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# CARBON FOOTPRINT ANALYSIS OF ENVIRONMENTAL LOADS GENERATED BY ELECTRIC GENERATORS IN URBAN AREAS CASE STUDY OF AL-KUT CITY

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## Abstract

Environmental loads are a set of direct and indirect impacts that occur as a result of human activities that put pressure on the natural environment. These loads include the consumption of natural resources such as energy and water, and the production of pollutants, heavy metals, and greenhouse gases that affect air, water, and soil quality, as well as ecosystems and human health. Environmental load management has become crucial to ensure resource sustainability and mitigate the effects of climate change. The research highlighted the environmental loads generated mainly from carbon dioxide (CO2) emissions and other pollutants resulting from the burning of fossil fuels during the operation of electric generators in urban areas. These emissions contribute to the phenomenon of global warming and negatively affect air quality and are recognized through the concept of carbon footprint, which is a measure of carbon emissions resulting from human activities, and is an essential part of environmental load analysis. The more generators are used in urban areas, the more carbon emissions they produce, and consequently the associated environmental loads increase. The carbon footprint of the activity of generating electricity using private generators was estimated by calculating the quantities of fuel consumed in this activity and factoring them with the emission factor. The carbon footprint of this activity amounted to 92,753.308 TCO2e annually, which is considered low compared to the transportation footprint or the footprint of electrical energy generated in power plants.

## Keywords

Carbon footprint, environmental loads, electric generators, environmental pollution, emission factor, global warming, Kut city

## Introduction

With the increasing demand for electricity in urban areas around the world, especially in developing countries and the continuous expansion of cities, many cities resort to using electric generators as an alternative to unstable electricity supplies and the deficit in the amount of energy produced by government power plants. These generators usually operate on fossil fuels such as diesel and gasoline, which results in carbon emissions that lead to increased environmental loads, and thus these loads lead to exacerbation of environmental pollution, rising local temperatures, and deterioration of the quality of life in urban areas (Yang et al., 2023). The carbon footprint of the energy produced by electric generators is an indicator for assessing the size of these loads and their environmental impacts. This research aims

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to study and analyze the carbon footprint of environmental loads resulting from electric generators in urban areas, focusing on the city of Kut as a case study. The amount of carbon emissions resulting from the operation of these generators will be evaluated, and from this standpoint, the research addressed the study of the direct carbon footprint of the operation of electric generators in the city and its negative impact on the city's environment. This impact is represented by adopting the descriptive analytical quantitative approach to the data and information obtained, as the research aims to identify one of the ways in which we can gain a quantitative understanding of the effects of our actions, whether positive or negative, is through what is called the carbon footprint and working to analyze the carbon footprint of this human activity through the fuel emissions coefficient to show the environmental effects resulting from air pollution in the study area. Measuring the carbon footprint helps in understanding the environmental impact of energy strategies and enhances the adoption of sustainable decisions to reduce emissions and can be a motive for moving to renewable energy sources, improving energy efficiency, striving towards energy sustainability in cities, and achieving urban sustainability, one of the main pillars of which is reducing emissions that cause the phenomenon of global warming. (Sama Hassan Radhi, 2024).

Environmental pollution

Initially, cities tended to be small, compact, and walkable. However, with the large population shifts from the countryside to the city, and the high population density led to their transformation into overcrowded cities suffering from poor living and environmental conditions in the nineteenth century (Nieuwenhuijsen, 2021) due to environmental pollution, which is defined as the introduction of unusable materials or the introduction of additional loads into the environment by humans in a direct manner that causes damage to their health or the environment in which they live or work (Khalifa, Nada, n.d.). Others defined it as any quantitative or qualitative change in the components of the living and non-living environment that ecosystems cannot absorb without disturbing their balance, which is the presence of a component of its components at a concentration higher than the concentrations permitted according to local and international environmental standards (Tarteel Faisal Ghaze Kanbar, 2024).

