$$\text{Sub adiabatic} \quad : \quad \Delta h = [-0.14V_s d + 2.24Q_h^{0.5}] \cdot \frac{1}{\mu}$$

- V_s is the emission exit speed from the stack [m/s],

- d is the stack diameter [m],

- Q_h is the heat emission rate from the stack [KJ/s],

- μ is the average wind speed at height h [m/s].

➤ **Maximum Ground Level Downwind Concentration**

In order to find the maximum ground level concentration, we can depend on Chart's method. Based on the σ_y and σ_z charts in Figure 9 above:

- For a given effective stack height "H", then σ_z is calculated using

$$\sigma_z = \frac{H}{\sqrt{2}} = 0.707H$$

- For the given stability class (C), the corresponding distance 'x' can be read from the σ_z versus x chart of Figure 9
- The obtained value of 'x' is in turn used to read the σ_y value from the corresponding σ_y chart of Figure 9.

- Substituting back into the Gaussian ground level downwind concentration expression $C(x, y, 0)$, and for H^2

$$C(x, y, 0) = \frac{Q}{\pi \mu \sigma_y \sigma_z} \cdot \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \cdot [\exp(-1)]$$

Setting $y=0$ gives the maximum downwind concentration expression:

$$C_{\max} = \frac{0.1171Q}{\mu \cdot \sigma_y \cdot \sigma_z}$$

➤ Optimum Stack Height

The emission rate from any industrial complex depends on fuel burning rate and on meteorological data such as wind speed and atmospheric stability. These parameters are usually difficult to change or optimize and therefore the only parameter through which concentration levels can, at the design stage, be controlled is the **stack height**.

The worst scenario to be accounted for is when the maximum concentration would occur at the centre of a populated area or at an environmentally- sensitive area, situated at a distance “x” from the source. To avoid this, the stack height could be pre-estimated so that the maximum concentration will occur outside this environmentally- sensitive area.

The steps are as follows:

- To determine the optimum stack height

$$\sigma_y \sigma_z = \frac{0.117 \cdot Q}{\mu \cdot C_{\max}}$$

- Parameters on the right side of this equation are known, therefore the obtained value of the $(\sigma_y \sigma_z)$ product is compared to the set of curves shown in Figure 10 below that represents the $(\sigma_y \sigma_z$ vs $x)$ characteristic.

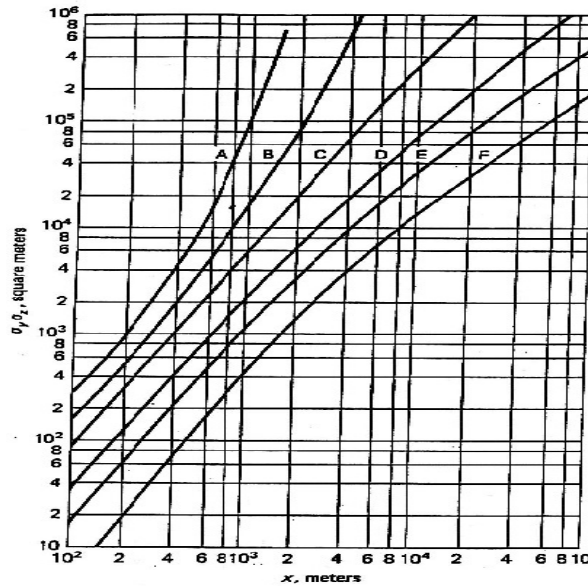


Figure 10:Chart for optimum stack height

- For a certain $\sigma_y \sigma_z$, and at a certain distance 'x' from the stack, one point is allocated on the graph. This point would most probably lie between 2 stability lines. The fractional deviation from these lines is estimated and this same deviation is applied to the σ_z -x curve to obtain the corresponding σ_z value.
- Finally, the equation below is used to find the required effective stack height such that:

$$H = \sqrt{2} \cdot \sigma_z$$

E. Area Source Model

Area source models are used to estimate concentration levels from a few sources distributed over a certain area of length 'L' and width 'W'. Its analysis is based on the fixed- box mathematical model that considers the following assumptions:

- The city is assumed to have a rectangular shape of length L and width W with a couple of sides parallel to the wind direction, see Figure 11.

