University of Baghdad
College of Engineering
JE
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.jcoeng.edu.iq

Volume 30 Number 7 July 2024

Urban Metabolism of Energy Consumption in Cities

Husam Ahmed Al-shiblawi [1,*], Suaad Jaber Laffta [2]

Center for Urban and Regional Planning for Postgraduate Studies, University of Baghdad, Baghdad, Iraq
hosam98ahmad@gmail.com[1], dr.suaad.j@iurp.uobaghdad[2]

ABSTRACT

The idea of the research came from the importance of the issue of energy consumption in cities as the cities of the world, in general, and Iraqi cities in particular, face significant environmental challenges from carbon emissions. The research problem revolves around the increase in the consumption of non-renewable energy using traditional methods, as is the case in the city of Zaafaraniya and this leads to an increase in the carbon footprint locally and globally and poses a threat to the lives of residents. This requires verification to find solutions through understanding the city's input and output processes as the urban metabolism. The research will summarize the concept of greenhouse gases, types of energy sources, measure the energy footprint of the case study, and the relationship of land use to energy. The research provided results that indicate the continuing population increase in cities, as the population of the Al- Zaafaraniya reached (889,000 people) in 2023. This was related to a continuous rise in energy consumption. The electricity footprint amounted to (491,507 tCO_2) which is the highest, and the fuel footprint of gasoline consumption amounted to (477,988 tCO_2). At the same time, the diesel footprint amounted to (411,877 tCO_2). There is a variance between different land uses. Residential use consumes 40% of energy. By following strategies to reduce energy consumption through an efficient city layout that encourages public transportation, walking, waste recycling, and using clean, renewable energy. It leads to lowering the carbon footprint.

Keywords: Urban metabolism, Energy consumption, Greenhouse gases.

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2024.07.10

Article received: 25/02/2024
Article accepted: 01/06/2024
Article published: 01/07/2024

الأيض الحضري لأستهلاك الطاقة في المدن

حسام احمد الشبلاوي*، سعاد جابر لفتة
مركز التخطيط الحضري والاقليمي للدراسات العليا، جامعة بغداد، بغداد، العراق

الخلاصة

جاءت فكرة البحث من أهمية موضوع استهلاك الطاقة في المدن حيث تواجه مدن العالم بشكل عام والمدن العراقية بشكل خاص تحديات بيئية كبيرة من تصاعد الانبعاثات الكربونية. اذ تدور المشكلة البحثية حول الزيادة في استهلاك الطاقة غير المتجددة وبالطرق التقليدية كما هو الحال في مدينة الزعفرانية وهذا يؤدي الى زيادة البصمة الكربونية محلياً وعالمياً ويشكل خطر على حياة الساكنين. مما يتطلب التحقق لأيجاد الحلول اللازمة من خلال فهم عمليات المدخلات والمخرجات للمدينة المتمثلة في عملية الأيض الحضري. سيلخص البحث مفهوم الغازات الدفيئة، وأنواع مصادر الطاقة، وقياس بصمة الطاقة لمنطقة الدراسة وعلاقة استخدام الأراضي باستهلاك الطاقة. وقدم البحث نتائج تعطي مؤشراً على الزيادة السكانية المستمرة في المدن إذ بلغ عدد سكان منطقة الزعفرانية (889,000 نسمة) في عام 2023 واقترن ذلك إلى زيادة مستمرة في استهلاك الطاقة مع زيادة السكان. بصمة الكهرباء بلغت (491,507 tCO_2) وتعد اعلى بصمة استهلاك للطاقة و بصمة وقود من استهلاك البنزين بلغت (477,988 tCO_2) اما بصمة الكَاز حيث بلغت (411,877 tCO_2). وهناك تباين بين استخدامات الأراضي المختلفة حيث الاستعمال السكني يستهلك طاقة بنسبة 40%. بأتباع استراتيجيات تقليل استهلاك الطاقة من خلال تخطيط كفوء للمدينة يشجع على النقل العام والمشي واعادة تدوير النفايات واستخدام طاقة متجددة نظيفة لمنطقة الزعفرانية يؤدي الى التقليل من البصمة الكربونية.

الكلمات المفتاحية: الأيض الحضري، استهلاك الطاقة، الغازات الدفيئة.