One type of environmental pollution is air pollution, which is defined as a change in the properties and size of air elements, i.e. a disruption in the air ecosystem as a result of the release of large quantities of particulate and gaseous pollutants, which leads to the transformation of many beneficial air elements into harmful elements (pollutants) with a negative impact and serious damage to living and non-living organisms. Air pollution is also defined as the presence of impurities or pollutants in the air that have occurred, whether by nature or man, in quantities and for periods sufficient to disturb the comfort of many people exposed to this air or to harm public health or the lives of humans, animals, plants and property in cities and areas affected by this air, according to what the American Medical Social Society for Industrial Health (Al-Alali, 2016) defined. About 90% of people living in cities have suffered from poor air quality in all its forms, while the percentage reaches 98% in low- and middle-income countries, which prompted the conclusion of several international agreements in this regard, including the Paris Agreement, the implementation of whose provisions can lead to the removal of carbon from about 90% of cities, taking into account energy efficiency and the development of renewable energies (Ouria & de

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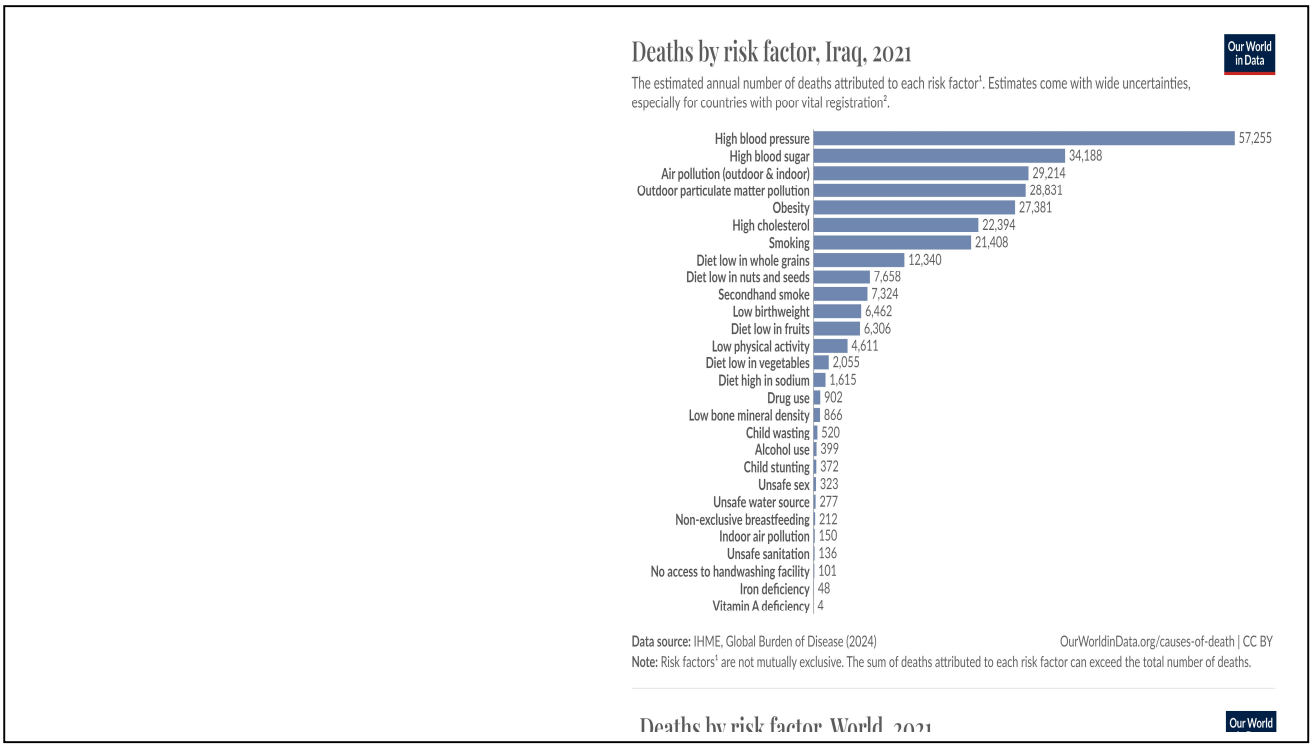
Almeida, 2021)

As shown Statistics show that the number of deaths due to air pollution is much greater than deaths resulting from water and soil pollution, and it is the second most common cause of death in the world, as 91% of the world's population is exposed to unhealthy levels of pollution (Abdulwahab, 2024). The number of deaths due to air pollution reached 8.08 million in 2021, making it the second most deadly risk in the world, according to the Our World in Data website (https://Ourworldindata.Org/Air-Pollution, n.d.)