- The wind speed is constant at any altitude.
- Temperature inversions occur at a height 'H', beyond which emissions cannot spread further. Therefore, the surface under investigation can be represented by a box of dimensions L, W, and H.
- The wind direction is always constant and is perpendicular to the side from which it is entering the box. The pollutants concentration of the incoming wind at the entrance point is C_{in} , (also known as background concentration) as shown in the figure below.
- No pollutants leak from the sides of the box parallel to the wind direction, nor from the top of the box.
- Pollutants are very quickly and completely mixed in the box, thus creating an average concentration 'C'. They do not undergo any reaction, decay, or any fall out of the wind stream. Also, same concentration is observed at the entrance and the exit sides.

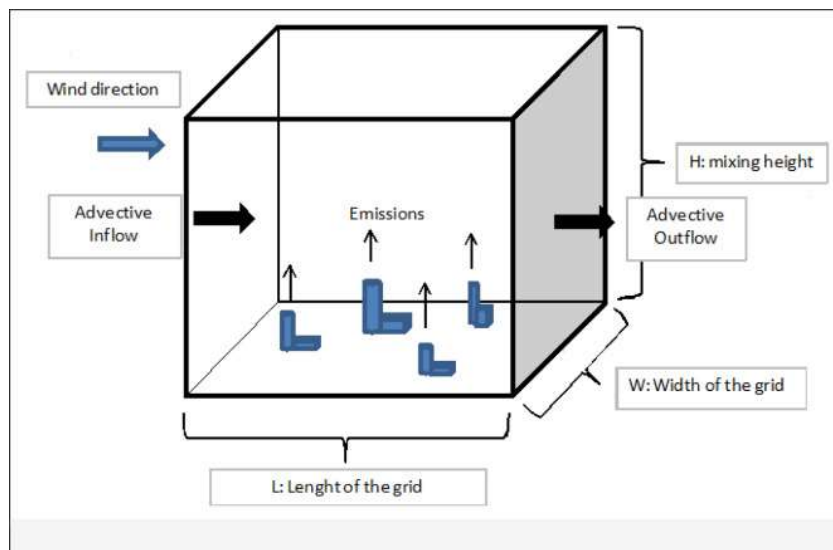


Figure 11: Area box model

Based on the above assumptions, the following analysis is conducted:

- Let q_s be the emission rate per unit area inside the box, (g/s.m^2), i.e., q_s represents all the emissions emitted within the box area.
- If the average pollutants concentration inside the box is “C”, then the number of pollutants in the box is the product of the pollutants concentration and the box volume, i.e. $(LWH)(C)$.
- The rate of air entering or leaving the box is the product of the area of entry side and the wind speed: ' $WH\mu$ '. The product $H\mu$ is known as ventilation coefficient.
- The rate at which pollutants are entering the box: ' WHC_{in} ', where C_{in} is the concentration of incoming pollutants.

The general balance equation is:

$$\text{Accumulation rate} = (\text{flow in rates}) + (\text{creation rates from within}) - (\text{flow out rates}) - (\text{destruction rates}).$$

Accordingly, the rate of change of concentration (accumulation rate) inside the box is equal to the difference between the exit rate and the entry rate, adding to it the internal emissions. The destruction rate is assumed zero.

Therefore:

$$LWH \frac{dC}{dt} = q_s LW + WH\mu C_{in} - WH\mu C$$

1. At steady state conditions: $dC/dt=0$, hence rearranging the above equation in terms of concentration 'C' inside the box gives:

$$C = \frac{q_s \cdot L + H \cdot \mu \cdot C_{in}}{H \cdot \mu} = \frac{q_s L}{\mu H} + C_{in}$$

2. The time- dependent increase of pollutants concentration can also be calculated as:

$$C(t) = \left[\frac{q_s L}{\mu H} + C_{in} \right] \cdot \left\{ 1 - e^{-\frac{\mu t}{L}} \right\} + C(0) \cdot e^{-\frac{\mu t}{L}}$$

where C (0) is the concentration inside the box at time t=0.

If the incoming wind is clean ($C_{in}=0$) and if the initial concentration inside the box is zero ($C(0)=0$), then equation will reduce to the following form:

$$C(t) = \frac{q_s L}{\mu H} \cdot \left\{ 1 - e^{-\frac{\mu t}{L}} \right\}$$

The box model predicts concentrations for only one specific meteorological condition. To find annual average concentration, the frequency distribution (percentage of occurrence) of various parameters such as wind speed and mixing height must be taken into consideration when calculating the concentration. Then the results are multiplied by the frequency to find the annual average.