1. INTRODUCTION

Cities are growing at an unprecedented rate, as more than 54% of the world's population lives in cities, and this is expected to lead to an increase in demand for resources (cities are already large consumers of resources and energy). Energy consumption through traditional methods, such as non-renewable energy and traditional city planning, leads to a continuous increase in carbon emissions in cities, thus increasing the carbon footprint at the global level. This process leads to identifying of urban metabolism, which refers to the biological concept of the constant exchange of materials and energy that live organisms maintain with their environment to function, grow, and reproduce. However, to comprehend the deeper elements of urban metabolism and its scope with city analysis in the context of sustainability, it is necessary to examine the concept's historical evolution and the theoretical foundations that support it **(Restrepo and Morales-Pinzón, 2018)**. The research argues that adopting sustainable planning strategies can reduce consumption and thus reduce your energy footprint and carbon emissions. Cities are emerging as significant centers for resource consumption and transformation. Cities now utilize around 75% of global material resources and 80% of global energy supply while producing approximately 50% of global waste and 75% of general carbon emissions. Consequences and challenges appear for cities that can be looked at in two aspects: limited energy resources and environmental pollution resulting from the consumption of fossil fuels. Consumption of available resources in the city significantly affects the region's carbon footprint. It is possible to reduce the carbon footprint by improving consumer behavior and consumption patterns, as the most influential aspects of the carbon footprint are related to the consumption of meat, electricity, and private cars **(Sawant and Babaleshwar, 2015)**. The study found that using renewable energy and gradually reducing fossil fuels significantly reduces the carbon footprint. Increasing renewable energy by 1% can reduce the carbon footprint by 0.16%. Renewable energy at the global level is constantly growing, especially solar and wind energy. This is due to the continuous decline in prices and many countries' commitment to the planned targets for renewable energy. Energy use comes in second in building costs the technology is based in the energy sector **(Elshimy and El-Aasar, 2020)**. The sustainable city has become one of Earth's most important architectural concepts. Due to energy crises, cities are considered the largest area that consumes energy. Therefore, one of the main goals of modern city planning is to reduce or conserve energy consumption in construction if possible. Urban construction is architecture that meets human architectural needs in terms of elegance, function, structural needs, and the ability to generate or reduce the energy needed to operate the building. Its energy needs reducing production, maintenance, consumption costs, and environmental conservation purposes to preserve the Earth and its resources for future generations **(Salim, 2008)**. After formative work in the 1970s, absence in 1980, and reemergence in 1990, there has been a renewed interest in studying urban metabolism over the last decade. The review identifies two non-contradictory schools of urban metabolism. The first explains metabolism in terms of energy equivalents, and another expresses a city's water, materials, and nutrients in terms of mass fluxes. Urban metabolism studies can be used for sustainability indicators, calculating greenhouse gas emissions, developing policy models, and guiding sustainable urban design, among other purposes. Future directions involve integrating social, health, and economic factors into urban metabolism. The urban metabolism concept is essential for creating sustainable cities and communities. Urban metabolism refers to the technical and socio-economic mechanisms that drive growth, generate energy, and eliminate trash in cities **(Wolman, 1965)**. Scientists have connected this analytical framework and political ecology, including environmental and economic problems and their impact on society. Marx used the concept of metabolism which refers to the metabolic interactions between nature and society resulting from human activities. Marx argued that humans, especially before the age of oil, were natural beings and producers of their own material needs. This shift affects Earth's systems, and climate change is perhaps the most extreme example of the population idea. Marx used the concepts of material and organizational exchanges to express man's relationship with nature represented by the concept of urban metabolism **(Foster, 2000)**. Urban metabolism studies quantify the inputs, outputs, and storage of energy, water, nutrients, materials, and waste in an urban zone. While research on urban metabolism has flourished it has diminished over the last 45 years but has accelerated in the recent decade. This review highlights the practical applications of urban metabolism **(Kennedy et al., 2011)**. Several authors developed the concept of urban space and applied sustainable planning steps. In **(Azevedo et al., 2007)**, authors studied Urban Metabolism (UM) scientists compared cities to living organisms. Like cities, living things need energy and resources to function and produce waste. In **(Engel et al., 2007)**, according to the authors, urban metabolism (UM) is a systems-based approach to understanding resource use, waste production, and environmental impacts in cities. Some ecologists argue that urban metabolism is not a valid biological parallel as only individual species have an urban metabolism, which is an unfair term for the town. In **(Golubiewski et**

al., 2012), the authors' study Cities can be compared to ecosystems with multiple metabolisms interacting together.
Therefore, this study aims to identify the concept of urban metabolism and calculate the carbon footprint of energy consumption in Al-Zaafaraniya to allow us to analyze the metabolic process of the case study.

2. METHODOLOGY

To document the theoretical aspect of the research and understand the process of urban metabolism after reviewing the literature from inputs represented by energy consumption and outputs defined by the carbon footprint. After that, data was also collected through research and visits to state institutions related to the per capita share of energy consumption (Electricity, Gasoline, Gas, Oil, and Diesel) and relying on the population of Al-Zaafaraniya and running operations to indicate the carbon footprint of the city. It allows adopting strategies to reduce the carbon footprint and benefiting from countries' experiences.

3. URBAN METABOLISM

Over the last decade, there has been a growing interest in understanding urban metabolism. It defines two non-contradictory approaches to urban metabolism .The first uses the energy system to explain the metabolic process represented by material input and output. At the same time, the other employs mass flows to describe water, materials, and nutrients in cities. Urban metabolism has four applications sustainability indicators, greenhouse gas emissions calculations, and sustainable urban design **(Kennedy et al., 2011)**.

3.1 Concept of Urban Metabolism

1. A complex collection of social, economic, and environmental processes that impact the flows of resources, energy, people, and information to produce a city system that meets the demands of its citizens while also influencing its surroundings **(Currie et al., 2017)**.
2. The urban metabolic process can be defined as the process by which cities get resources from natural settings or through trade and use them to generate economic output and social services that meet the requirements of inhabitants **(Bancheva, 2014)**.
3. Urban metabolism refers to the processes of social-ecological interchange and changes in cities' energy flows that focus on production or the interaction between human activity and resource consumption in the urban environment **(Saguin, 2019)**.

In summary, urban metabolism relates to the city's inputs and outputs, including resource use and the resulting environmental repercussions, such as carbon dioxide emissions.

3.2 Urban Metabolic Processes

1. A baseline study of urban metabolism in all nations is required to ensure that cities in developed and developing countries are comparable.
2. Using a top-down or bottom-up technique to collect missing data and build a database **(UNEP, 2018)**.
3. Linking geographical and temporal concerns in evaluating the urban metabolism process.
4. Advancing a complete agenda that considers all social, economic, and environmental components in the long run **(Pincetl et al., 2012)**.

5. Encouraging modeling to investigate the intricate dynamic links between urban metabolism's physical and social processes and their impact on urban planning and design and portraying them as inputs (resources) and outputs (environmental consequences), as shown in **Fig. 1**.

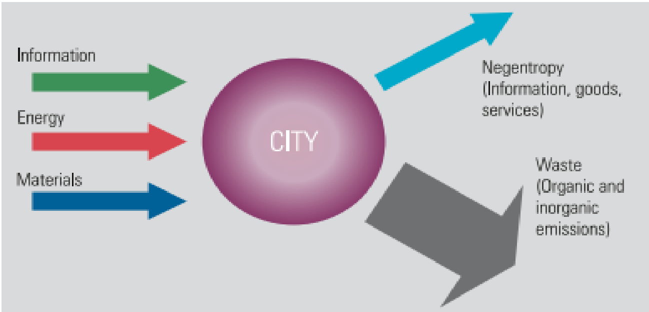

Figure 1. Shows the inputs and outputs of urban metabolism **(Butera et al., 2018)**

3.3 Energy Consumption

It includes all activities that consume energy, whether at home, in industry, or in transportation. This topic relates to how we use energy sources. Energy consumption is the most significant contributor to carbon dioxide emissions. Energy is one of the most important elements on which life is based and is the main driver of all basic activities. At the same time, it is also the main cause of environmental problems **(Ma et al., 2011)**. After that, will lead to identify the concept of urban energy consumption. It is a basic concept related to every aspect of our daily lives and refers to the total energy used during a specific unit of time. This consumption could be in the form of electricity to operate household and industrial appliances, fuel for car equipment, or even the energy required for heating and cooling **(Yıldırım et al., 2017)**.