Recently, climate change and the deterioration of the global environmental balance have prompted




researchers to focus on this field and the reasons that led to it, and because one of the main reasons for these crises is the burning of fossil fuels, which results in greenhouse gases, especially carbon dioxide. Therefore, the effects of climate crises can be mitigated by reducing greenhouse gas emissions through energy transformation, environmental awareness, government policies, and urban policies that play a fundamental role in adopting environmental urban planning as a basis for their future cities and improving the performance of their existing cities. Advanced cities have made great strides in establishing environmentally friendly cities, while other cities still have urban policies that are far from realizing the importance of adopting an environmental approach in urban planning and design. This disparity in environmental awareness has led to the creation of a large percentage of disparity in the actual achievement of environmental cities, which has made them concentrated in certain parts of the world and disappear in other parts (Mirhussein et al., n.d.).

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Environmental Loads

Although cities cover less than 2% of the Earth's surface, they consume about 78% of the planet's available energy, in addition to the fact that what is produced (food, building materials, minerals, etc.) requires indirect energy consumption. This figure can be explained from an economic and social perspective, as cities provide their residents with new opportunities for business, education, security and social life. Supporting these activities requires large amounts of resources, leading to environmental pressures at the local and global levels. (Viglia et al., 2018)

When a process requires environmental services, it imposes a load on the environment. Environmental load is the concept that once an environmental service is used by one process, it is no longer available to another process. In the most general case, the environment has a renewable capacity to support economic processes and human efforts, but in doing so this capacity is used up or consumed. If a process consumes all of its renewable support function, other processes cannot be added to the support base at the same time without seriously degrading the local environment. Thus there is a carrying capacity for economic development and environmental load is much like the load on an electrical circuit; when all of the available energy is consumed, additional loads cannot be added to the circuit without causing overloading (Brown & Ulgiati, 2002).

It is a concept that refers to the pressure or burden that human activities impose on the environment. These loads include the effects of pollution, consumption of natural resources, greenhouse gas emissions, and waste generation. In other words, environmental loads are all activities that cause changes or depletion of the surrounding environment and negatively affect the balance of ecosystems and human health. There are several types of environmental loads:

1. Air pollution: Includes emissions of greenhouse gases such as carbon dioxide ($CO_2$) and methane, which lead to global warming and climate change.
2. Water pollution: Represents the discharge of chemical and industrial waste into rivers and lakes, which harms biodiversity and affects water quality.
3. Depletion of natural resources: Includes the unsustainable exploitation of natural resources such as water, minerals, and energy, leading to their scarcity or destruction of natural habitats.
4. Solid and liquid waste: Includes the production of large quantities of industrial and household waste that require complex treatments for safe disposal.

Global warming

The phenomenon of global warming is the gradual rise in the temperature of the lower layer of the atmosphere surrounding the Earth that is close to its surface. The reason for this is the increase in the amount of greenhouse gas emissions GHGs. The first to use the term global warming was the Swedish chemist (Svante Arrhenius) in 1896 AD (Dr.n.khalifa & Estabraq.shawqi, 2022). Greenhouse gases are defined as a number of gases that trap heat in the atmosphere and thus contribute to increasing the temperature of the Earth. These gases constitute an essential part of nature, as they contribute to maintaining the Earth's temperature suitable for life, but when quantities exceed natural levels as a result of human activities such as combustion, fossil fuels and industries, this increase may lead to an increase in the Earth's temperature and the natural disasters that result from it (Al-shiblawi & Laffta, 2024, p6)

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Carbon footprint: -
The term carbon footprint was first coined by Andrew J. Hoffman in his 1997 book, Humanity and the Biodiversity Crisis. Since then, it has become widely used to refer to the environmental impact of activities that produce or consume energy, such as burning fossil fuels for electricity or transportation, especially with the emergence of the effects of climate change and global warming. It is the mark we leave on the Earth in terms of greenhouse gases and can be measured by assessing greenhouse gas emissions. The carbon footprint is often expressed as the amount of carbon dioxide equivalent (CO2) emitted over a specific period of time and is measured in tons of carbon. It is related to the amount of carbon dioxide emitted resulting from activities, services and goods. There are several definitions of the concept of carbon footprint, including: -
• It is a measure of the total amount of carbon dioxide emissions resulting directly and indirectly from an activity or accumulated over the life stages of a product. Meanwhile, the carbon footprint is a measure of carbon dioxide emissions (Gao et al., 2014)
• It is the total amount of greenhouse gas emissions (greenhouse gases) caused by an individual, company, human activity, industrial or natural event, a specific institution, or a product. Definitions vary between carbon dioxide emissions and the emission of some or all greenhouse gases.