CHAPTER III

METHODOLOGY

According to the above information, we will start by developing a software user-friendly tool to support in calculation of the maximum emissions concentrations. Moreover, we will include an iterative process to allow a precise calculation of the concentration thus avoiding the use of the charts methods to find the dispersion coefficients. Same iterative approach is used to estimate the optimum stack height. After that, an estimation for Beirut on using private diesel generators and fuel consumption to work using the area box model to calculate the SO₂ and PM emission concentration and compare the results to the WHO standards and previous measured concentrations. Moreover, the impact of private diesel generators on noise levels will be discussed as well.

CHAPTER IV

RESULTS AND ANALYSIS

A. Software Development Tool

The Gaussian model offers an established method to estimate the emissions concentration due to its simplicity. However, depending on the charts to find the dispersion coefficients might be difficult as they are in logarithmic scale and might not give precise values. Thus, we integrated the mathematical model with the equations of the dispersion coefficients along with stability classes into a user-friendly software tool to give precise and accurate calculation. The developed tool gives a solution for the concentration of a point source, maximum ground level concentration, optimum stack height and area source concentration.

To calculate the maximum ground level concentration, we depended on an iterative process of finding the concentrations at ground level to reach a maximum, hence, giving up on using the charts method. Moreover, to find the optimum stack height, we included the NAAQS standards of pollutants and an iterative process over the stack height was done; the height that gives the concentration within the limit of the standard is considered the optimum stack height.

For instance, for a stack of effective height 90 m and wind speed at stack height of 2 m/s having emission rate of 260 g/s and stability class A, after entering these values as inputs to the tool, we find from the developed graph in Figure 12 that the maximum concentration is 2598 $\mu\text{g}/\text{m}^3$ at distance 450 m. However, depending on Charts method, and due to the logarithmic scale, we find that maximum concentration happens at 350 m

with a value of $2990 \mu\text{g}/\text{m}^3$. This proves that the iterative suggested process improves planning and emissions calculation.

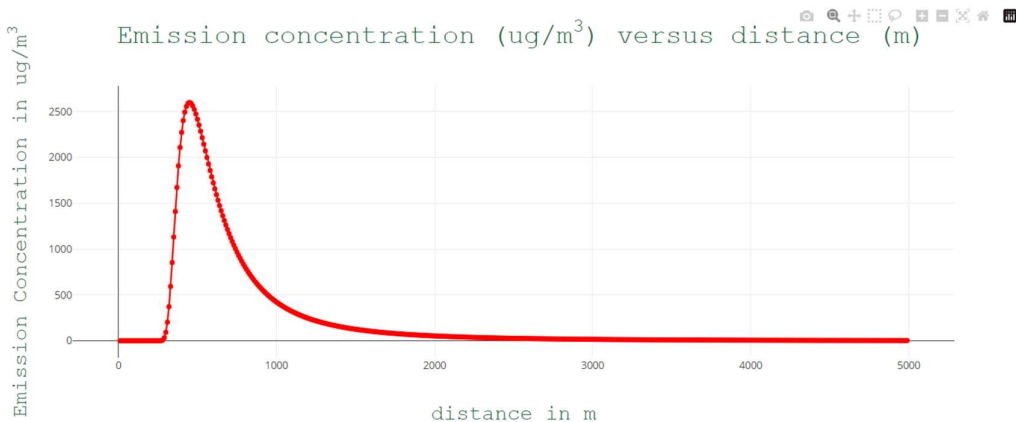


Figure 12: Emission concentration vs distance from stack.

B. Greater Beirut Area Calculated Emissions

To apply the area model in Beirut, we need to define few inputs ranging from the amount of power demand to the amount of diesel used and its composition, and the parameters of the city of Beirut (L, W and H).

- Temperature Inversion: In normal conditions, air cools up with height but when cool air lies under warmer air, temperature inversion happens as illustrated in Figure 13, and this will prevent emissions from going upwards anymore. The height that the temperature inversion happens is the mixing height H.