3.4 Greenhouse Gases (GHGs)

A group of gases that trap heat in the atmosphere and thus contribute to increasing the Earth's temperature and causing what is known as the phenomenon of global warming. These gases are an essential part of nature as they contribute to maintaining the Earth's temperature, which is suitable for life. However, when their quantity exceeds natural levels as a result of human activities such as combustion, Fossil fuel, and production industries, this increase could lead to a rise in the Earth's temperature and the resulting catastrophic effects on the environment, such as air pollution, melting ice, rising sea levels, and extreme changes in weather. The effects of these gases vary depending on the type of gas, its strength in trapping heat, and the period of its presence in the atmosphere. Greenhouse gases include carbon dioxide (CO_2) from fossil fuel combustion, methane gas (CH_4) from agricultural activities, water desalination, water vapor from evaporation, and others **(Evans, 2007).** Or they are gases that contain carbon from human activities such as burning fossil fuels such as coal, oil, and natural gas. Emissions include carbon dioxide (CO_2), methane (CH_4), and nitrous oxides (N_2O). Most greenhouse gas emissions into the atmosphere also come from carbon dioxide, as shown in **Table 1 (Wiśniewski and Kistowski, 2017).**

Table 1. The rates of greenhouse gases emitted into the atmosphere
(Wiśniewski and Kistowski, 2017)

Type of gas	Chemical composition	Rate %
Carbon dioxide	CO_2	83
Methane	CH_4	10.3
Nitrous oxide	N_2O	4.5
Hydrofluor-carbons, Perfluorocarbons Sulfur, hexafluoride	HFC_S, PFC_S, SF_6	2.2
Total summation		100

4. ENERGY RESOURCES

Energy is a scarce resource. These sources contribute significantly to meeting global energy needs and form an essential part of the economic infrastructure of many countries. However, there are environmental and economic challenges related to harmful emissions. There are two types of energy: non-renewable and renewable. Non-renewable energy is scarce, or what is known as traditional energy, which is polluting energy that produces high-carbon gases such as oil, gas, and others **(Boersema and Reijnders, 2009)**. Renewable energy is a type of sustainable energy that can be used continuously and unlimitedly, and there are many renewable energy sources, such as solar energy and wind energy. Renewable energy is increasingly being used to generate electricity around the world. In 2007, renewable energy represented about 18% of total global energy production. Plans aim to consume clean energy to provide all services and meet the population's needs **(Al-Najjar, 2015)**. And learn about every kind of energy in particular in terms of chemical compounds, their availability and pollution resulting from energy consumption. There are different types of energy resources, as shown in **Fig. 2**.

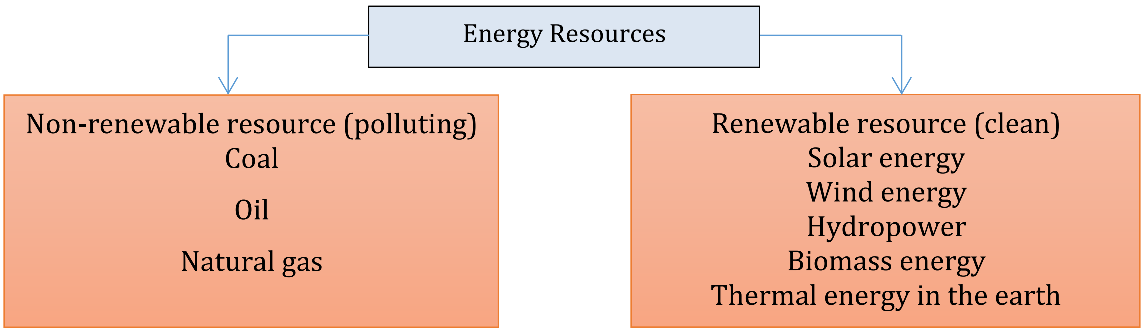

Figure 2. The sources of energy **(Khitoliya, 2004)**

4.1 Non-renewable Energy Resource

a. Coal: is a vital energy source and consists mainly of carbon, impurities, and other compounds. The components of coal can be divided into major elements, including carbon, hydrogen, oxygen, nitrogen, and sulfur **(IEA, 2005)**.
b. Petroleum: It is an essential resource in our country due to its presence in large quantities. Crude oil is a complex mixture of organic compounds, mainly of hydrocarbons. The composition of crude oil varies in size and composition. There are energy sources from nuclear reactors with high pollution and dangerous radiation.

C. Natural gas: It is a necessary fossil fuel that produces energy and heat. It consists mainly of a mixture of hydrocarbon compounds, and its most important compounds are methane, CH_4, ethane, $C2H_6$, and a small percentage of carbon dioxide, hydrogen sulfide, nitrogen, and helium, as it is formed through the anaerobic decomposition of organic materials. Methane constitutes the most significant percentage, 85%, and is less polluted than other types of fossil fuels **(Ghassemi, 2001)**.

4.2 Renewable Energy Resources

a. Solar energy: This renewable and clean energy uses sunlight to generate electricity or heat. Solar energy can be obtained through photovoltaic solar cells and solar mirrors. Photovoltaic solar cells are considered a common way to convert sunlight directly. Solar mirrors are used to concentrate and collect sunlight to develop highly concentrated heat to generate steam, thus operating turbines to generate electricity **(Twidell, 2021)**.

b. Wind Energy: Wind energy is a form of renewable energy that uses the wind's power to generate electricity. This is usually done using "wind generators" that convert air movement into electrical energy. Electricity is generated from the wind by using the kinetic energy of the wind movement to rotate giant fans called "wind turbines," which convert this rotational movement into electrical energy via an electric generator **(Blanco, 2009)**.

c. Water Energy: Electricity is generated from water energy by using the power of flowing or stored water to rotate electric turbines that generate electricity. Multiple sources of water energy are available, including dams, small dams, tides, thermal heaters, surface dams, water tunnels, wave energy, and sea currents. This water energy is converted into mechanical energy and then into electricity. The great advantage of water energy is that it is clean, renewable, non-polluting, and has a high electricity production if used. Sustainably hydropower can provide a stable and reliable source of electricity **(Khitoliya, 2004)**.