Its increase is considered an indicator of environmental degradation, which is defined as a decrease or decrease in the quality of the surrounding environment from the natural level in which it was found (Khalifa, Nada, n.d.) due to the increase in greenhouse gas emissions, the most important of which is CO2, which is produced from the combustion of millions of tons of fossil fuels using industrial facilities, power plants, and various means of transportation, as approximately 20 billion tons of CO2 are emitted every year, as well as CH4, which is produced by many human activities (Dr.n.khalifa & Estabraq.shawqi, 2022)
It has a set of internationally recognized standards, The most common is the World Bank's Emissions Inventory Protocol, which limits emissions to three axes
The first axis: - Emissions from factories or companies and represent direct emissions, which are energy consumption rates or fuel consumption rates
The second axis: - How to measure energy emissions and how to calculate them indirectly.
The third axis: - It is related to the supply chains of these pedestrians.
Two types of carbon footprint can be identified, which are (Kumar et al., 2014):-
• Primary footprint: It represents the amount of energy consumed and enables us to directly control the amount of emissions released
• Secondary footprint: It represents the indirect emissions of carbon dioxide resulting from the product's life cycle from manufacturing to consumption and waste disposal

Generators
are machines used to convert mechanical energy produced by burning fossil fuels, such as diesel or gasoline, into electrical energy that operates on the principle of electromagnetic induction when a conductor passes through a magnetic field, which stimulates voltage across the two ends of the

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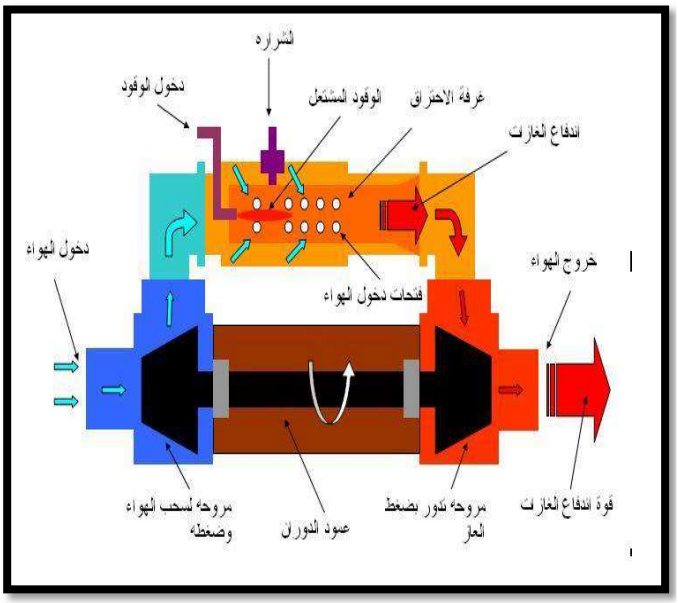
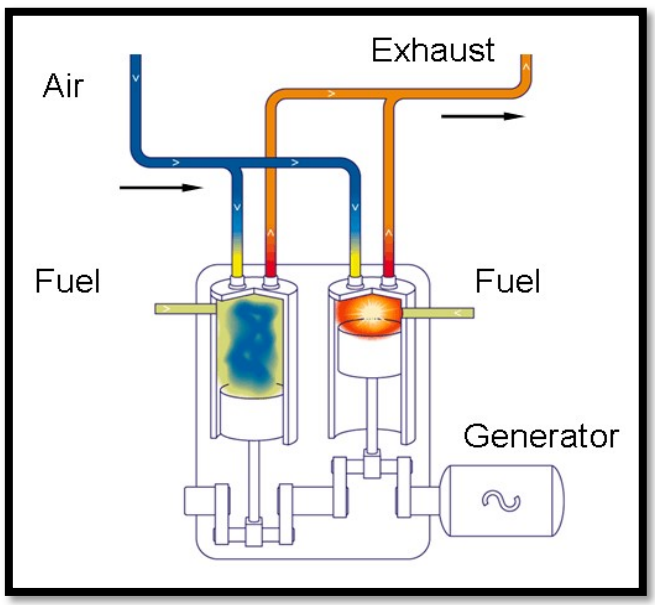
conductor, then transmits this electricity and distributes it through power lines to local, commercial, industrial and residential customers. They are used to generate electrical energy and are used in areas that suffer from shortages or instability in government electricity supplies as a backup power source during power outages or emergencies. They work as backup power solutions for mobile applications such as mining sites, agricultural operations and contractor needs. Diesel generators typically consume liquid fuel or natural gas as their primary fuel source, and provide power ratings of less than 75 kilovolt-amperes, between 75-375 kilovolt-amperes, 375-750 kilovolt-amperes, and above 750 kilovolt-amperes. In order to obtain the concentrations of traditional pollutants emitted from generator exhausts, it is necessary to know the mechanism of operation of these generators, as the operating principle of electric generators does not differ from the principle of vehicles, as both are used Fuel (gasoline or diesel) for the purpose of generating kinetic energy in the car, which leads to the movement of the car, and in the generator, it leads to the generation of electrical energy. The work of these generators produces gaseous pollutants resulting from the combustion of fuel into the outside atmosphere through the exhaust pipe outlet or any outlet in its path. These pollutants include NO2 CO, H2S, SO2 and hydrocarbons, which are considered hazardous pollutants that contribute effectively and significantly to human exposure to pollution risks (Alrawi, 2013). In Iraq, surveys indicated that the total number of generator sites reached 25,295 sites distributed across the governorates of Iraq, distributed at the urban and rural levels. The percentage of their presence in the urban environment reached 83%, while their percentage in the rural environment was 17%. The number of beneficiaries of the electricity service produced by private generators reached 6,700,665 subscribers, and it was found that this activity contributes to the production of 25,875,722 amperes throughout the country (Private Sector Electrical Power Generators Survey 2023, 2023)