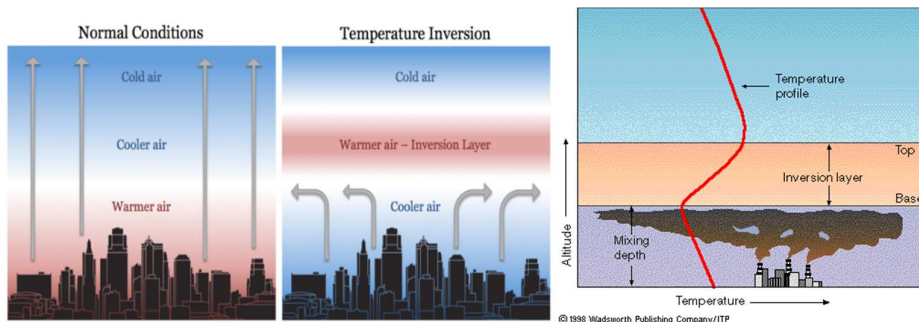


Figure 13: Temperature inversion illustration.

- As provided by General Directorate of Oil at MEW, imported heavy fuel oil has a maximum of 1% of sulphur (S). According to MEW, EDL uses 0.1% S and 1% particulate matter (PM) fuel. Also, the current standby generation statistics reveal that Beirut has a demand of 800 MW supplied from private diesel generators which according to UNHCR are used for around 12 hours daily [17].

- Daily amount of diesel **burnt**:

To generate 1 kWh, 0.27 – 0.32 litres of diesel is needed which is around 250 g/kWh.

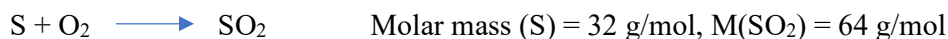
Daily amount of diesel: $800 \text{ MW} \times 10^9 \times 12 \text{ hr} \times 250 \text{ g/kWh} = \mathbf{2400 \text{ tons/day}}$

1. Sulphur Dioxide Emitted Concentration

As the Sulfur content is 0.1%, assume 90% of sulfur is burnt.

Then the amount of S emitted: $2400 \text{ tons/day} \times 0.1\% \times 90\% = \mathbf{2.16 \text{ tons/day}} = \mathbf{25 \text{ g/s}}$

Sulfur undergoes chemical reaction with oxygen to produce sulfur dioxide SO₂:



According to the law of conservation of mass in a chemical reaction where the mass is neither created nor destroyed, the amount of SO₂ emitted: $25 \text{ g/s} \times (64 / 32) = \mathbf{50 \text{ g/s}}$

Assuming the dimensions of Beirut to be 5 km x 5 km of Beirut, see Figure 14, the area model is applied to find the concentration of sulfur dioxide and particulate matter. The average wind speed in Beirut is considered to be 3 m/s.

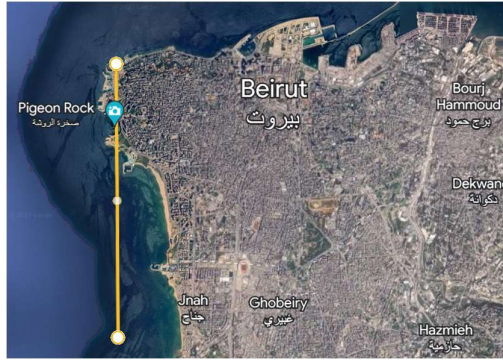


Figure 14: Beirut 5 km x 5 km

The emission rate per unit area inside Beirut: $q_s = \frac{50 \frac{g}{s}}{5 \cdot 5 \cdot 10^6} = 2 \cdot 10^{-6} g/m^2 s$

Since the incoming wind comes from the sea most of the year, we can assume that the wind is almost pollution- free, and hence $C_{in} = 0$.

According to Constantinides et al. temperature inversion occurs at heights between 100 m and 200 m in the East Mediterranean [24]. We will take both scenarios into consideration during our calculations.

- Mixing Height $H = 100$ m

$$C(t) = \frac{q_s L}{\mu H} \cdot \left\{ 1 - e^{-\frac{\mu t}{L}} \right\} = \frac{2 \cdot 10^{-6} \cdot 5000}{3 \cdot 100} * \left(1 - e^{-\frac{3 \cdot 12 \cdot 3600}{5000}} \right) = 3.33 \times 10^{-5} g/m^3 = \mathbf{33.3 \mu g/m^3}$$

- Mixing Height $H = 200$ m

$$C(t) = \frac{q_s L}{\mu H} \cdot \left\{ 1 - e^{-\frac{\mu t}{L}} \right\} = \frac{2 \cdot 10^{-6} \cdot 5000}{3 \cdot 200} * \left(1 - e^{-\frac{3 \cdot 12 \cdot 3600}{5000}} \right) = 1.67 \times 10^{-5} g/m^3 = \mathbf{16.7 \mu g/m^3}$$

2. Particulate Matter Emitted Concentration

As the content of Particulate Matter is 1% of diesel.