d. Biomass energy (bio-energy): The source of this energy is by burning biomass (direct burning). It depends on using biodegradable organic materials such as firewood, rice husk, grain husk, etc., and converting them into thermal energy first and then electricity. Biomass is modified through burning or fermentation processes. When the biomass is burned, it is ignited in an environment without oxygen (in a lack of oxygen) where it is used. The heat of combustion heats water and turns it into steam, which drives an electric turbine that generates electricity.

e. Geothermal energy: Geothermal fluid can be used to produce electricity and is a safe renewable energy resource. This energy depends on taking advantage of the heat stored in rocks, liquids, and even gases in the earth's inner layers. The process usually works on heating media, such as water in the ground, which is transformed into hot steam that can drive turbines to generate electricity **(Archer, 2020)**.

5. ENERGY FOR LAND USE IN THE CITY

Planning has a significant impact on energy use in cities. We will learn about land uses based on consumption:

a. Residential use: covers all energy needed for activities performed by residents, excluding modes of mobility.

b. Industrial use: it covers the energy consumed in the production process because it represents a combination of all industries. Examples include mining, quarrying, iron, and construction.
c. Commercial use refers to energy utilized in commercial and public services such as wholesale and retail commerce, hotel and restaurant operations, and other real estate, rental, and commercial activities.
d. Transport :Land transport encompasses all fuel types utilized in land vehicles, including military, agricultural, and industrial. Agriculture, hunting, and forestry include the energy consumed in agricultural and hunting operations.
e. Energy is consumed in public service: Facilities such as government buildings, street lighting, and open spaces **(UN-Habitat, 2008)**. **Fig. 3** below shows the effect of land use on energy consumption.

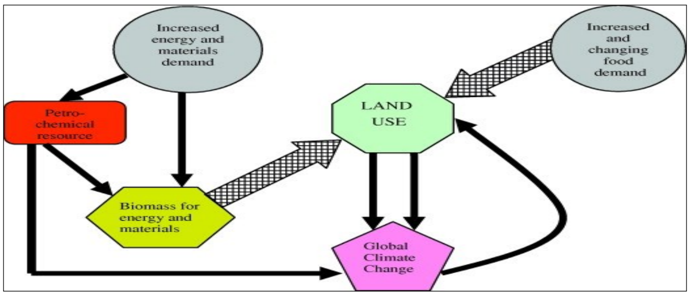

Figure 3. Shows the impact of land use on energy **(Harvey and Pilgrim, 2011)**

6. CASE STUDY

The Al-Zaafaraniya area was chosen as an area, and the Al-Zaafaraniya area is considered one of the residential areas that emerged after the modern city of Baghdad emerged from the threat of the Tigris River flood in 1954. Before that, it included agricultural land, which was among the floods of the Tigris River, where water flooded an area for four days between 1942 and 1954. Its name is clear saffron, as it was the saffron-growing area (Al-Zaafaraniya district).

6.1 Population of Case Study

The population of Al-zaafaraniya, according to 2010 statistics, reached 640,000 people, and the growth rate for Iraq in 2023 is 2.56 % (Iraqi Ministry of Planning). To predict the population in 2023, apply the population growth equation:

$$Pn = P0\ (1\ +\ r)\ n^{n} \quad (1)$$

Where:
• Population for the required year (Pn)
• Population for the known year (P0)
• Population growth rate (r)
$P\ 2023\ =\ 640{,}000\ (1 + 2.56\ \%)^{13}\ =\ 889{,}000\ people$

6.2 Location and Area

The Al-Zaafaraniya area is located southeast of Baghdad in Al-Rusafa, at the intersection of latitude (44°33) and longitude (35°44). It has an area of 4,760 hectares. The Tigris River borders the area to the west and the Diyala River to the south. Baghdad is linked to the Al-Zaafaraniya area by an old main road towards the southern governorates. **Fig. 4** shows the location of the Al-Zaafaraniya area in relation to the city of Baghdad (Karada Municipality Directorate, GIS). Administratively, it consists of three main communities (Al-Zaafaraniya community, Sindbad community, and Diyala community). These communities are divided into 25 neighborhoods, as shown in **Fig. 5**.

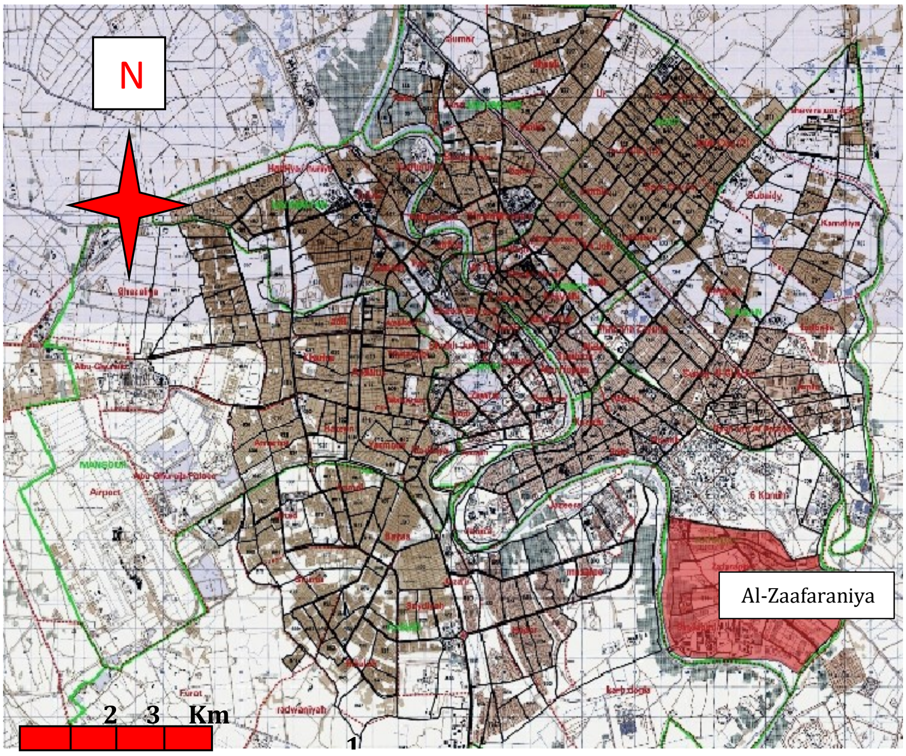

Figure 4. Shows the location of Al-Zaafaraniya from Baghdad (Baghdad Municipality - GIS Department of Geographic Information Systems)