Emission factor

The emission factor expresses the relationship between the amount of fuel burned in any human activity

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and the amount of carbon emissions resulting from combustion. It can be defined as the weight of emissions resulting from burning a specific amount of fuel. The emission factor varies from one type to another according to the type of fuel according to its components of carbon and hydrocarbons (Lama Abdul Manaf Rahim, 2020). The greenhouse gas conversion factor includes the effect of carbon dioxide, methane and nitrous oxide combined, and is referred to as kilograms of carbon dioxide equivalent per unit of fuel consumed (Dr.n.khalifa & Estabraq.shawqi, 2022). Energy conversion factors are defined as the total kilogram of direct carbon dioxide equivalent KgCO2e per unit of fuel consumed. These factors do not include indirect emissions, such as emissions associated with natural gas extraction, oil refining and supply stages (carbon trust & 2023, 2024)

| Fuel[1] | Units | $kgCO_2e$ per unit |
|---|---|---|
| UK Grid electricity[2] | kWh | 0.20707 |
| Renewable electricity[3] | See footnote [3] | See footnote [3] |
| Natural gas | kWh | 0.18293 |
| | therms | 5.36115 |
| | cubic meters | 2.03839 |
| LPG | kWh | 0.21450 |
| | therms | 6.28637 |
| | litres | 1.55713 |
| Gas oil | tonnes | 3,228.89 |
| | kWh | 0.26813 |
| | litres | 2.75857 |
| Fuel oil | tonnes | 3,229.20 |
| | kWh | 0.26816 |

| Fuel[1] | Units | $kgCO_2e$ per unit |
|---|---|---|
| Burning oil | tonnes | 3,165.04 |
| | kWh | 0.24677 |
| Diesel[4] | tonnes | 3015.65 |
| | kWh | 0.23908 |
| | litres | 2.51206 |
| Petrol[4] | tonnes | 2,806.66 |
| | kWh | 0.22166 |
| | litres | 2.09747 |
| Industrial coal | tonnes | 2,396.48 |
| | kWh | 0.32262 |
| Wood pellets[5] | tonnes | 51.56192 |
| | kWh | 0.01074 |

Liquid Fuel Measurements and Conversions, 2023, p 3-7) Energy conversion factors

Research boundaries Geographical location

The research area is the center of (Wasit Governorate) Al-Kut city as shown on the map, surrounded by the Tigris River from three directions to give the city a peninsula shape consisting of 4 sectors, each sector consisting of a number of neighborhoods formed from a group of shops with diverse land uses.