Then the amount of PM emitted: 2400 tons/day x 1% = **24 tons/day = 277 g/s**

The emission rate per unit area inside Beirut: $q_s = \frac{277 \frac{g}{s}}{5 \times 5 \times 10^6} = 1.108 \times 10^{-5} g/m^2 s$

Assume $C_{in} = 0$

- Mixing Height $H = 100$ m

$$C(t) = \frac{q_s L}{\mu H} \cdot \left\{ 1 - e^{-\frac{\mu t}{L}} \right\} = \frac{1.108 \times 10^{-5} \times 5000}{3 \times 100} * \left(1 - e^{-\frac{-3 \times 12 \times 3600}{5000}} \right) = 1.84 \times 10^{-4} g/m^3 = \mathbf{184}$$

$\mu g/m^3$

- Mixing Height $H = 200$ m

$$C(t) = \frac{q_s L}{\mu H} \cdot \left\{ 1 - e^{-\frac{\mu t}{L}} \right\} = \frac{1.108 \times 10^{-5} \times 5000}{3 \times 200} * \left(1 - e^{-\frac{-3 \times 12 \times 3600}{5000}} \right) = 9.23 \times 10^{-5} g/m^3 = \mathbf{92.3}$$

$\mu g/m^3$

Table 6: Summary of results

Mixing Height	Concentration of SO ₂	Concentration of PM
H = 100 m	33.3 $\mu g/m^3$	184 $\mu g/m^3$
H = 200 m	16.7 $\mu g/m^3$	92.3 $\mu g/m^3$

Comparing the concentrations obtained, as shown in Table 6, we can observe an anti-correlation between the mixing height and the concentration of pollutant emitted. This confirms that the mixing height plays a critical role in the information of pollution in urban areas. So, decreasing the mixing height in Beirut is strongly correlated with the increase in SO₂ and PM concentration.

Table 7: Air quality international guidelines

Pollutant	WHO standards 2021 [24]	NAAQS 2008 [25]
PM2.5	5 $\mu\text{g}/\text{m}^3$ (Annual)	15 $\mu\text{g}/\text{m}^3$ (Annual)
	15 $\mu\text{g}/\text{m}^3$ (24hrs)	35 $\mu\text{g}/\text{m}^3$ (24hrs)
PM10	15 $\mu\text{g}/\text{m}^3$ (Annual)	150 $\mu\text{g}/\text{m}^3$ (24hrs)
	45 $\mu\text{g}/\text{m}^3$ (24hrs)	
O3	100 $\mu\text{g}/\text{m}^3$ (8 hrs)	0.075 ppm (8hrs)
NO2	10 $\mu\text{g}/\text{m}^3$ (Annual)	53 ppb (Annual)
	25 $\mu\text{g}/\text{m}^3$ (24hrs)	100 ppb (1hr)
SO2	40 $\mu\text{g}/\text{m}^3$ (24hrs)	0.03 ppm (Annual)
		0.14 ppm (24hrs)
		75 ppb (1hr)
CO	4 mg/m^3 (24hrs)	35 ppm (40 mg/m^3) (1hr)
		9 ppm (10 mg/m^3) (8hrs)

Comparing these results to the international standards available from WHO and NAAQS, shown in Table 7, we can observe that SO_2 concentration in Beirut does not exceed the limit recommended of $40 \mu\text{g}/\text{m}^3$ in 24 hours by WHO. However, with respect to PM concentration, it exceeds the air quality guidelines recommendations from the NAAQs of $150 \mu\text{g}/\text{m}^3$ in 24 hours.

C. Beirut Area Divided to 3 sub-regions

The area box model assumes the concentration of pollutant to be uniformly distributed over the area studied. So, to get more precise vision over Beirut, we will divide it into three areas as shown in the figure below A1 and A2 of Length 2 km and width 5 km each, A3 of Length 1 km and width 5 km.