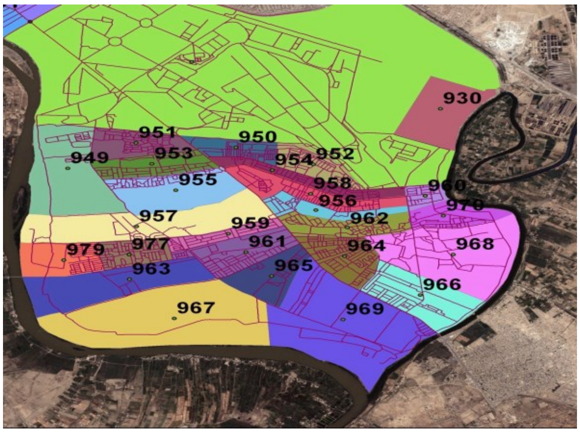

Figure 5. Shows the neighborhoods in the Al-Zaafaraniya area (Karrada Municipality)

The Al-Zaafaraniya area was administratively part of the Karrada municipality and was separated from the Al-karrada area in the year 2023 and has been listed as a district in the directory of administrative units of the Republic of Iraq (Iraqi Ministry of Planning).

6.3 Reasons for Choosing the Case Study

Because of its important location in Baghdad, as the Tigris River borders it, has witnessed high population growth and increase in recent times. The diversity of land characterizes its uses, as shown in **Fig. 6** for housing and industry, as it contains many small industries, including the Pepsi Baghdad factory, military industries, other industries, the Baghdad Thermal Power Station, the Second South Baghdad Gas Station and important, government buildings including the Central Technical University and its departments, Al-Zaafaraniya General Hospital, and other government buildings and many commercial uses. **Table 2** shows the usage rates.

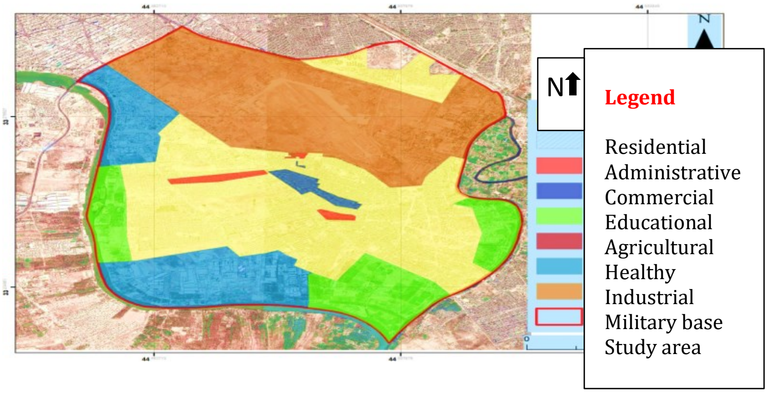

Figure 6. Shows the land uses of Al-Zaafaraniya area **(Obaid, 2023)**

Table 2. The percentages of land use in Al-Zaafaraniya depend on (GIS)

Usage	Usage rate %
Residential	45
Government	24
Transport	12
Industrial	11
Commercial	2
Other uses (public utilities + agricultural)	6
Total	100

6.4 Energy Footprint of Case Study

Although the carbon footprint has become an important tool for monitoring greenhouse gases, the methods for calculating the carbon footprint are still under development, and a regulatory framework can be created to measure the carbon footprint. The framework consists of four steps **(Pandey and Agrawal, 2011)**.

1. Determine the greenhouse gases to be calculated.
2. Determine the required period.
3. Determine the required area.
4. Collect and analyze data and calculate the carbon footprint.

There is a question when calculating the carbon footprint does the carbon footprint and the energy footprint represent one concept? The energy footprint on a smaller scale is the cause of the increase or decrease in carbon emissions and has a direct relationship with the carbon footprint. From the quantitative side, the energy footprint represents the carbon footprint. The energy footprint will be classified into several footprints, as shown in **Fig. 7**, **(Malmodin and Lundén, 2018)**.

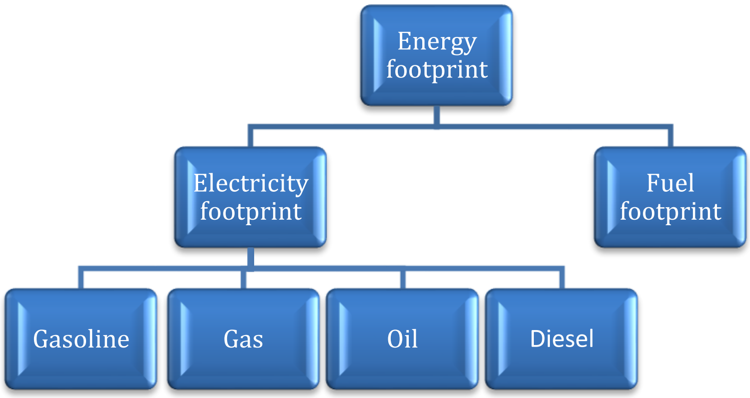

Figure 7. Classification of energy footprint **(Estabraq, 2021)**

6.4.1 Electricity Footprint

The per capita share of electricity for 2023 is (2670 kwh) where kwh means one kilowatt per hour **(Iraqi Ministry of Electricity, 2023)**. The population of Al-Zaafaraniya in 2023 is (889,000 people)

Consumption of Electricity in Al-Zaafaraniya = 2670 * 889,000 = 2,373,630,000 kwh
This quantity is equivalent to 491,507 kgCO2 through **(Rensmart, 2024)**
To convert to metric tons of CO_2, where ($1tCO_2$ = 1000 KgCO2)
Electricity footprint of Al-Zaafaraniya = 491,507 tCO_2

6.4.2 Fuel Footprint

The fuel footprint will be calculated by fuel type and carbon equivalent as follows:

6.4.2.1 *Gasoline*

Iraq's consumption of gasoline is (31 million liters per day) in 2023 (Iraqi Ministry of Oil). The population of Iraq in 2023 (45,262,225 people) according to statistics (Iraqi Ministry of Planning).

$$\text{Iraqi per capita daily share} = \frac{31{,}000{,}000}{45{,}262{,}225} = 0.68 \text{ liters}$$

$\text{Per capita annual rate} = 0.68 * 365 \text{ days} = 248 \text{ litres}$
$\text{Consumption of gasoline in Al} - \text{Zaafaraniya} = 248 * 889{,}000 = 220{,}472{,}000 \text{ liters}$
$\text{Where energy conversion factor} = (1 \text{ liter of gasoline is equivalent to } 2.168{,}020 \text{ kgCO2})$
$2.168{,}020 * 220{,}472{,}000 = 477{,}987{,}705 \text{ kgCO2}$ **(UK-GHG, 2020)**
$\text{Gasoline footprint in ton} = 477{,}988 \text{ tCO2}$

6.4.2.2 *Gas*

Iraq's consumption of gas is (6,800,000 tons per day).
The population of Iraq (45,262,225 people) in 2023 (Iraqi Ministry of Oil). To convert into cubic meters, where (1 ton = 2.12 cubic meters) $6{,}800{,}000 * 2.12 = 14{,}416{,}000$ m3

$$\text{Iraqi per capita daily share} = \frac{14{,}416{,}000}{45{,}262{,}225} = 0.32 \text{ m3}$$

$\text{Per capita annual rate} = 0.32 * 365 \text{ days} = 116.8 \text{ m3}$
$\text{Consumption of gas in Al} - \text{Zaafaraniya} = 116.8 \text{ m3} * 889{,}000 = 103{,}835{,}200 \text{ m3}$
$\text{Where energy conversion factor} = (\text{1 cubic meter of gas is equivalent to } 2.02266 \text{ kgCO2})$
$103{,}835{,}200 * 2.02266 = 210{,}023{,}305 \text{ kgCO2}$ **(UK-GHG, 2020)**
$\text{Gas footprint in ton} = 210{,}023.305 \text{ tCO2}$

6.4.2.3 *Oil*

Iraq's consumption of oil was (3064 * 10^6 liters) in 2012 **(Arab Energy Conference).** The population for the same year was (33.86 million people)

$$\text{Per capita annual rate} = \frac{3064 * 10^6}{33{,}860{,}000} = 90 \text{ liters}$$

$\text{Consumption of oil in Al} - \text{Zaafaraniya} = 90 * 889{,}000 = 80{,}010{,}000 \text{ liters}$
$\text{Where energy conversion factor} = (\text{1 liter of oil is equivalent to } 2.65576 \text{ kgCO2})$
$80{,}010{,}000 * 2.65576 = 212{,}487{,}358 \text{ kgCO2}$ **(UK-GHG, 2020)**
$\text{Oil footprint in ton} = 212{,}487.358 \text{ tCO2}$

6.4.2.4 *Diesel*

Iraq's consumption of diesel is (21 million liters per day) in 2023 (Iraqi Ministry of Oil). The population of Iraq in the 2023, which is (45,262,225 people)

$$\text{Iraqi per capita daily share} = \frac{21{,}000{,}000}{45{,}262{,}225} = 0.46 \text{ liters}$$

$\text{Per capita annual rate} = 0.46 * 365 \text{ days} = 168 \text{ litres}$
$\text{Consumption of diesel in Al} - \text{Zaafaraniya} = 168 * 889{,}000 = 149{,}352{,}000 \text{ liters}$
$\text{Where energy conversion factor} = (\text{1 liter of gasoline is equivalent to } 2.75776 \text{ kgCO2})$
$149{,}352{,}000 * 2.75776 = 411{,}876{,}971 \text{ kgCO2}$ **(UK-GHG, 2020)**
$\text{Diesel footprint in ton} = 411{,}877 \text{ tCO2}$

7. RESULTS AND DISCUSSION

$\text{Fuel footprint of Al} - \text{Zaafaraniya in 2023} = 477{,}988 + 210{,}023.305 + 212{,}487.358 +$
$+ 411{,}877 = 1{,}312{,}375 \text{ tCO2}$
$\text{Energy footprint} = \text{electricity footprint} + \text{fuel footprint}$
$\text{Energy footprint of Al} - \text{Zaafaraniya in 2023} = 491{,}507 + 1{,}312{,}375 = 1{,}803{,}882 \text{ tCO2}$
$\text{Energy footprint in kilotons of Al} - \text{Zaafaraniya in 2023} = 1804 \text{ ktCO2}$

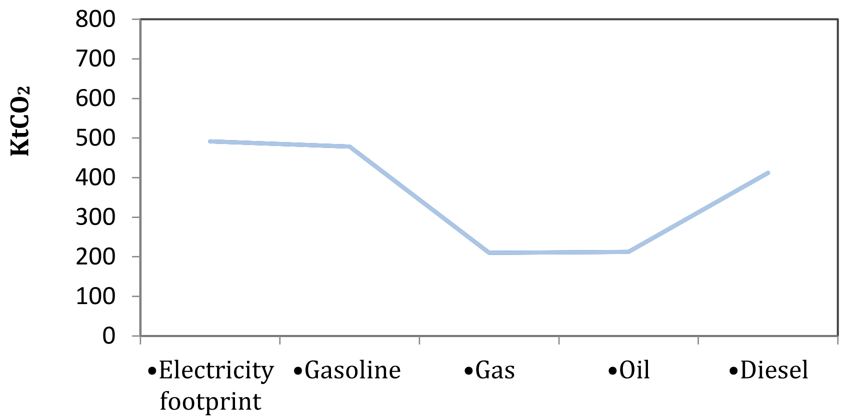

Figure 8. Shows the carbon footprint of energy consumption in Al- zaafaraniya

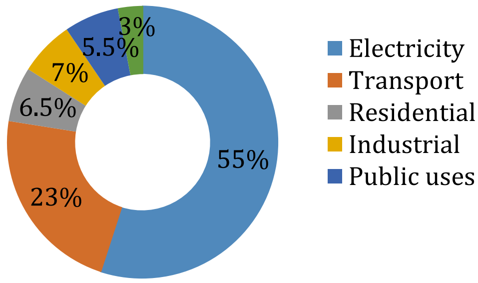

Figure 9. Shows the rates of energy consumption by sectors **(Ersoy and Terrapon-Pfaff, 2022)**