The city's location is characterized by a certain specificity, which is that the Tigris River course penetrates the city from the middle, which makes its neighborhoods overlook the side edges of the river. The river is also characterized by bends as it surrounds the city from three sides, which makes it a peninsula and gives it a distinctive shape. As for the astronomical location of Al-Kut city, it extends

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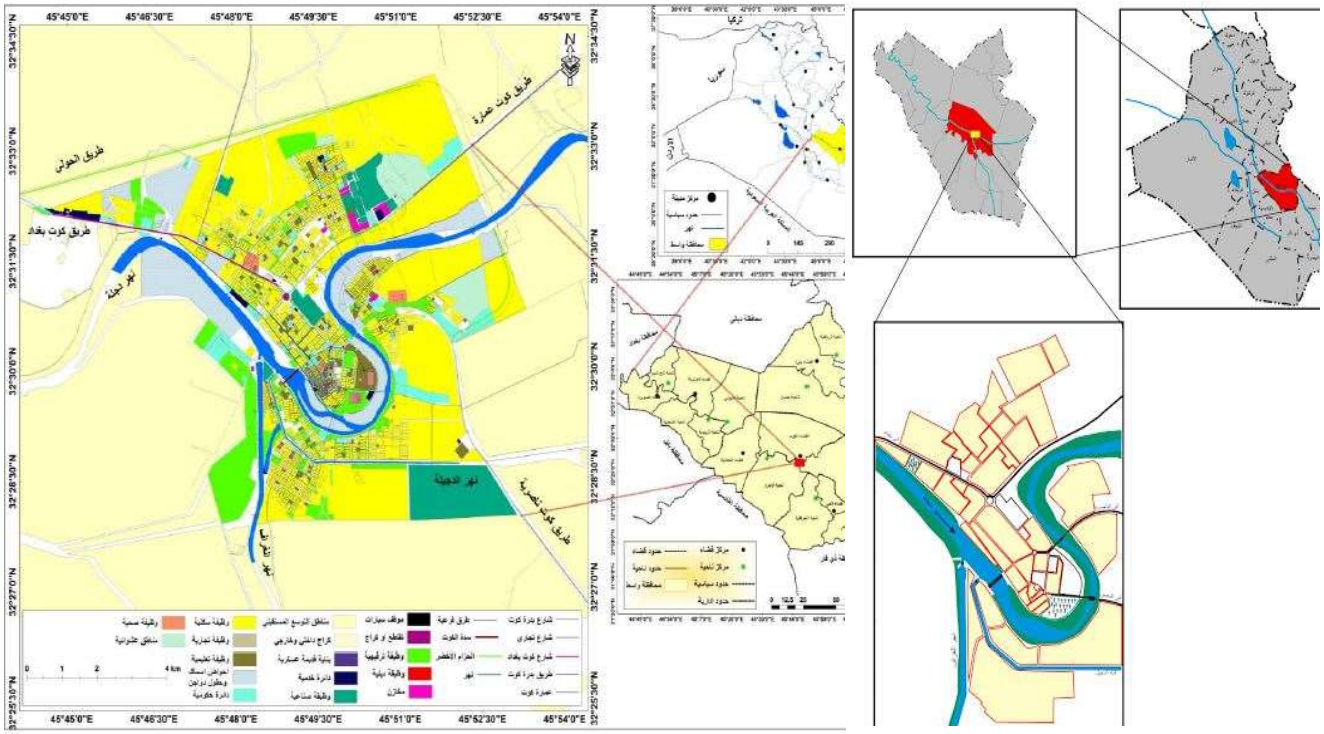
between latitudes (28. 32˚ -32.33˚) north and between longitudes 45.47˚ -45.51˚ east of Krich. This location has a limited impact on the climate, which is related to water resources and river drainage in the region. The city of Kut - the center of Wasit Governorate - is located in central Iraq, 170 km south of Baghdad, on the highway linking Basra - Baghdad. Its area is 1,761 km2, and the city's population is 410,070 according to population projections for the year 2020.