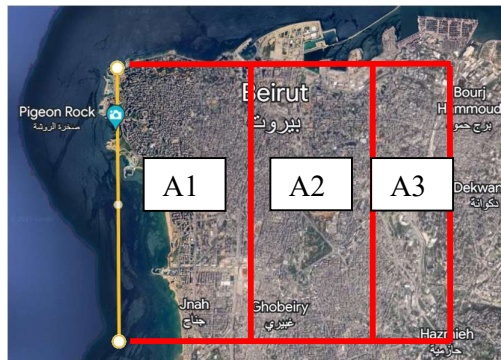


Figure 15: Beirut area divided into 3 zones.

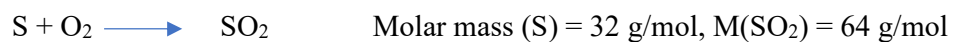
As Beirut assumed to consume a total of 800 MW power, we will assume that regions A1 and A2 consumes same amount of power (320 MW) and double that of A3 (160 MW). Thus, the daily amount of diesel consumed in regions A1 and A2 is 960 tons/day each and in region A3 is 480 tons/day.

1. Sulfur dioxide Concentration

➤ Region A1:

The amount of S emitted: $960 \text{ tons/day} \times 0.1\% \times 90\% = 0.864 \text{ tons/day} = 10 \text{ g/s}$

Sulfur undergoes chemical reaction with oxygen to produce sulfur dioxide SO_2 :



according to the law of conservation of mass in a chemical reaction where the mass is neither created nor destroyed then the amount of SO₂ emitted: 10 g/s x (64 / 32) = **20 g/s**

The emission rate per unit area inside A1: $q_s = \frac{20 \frac{g}{s}}{5 * 2 * 10^6} = 2 * 10^{-6} g/m^2 s$

Assume C_{in} = 0

Mixing Height H = 100 m and average wind speed is 3 m/s

$$C(t) = \frac{q_s L}{\mu H} \cdot \left\{ 1 - e^{-\frac{\mu t}{L}} \right\} = \frac{2 * 10^{-6} * 2000}{3 * 100} * \left(1 - e^{-\frac{-3 * 12 * 3600}{2000}} \right) = 1.33 * 10^{-5} g/m^3 = \mathbf{13.3}$$

μg/m³

➤ Region A2:

Following the exact same steps as in A1, the emission rate per unit area inside

$$A2: q_s = \frac{20 \frac{g}{s}}{5 * 2 * 10^6} = 2 * 10^{-6} g/m^2 s$$

However, C_{in} will be equal to C(t) from A1 which is **13.3 μg/m³**

Mixing Height H = 100 m and average wind speed is 3 m/s

$$C(t) = \left[\frac{q_s L}{\mu H} + C_{in} \right] \cdot \left\{ 1 - e^{-\frac{\mu t}{L}} \right\} = \left[\frac{2 * 10^{-6} * 2000}{3 * 100} + 13.3 \mu g/m^3 \right] * \left(1 - e^{-\frac{-3 * 12 * 3600}{2000}} \right) =$$

$$2.66 * 10^{-5} g/m^3 = \mathbf{26.6 \mu g/m^3}$$

➤ Region A3:

The emission rate per unit area inside A2: $q_s = \frac{10 \frac{g}{s}}{5 * 1 * 10^6} = 2 * 10^{-6} g/m^2 s$

C_{in} will be equal to C(t) from A2 which is **26.6 μg/m³**

Mixing Height H = 100 m and average wind speed is 3 m/s

$$C(t) = \left[\frac{q_s L}{\mu H} + C_{in} \right] \cdot \left\{ 1 - e^{-\frac{\mu \cdot t}{L}} \right\} = \left[\frac{2 \cdot 10^{-6} \cdot 1000}{3 \cdot 100} + 26.6 \mu\text{g}/\text{m}^3 \right] \cdot \left(1 - e^{-\frac{3 \cdot 12 \cdot 3600}{1000}} \right) = 3.32 \times 10^{-5} \text{ g}/\text{m}^3 = \mathbf{33.2 \mu\text{g}/\text{m}^3}$$

This shows that the concentration of SO₂ will sum up to reach the uniformed concentration calculated when Beirut was taken as a whole area. However, it shows that the concentration will increase with distance travelled away from the sea where C_{in}= 0. So, to take very precise measurements, one can divide Beirut to n boxes and perform n area model calculation for the pollutant concentration. This might be challenging as well, as we don't have clear data about private diesel generators distribution or the electric power demand in each area.