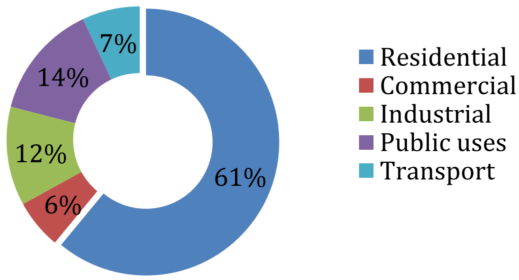

Figure 10. Shows the rates of electricity consumption relative to uses in cities **(Iraqi Ministry of Planning, 2023)**

- Based on the figure above, it is possible to distribute the 55% of electricity consumption among uses to extract the energy consumption for land uses in the study area.
- For example, if we want to calculate the percentage of consumption for residential use, we can use the following formula: $[(0.61 * 0.55) + 0.065] * 100\% = 40\%$

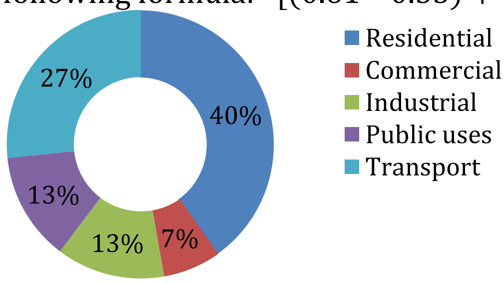

Figure 11. Shows the percentages of energy consumption for land use in Al- Zaafaraniya

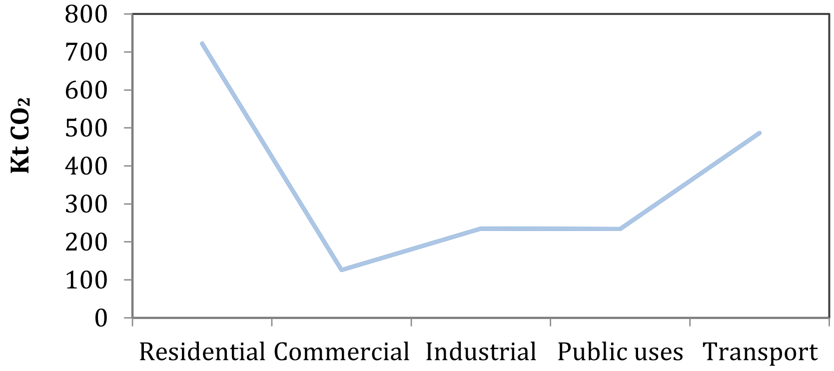

Figure 12. Distribution of the footprint of energy consumption in Al-Zaafaraniya according to land use

8. CITY PLANNING STRATEGIES TO REDUCE THE CARBON FOOTPRINT OF ENERGY CONSUMPTION

The city planning strategy depends on reducing energy consumption and thus reducing pollution resulting from carbon emissions. Applying these strategies to the city of Al-Zaafaraniya is possible **(Shaheen, 2016)**.

1. Therefore, compact design increases the density of buildings, facilitates accessibility, facilitates public transportation, and combines land use and green spaces. Thus, reducing energy consumption can be applied to the city of Al-Zaafaraniya. There is an inverse relationship between compactness and energy consumption. The greater the compactness leads, the lower the energy consumption curve, as shown in **Fig.13**.

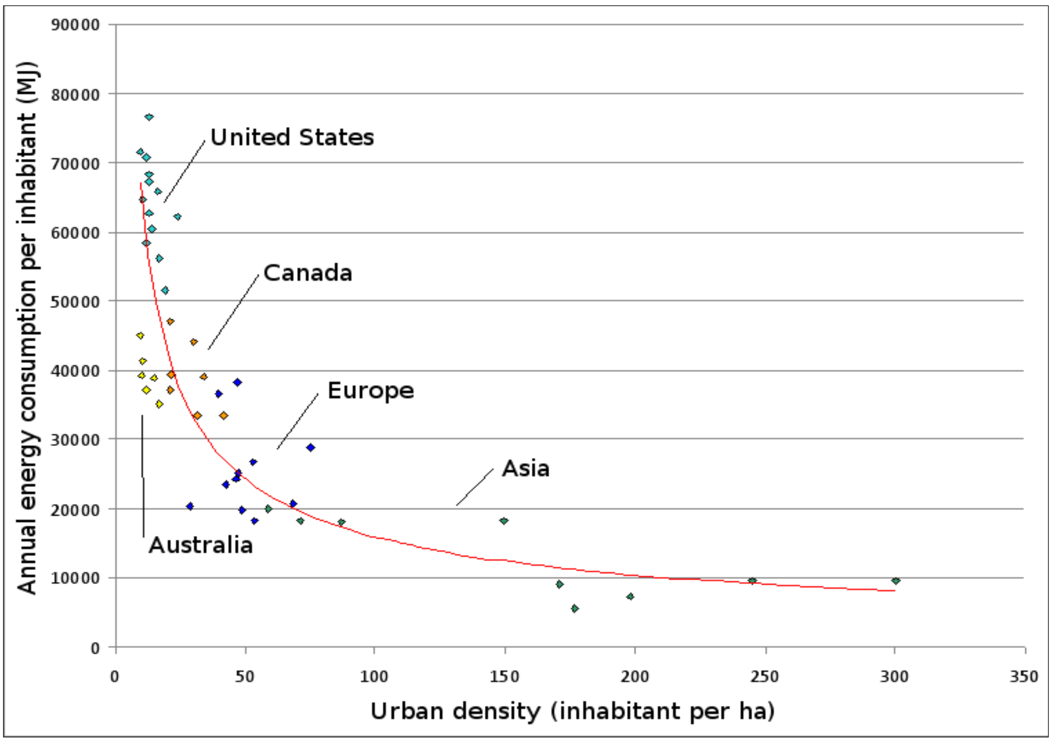

Figure 13. Relationship between compaction and energy consumption **(Le Nechet, 2012)**

2. The house's unique design depends on solar energy to generate electricity and provide comfort in terms of ventilation and lighting, as it is easy to rely on this in Al-Zaafaraniya to cover electricity consumption, reducing 55% of the total energy consumption.
3. Waste recycling after sorting waste from buildings is transported using vehicles designated for each material and then utilized by recycling and using it again. Waste that cannot be recycled can be disposed of by landfilling or burning, and the methane gas generated from burning waste can be used to generate energy, thus reducing it to as much waste as possible **(Newman et al., 2008)**.
4. And then at the city level, by consuming renewable energy to meet residents' energy needs and recycling waste to reduce lost energy. Increasing renewable energy by 1% can reduce the carbon footprint by 0.16% **(Elshimy and El-Aasar, 2020)**.