Source: Wasit Urban Planning Directorate

Practical aspect: -

The burning of fuel (gas oil) is considered the main source of a large number of air pollutants emitted directly into the air and harmful to human health, including suspended particles, some greenhouse gases and global warming, including carbon monoxide, sulfur dioxide, nitrogen dioxide, hydrogen sulfide and hydrocarbons (Alrawi, 2013), in addition to small amounts of other greenhouse gases, including methane (CH4) and nitrous oxide (N2O). In order to analyze the carbon footprint of electrical energy produced by electric generators in the urban area, which is the amount of greenhouse gases, especially carbon dioxide (CO2), resulting from this activity, the equivalent amount of carbon dioxide required to give the same greenhouse effect is calculated using the "global warming potential". This amount is determined in units of kilograms of carbon dioxide equivalent (kgCO2e). When gas oil is burned, it produces 76% nitrogen, 7% water, Carbon dioxide 7%, oxygen 10% in the form of emitted gases (Al-Shablawi, 2024) as diesel fuel or kerosene is consumed in the city to operate private electric generators. The kerosene or diesel footprint will be calculated based on the emission factor resulting from the fuel

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used to operate the generators during the months of the year for the period 1/1/2023-31/12/2023, which amounts to 2.75857 kgCO2e per liter (carbon trust & 2023, 2024) where the carbon footprint is measured by multiplying the amount of fuel consumed in the generators x the emission factor, as it measures the amount of carbon dioxide emissions in tons / year from various human activities, including the activity of operating electric generator engines in various residential, governmental, service, and other activities of the city.

Data

The number of registered generators until the end of 2023 reached (640) generators in the city of Kut with different capacities and operating on gas oil fuel in varying quantities throughout the year, equipped by the Oil Products Distribution Company according to the standard of operating hours and engine size, as shown in the table below.

| period | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| no.generator | **640** | **604** | **607** | **606** | **606** | **612** |
| kva | **137,293** | **130,646** | **131,511** | **131,688** | **131,688** | **132,758** |
| liter/kva | **10** | **15** | **5** | **5** | **10** | **30** |
| fuel quantity(liter) | **1,372,930** | **1,959,690** | **657,555** | **658,440** | **1,316,880** | **3,982,740** |

| **period** | July | August | September | October | November | December |
|---|---|---|---|---|---|---|
| **no.generator** | **616** | **616** | **640** | **639** | **639** | **640** |
| **kva** | **133,470** | **133,470** | **137,324** | **137,293** | **137,293** | **137,293** |
| **liter/kva** | **45** | **45** | **30** | **20** | **10** | **10** |
| **fuel quantity(liter)** | **6,006,150** | **6,006,150** | **4,119,720** | **2,745,860** | **1,372,930** | **1,372,930** |
| Prepared by the researcher using unpublished data, Directorate of Distribution of Oil Products / Wasit | | | | | | |

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| | |
|---|---|
| **Total quantity of fuel (liter)** | **31,571,975** |

In addition, there are a number of generators affiliated with government and service departments 2023, as shown in the table below.

| Annual fuel quantity(liters) | Type of institution | The institution |
|---|---|---|
| **155,000** | Buildings of municipal departments and the directorate building | **Directorate of Kut Municipality** |
| **400,000** | Directorate building and sewage stations | **Directorate of Sewerage** |
| **564,500** | Directorate building and water complexes in the city | **Directorate of Water** |
| **110,000** | General hospital | **Al-Zahraa Teaching Hospital** |
| **30,000** | General hospital | **Al-Karamah Teaching Hospital** |
| **17,000** | Hospital specialized in maternity and children | **Al-Batoul Hospital** |
| **65,400** | Health centers on the left side of the city | **First Kut Health Sector** |
| **90,400** | Health centers on the right side of the city | **Second Kut Health Sector** |
| **425,667** | Buildings of directorates, centers and headquarters of regiments located within the city with 187 multi-capacity generators | **Wasit Police Directorate** |
| **23,750** | Headquarters | **National Card Directorate** |
| **80,000** | Generators operating the mill | **Al-Mutanabbi Mill** |
| **90,000** | Type of institution | **Gas Cylinder Factory** |
| **2,051,717** | Buildings of municipal departments and the directorate building | **Total** |

Prepared by the researcher from the governorate departments

The carbon footprint of fuel consumed to generate electricity from private generators and government uses in Kut city is the product of the total amount of fuel consumed in these generators by the gas oil emission factor per 1 liter, which is 2.75857 kgCO2e per liter