2. Particulate Matter Concentration

➤ Region A1:

The amount of PM emitted: 960 tons/day x 1% = **9.6 tons/day = 111 g/s**

The emission rate per unit area inside A1: $q_s = \frac{111 \frac{\text{g}}{\text{s}}}{5 \cdot 2 \cdot 10^6} = 1.111 \cdot 10^{-5} \text{ g}/\text{m}^2 \text{ s}$

Assume C_{in}= 0

Mixing Height H = 100 m and average wind speed is 3 m/s

$$C(t) = \frac{q_s L}{\mu H} \cdot \left\{ 1 - e^{-\frac{\mu \cdot t}{L}} \right\} = \frac{1.111 \cdot 10^{-5} \cdot 2000}{3 \cdot 100} \cdot \left(1 - e^{-\frac{3 \cdot 12 \cdot 3600}{2000}} \right) = 7.407 \times 10^{-5} \text{ g}/\text{m}^3 = \mathbf{74.07 \mu\text{g}/\text{m}^3}$$

μg/m³

➤ Region A2:

Following the exact same steps as in A1, the emission rate per unit area inside

$$\text{A2: } q_s = \frac{111 \frac{\text{g}}{\text{s}}}{5 \cdot 2 \cdot 10^6} = 1.111 \cdot 10^{-5} \text{ g}/\text{m}^2 \text{ s}$$

However, C_{in} will be equal to $C(t)$ from A1 which is **74.07 $\mu\text{g}/\text{m}^3$**

Mixing Height $H = 100$ m and average wind speed is 3 m/s

$$C(t) = \left[\frac{q_s L}{\mu H} + C_{in} \right] \cdot \left\{ 1 - e^{-\frac{\mu \cdot t}{L}} \right\} = \left[\frac{1.111 \cdot 10^{-5} \cdot 2000}{3 \cdot 100} + 74.07 \mu\text{g}/\text{m}^3 \right] \cdot \left(1 - e^{-\frac{-3 \cdot 12 \cdot 3600}{2000}} \right) =$$

$$14.814 \times 10^{-5} \text{ g}/\text{m}^3 = \mathbf{148.14 \mu\text{g}/\text{m}^3}$$

➤ Region A3:

The emission rate per unit area inside A2: $q_s = \frac{55.5 \frac{\text{g}}{\text{s}}}{5 \cdot 1 \cdot 10^6} = 1.111 \cdot 10^{-5} \text{ g}/\text{m}^2 \cdot \text{s}$

C_{in} will be equal to $C(t)$ from A2 which is **148.14 $\mu\text{g}/\text{m}^3$**

Mixing Height $H = 100$ m and average wind speed is 3 m/s

$$C(t) = \left[\frac{q_s L}{\mu H} + C_{in} \right] \cdot \left\{ 1 - e^{-\frac{\mu \cdot t}{L}} \right\} =$$

$$\left[\frac{1.111 \cdot 10^{-5} \cdot 1000}{3 \cdot 100} + 148.14 \mu\text{g}/\text{m}^3 \right] \cdot \left(1 - e^{-\frac{-3 \cdot 12 \cdot 3600}{1000}} \right) = \mathbf{185 \mu\text{g}/\text{m}^3}$$

The same conclusion can be drawn here as well. Where as we go in depth of Beirut, the concentration of PM will increase at each area. And the cumulative concentration of PM is equal to the concentration calculated in the last division of Beirut A3.

D. Noise Pollution Measurement

Another important problem besides the environmental impact of diesel generators is the noise produced due to the exhaust and the mechanical operation of the generator.

Usually, a 50-kW diesel generator produce a noise between 75 to 85 dB in highly populated Beirut making the noise level due to standby generation a major concern.

A measurement has been conducted to manifest the impact of noise produced by diesel generator using a sound pressure meter CM-170 in Figure 16. It measures frequency range of 20 Hz to 80 kHz and comes with data logging facility.



Figure 16: Sound pressure meter

The measurement below shows when the generator was on, the noise level was around 55 dB at 10 m away from the generator. This level was increasing as we measure near the generator to reach above 63 dB at 1 m away from it. Measured noise levels are shown in Figures 17 and 18.

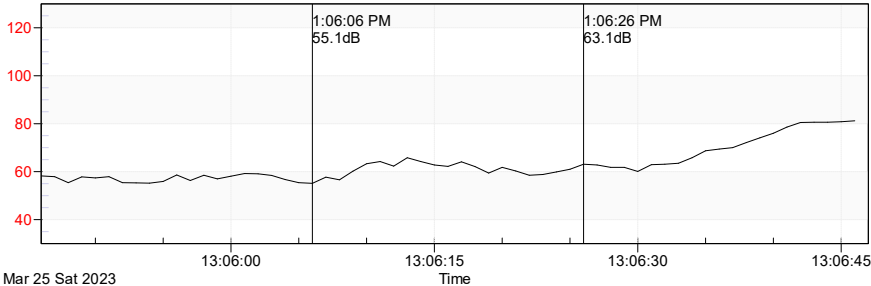


Figure 17: Noise measurement when generator is On.

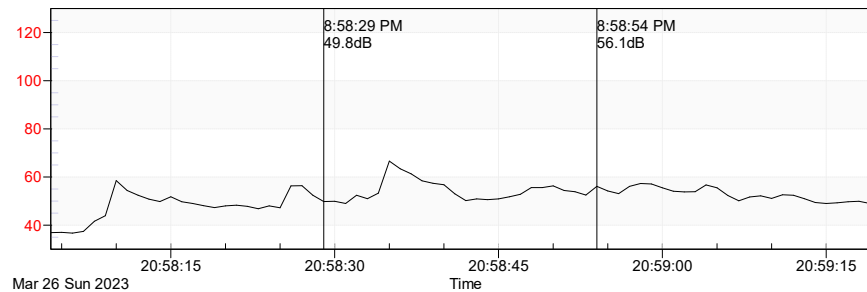


Figure 18: Noise measurement when generator is Off.

Other measurements taken during days and nights time, with and without standby generators have shown that there is an average increase in noise levels by around 6 dB. That is, noise levels varied between 41 and 48 dB during the night, and between 63 and 70 during the days.

Knowing that doubling the noise levels leads to an increase of 3 dB in measured sound levels gives a clear indication to the impact of standby generators on local neighborhoods where noise levels increase by around 3-4 times.

E. Pollution Prevention and Emission Control

A lot of work is being done by international organization and public institutions to reduce emissions and enhance the air quality in Lebanon. One of the main mitigation processes is to enforce legislation and update standards as the ambient air quality standards in Lebanon are outdated and go back to 2001. Moreover, the scarcity of data about emission inventories is limiting the development of predictive models through research. An investment in data collection will allow air quality management and planning. The absence of reliable and sustainable public transport sector has shaped the habits of Lebanese people to rely on private cars and motors for mobility. Thus, the investment in promoting public transport sector will reduce traffic congestion as well as

pollutants emissions. According to the World Bank in 2018, a shift into public transit system will reduce annual CO, NO_x, SO₂ and PM₁₀ emissions in 2023 by 1,232 tons per year, 642 tons per year, 35 tons per year and 36 tons per year, respectively, as well as GHG emissions in Lebanon by 590 Gg/year of CO₂ eq [17]. Also, knowing that Lebanon mainly depend on fossil fuel to produce energy, an investment in renewable energy and energy efficiency will help reduce pollutants emissions. Over the past 2 years, the PV penetration in the building sector witnessed a high increase reaching around 1000MW, according to LCEC, of installed capacity in 2023, and this to a big extent is mitigating the pollution and noise impacts of standby generators.

CHAPTER V

CONCLUSION

This thesis presented case studies of the air quality deterioration of Lebanon over the years. Lebanon suffers from high air pollution levels causing dangerous impact on people's health and the environment in general. The Gaussian model proved its simplicity in predicting emissions concentration as well as the area source box model. These models were integrated into a software tool to support in a precise calculation and avoid the use of the relevant graphs in calculating the concentration of emissions and in optimizing the stacks heights. This facilitates to a big extent the development of software packages used for this purpose. Moreover, the sulfur dioxide emissions and particulate matter emissions were calculated in Greater Beirut Area taking into account the energy crisis, that deployment of standby generators is negatively impacting the quality of air in Beirut as well as other major urbanized areas of the country. According to the considered case study, the concentration of SO₂ is still within the limit set by WHO. However, the PM concentration is increasing in GBA and reaching alarmingly high numbers above the WHO limits. Also, the noise levels have increased on average by around 3 times due to the operation of these generators. It is suggested to reduce the reliance on fossil fuel especially in the energy and transport sectors to reduce the emissions concentration, hence, saving lives and reducing the economic losses due to the high pollution levels. Deployment of PV panels is one effective mitigation measures being currently deployed by private initiatives.

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