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| | |
|---|---|
| Total quantity of fuel (liter) civil electric generator | ***31,571,975*** |
| Total quantity of fuel (liter) government electric generator | ***2,051,717*** |
| **Total quantity of fuel (liter)** | ***33,623,692*** |

| **Total quantity of fuel (liter) A** | **gas oil emission factor kgCO2e B** | **Amount of carbon footprint kgCO2e A*B** | **Amount of carbon footprint TCO2e** |
|---|---|---|---|
| **33,623,692** | **2,051,717** | **92,753,308** | **92,753.308** |

Discussion of the results

In order to know the extent of the impact of the generators' footprint, the table below shows the carbon footprints of some cities and some activities, and it shows: -

• It is clear that the carbon footprint of the operation of electric generators is less than the transportation footprint in the city of Kut, because the emission factor of diesel oil is less than the emission factor of gasoline, and because most means of transportation within the city operate on gasoline fuel.

| **Pollutant volume tons/year** | **Researcher** | **Study** | **City** |
|---|---|---|---|
| **364,748** | Md. Lama Abdel Manaf Rahim | PhD Thesis Carbon Footprint of Transportation in Kut City 2017 | **Kut** |
| **1,066 (لمى عبد مناف رحيم, (2020** | Md. Lama Abdel Manaf Rahim | Published Research Carbon Footprint of Ovens and Bakeries in Kut City 2020 | **Kut** |
| **411,877 Al-shiblawi & ) (Laffta, 2024** | Hossam Ahmed Al-Shablawi | Published Research Carbon Footprint of Gas Oil Fuel Consumed in Al-Zafaraniya Area 2023 | **Al-Zaafaraniya** |

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| | | | |
|---|---|---|---|
| **4,094 Dr.n.khalifa & ) Estabraq.shawqi, (2022** | Researcher | Published Research The Impact of Fossil Fuel Combustion on the Carbon Footprint of the City (Eastern Karrada Area) Case Study | **Al-Karrada** |

**Conclusions**

• Through the value of the carbon footprint of operating electric generators, it can be said that our awareness and deep understanding of the environmental crises facing the city in particular and the planet Earth currently and in the future imposes responsibility on us all, by making sound and smart decisions in producing, purchasing and consuming goods and products that take into account the environmental balance, to protect our health and the health of the deteriorating planet Earth.

• The study concluded that electric generators contribute significantly to greenhouse gas emissions, especially carbon dioxide (CO2), which increases the impact of climate change and global warming.

• The results indicated that old or inefficient generators contribute more to carbon emissions compared to modern technologies that use more efficient combustion technologies or clean energy sources

• It can be noted that reducing the carbon footprint of generators not only has environmental benefits, but also economic benefits in terms of reducing fuel consumption and lowering operating costs in the long term

**Recommendations**

• The need for regulatory policies: i.e. the need to strengthen government policies to encourage the shift to clean energy and provide financial incentives to companies and consumers who invest in environmentally friendly technologies.

• Policies and legislation: Requiring government agencies to set stricter laws on emissions from electric generators, including setting permissible emission levels and imposing taxes or fines on the use of polluting generators.

• Promoting the use of environmentally friendly technologies by encouraging the use of electric generators that rely on clean energy or hybrids that combine traditional fuels with solar or wind energy, with the aim of reducing carbon emissions.

• Improving the efficiency of electric generators by developing combustion technologies and improving generator designs to increase their efficiency, which reduces fuel consumption and thus reduces greenhouse gas emissions. And conducting periodic maintenance of generators to improve their performance and reduce air pollution.

• Proposing policies and programs that reduce carbon emissions and are an incentive to work on increasing the city's biological capacity through the spaces needed to absorb pollution resulting from transportation and energy emissions in the urban area

• Community and environmental awareness: launching awareness campaigns to raise users' awareness of the environmental impacts of using electric generators, and encouraging them to use energy

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responsibly by providing workshops or guidance on how to improve fuel use and reduce reliance on generators. Providing financial incentives or tax exemptions for users who invest in more efficient generators or alternative energy systems.

• Encouraging research and development by supporting research and development in the field of low-emission electric power generation technologies, to accelerate innovation in this field and provide cleaner and more sustainable alternatives.

• The need to reconsider the spatial signature of electric generators in residential areas and set limits on their installation locations

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