Germany's use of renewable energy (water, solar energy, wind, biomass, subsurface temperature) has reached 20% of energy savings. An innovative future situation is to use 50% of the energy to produce services. If this percentage were applied, we could reduce the carbon footprint in Al-Zaafaraniya by half. It becomes an amount (902 $ktC0_2$).

9. CONCLUSIONS

This study identified the city's inputs represented by energy consumption in human activity and the resulting carbon gas outputs defined by the energy footprint that was calculated based on the case study and how traditional methods and planning increase energy consumption and the research reached these conclusions:

1. Greenhouse gases cause global warming and climate change, as carbon dioxide constitutes 83% of greenhouse gases.
2. The study area represented by Al- Zaafaraniya is witnessing a high population increase. In 2010, the population, according to statistics, was 640,000 people, while in 2023, it was 889,000 people. This increase is accompanied by high energy consumption and, thus, an increase in the energy footprint.
3. The highest energy footprint is electricity consumption due to traditional methods of using electricity in homes and relying on conventional energy to generate electricity.
4. Gasoline consumption ranks second in terms of footprint, with Iraq’s consumption (31 million liters per day) in 2023 due to its high dependence on private vehicles.
5. Diesel comes in third place with a high energy consumption compared to vehicle consumption and the share of private generators in producing electricity for residents, where the daily per capita share is 0.46 liters.
6. The highest energy footprint is in residential use at 40%, followed by transportation at 27%. We notice a difference between other uses compared to residential use and transportation.
7. The energy footprint reached in case study (1804 $ktCO_2$) is not at the level of danger, but this footprint is constantly increasing.
8. It is possible to follow sustainable planning strategies to reduce the continuous increase in the carbon footprint, such as relying on clean energy to generate electricity, which reduces the carbon footprint by 50% by following the rationalizing electrical energy consumption in homes through good manufacturing of electrical appliances, imposing fees on excessive use, encouraging public transportation, reducing migration to city centers, and increasing green spaces.

Acknowledgements

Thanks to the Center for Urban and Regional Planning at the University of Baghdad for their scientific support in completing this research paper.

Credit Authorship Contribution Statement

Husam Ahmed Al-Shiblawi is responsible for collecting data, performing numerical operations and applying it to the case study, analyzing and interpreting the manuscript, and reviewing and editing the manuscript. Suaad Jaber Laffta supervised, reviewed and edited the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

REFERENCES

Al-Najjar, H. M. T., 2015. Study of energy gains by orientation of solar collectors in Baghdad city. *Journal of Engineering*, *21*(10), pp. 17-35. Doi:10.31026/j.eng.2015.10.02

Al-Rafo, S., Shaheen, B., 2008. Sustainable environmental planning & designing as an energy conservation basics. *Journal of Engineering*, 14(03), pp. 420-442. Doi:10.31026/j.eng.2008.03.03

Archer, R., 2020. Geothermal energy. In Future Energy, Elsevier, pp. 431-445. Doi:10.1016/B978-0-08-102886-5.00020-7

Azevedo, A., Bettencourt, P., Almeida, P. B., Santos, A. C., Abreu-Lima, C., Hense, H. W., and Barros, H., 2007. Increasing number of components of the metabolic syndrome and cardiac structural and functional abnormalities–cross-sectional study of the general population. *BMC Cardiovascular Disorders*, *7*, pp. 1-9. Doi:10.1186/1471-2261-7-17

Bancheva, S., 2014. Integrating the concept of urban metabolism into planning of sustainable cities: analysis of the eco2 cities initiative. *Development Planning Unit, University College London*. Doi:10.13140/RG.2.2.13693.77280

Blanco, M. I., 2009. The economics of wind energy. *Renewable and Sustainable Energy Reviews*, *13*(6-7), pp. 1372-1382. Doi:10.1016/j.rser.2008.09.004

Boersema, J. J., and Reijnders, L., 2009. Principles of environmental sciences *Netherland,* pp. 3-14. Doi:10.1007/978-1-4020-9158-2

Butera, F. M., Morello, E., Pastore, M. C., and Leonforte, F., 2018. Energy and resource efficient urban neighbourhood design principles for tropical countries. Practitioner's guidebook, UN-HABITAT, Nairobi, Kenya, HS Number: HS/058 E, 18. Doi:10.1016/B978-0-08-102074-6.00017-6

Currie, P. K., Musango, J. K., and May, N. D., 2017. Urban metabolism: a review with reference to Cape Town. *Cities*, *70*, pp. 91-110. Doi:10.1016/j.cities.2017.06.005

Elshimy, M., El-Aasar, K.M., 2020. Carbon footprint, renewable energy, non-renewable energy, and livestock: testing the environmental Kuznets curve hypothesis for the Arab world. *Environ Dev Sustain*, pp. 6985–7012. Doi:10.1007/s10668-019-00523-0

Engel-Yan, J., Kennedy, C., Cuddihy, J., 2007. The changing metabolism of cities. *Journal of Industrial Ecology*, *11*(2), pp. 43-59. Doi:10.1162/jie.2007.1107

Ersoy, S. R., Terrapon-Pfaff, J., 2022. Sustainable transformation of Iraq's energy system development of a phase model. https://nbnresolving.org/urn:nbn:de:bsz:wup4-opus-78914.

Estabraq Sh. Abdulbari, 2021. Carbon footprint and its implications for city sustainability, M.Sc. thesis in *Urban and Regional Planning* at the university of Baghdad, Iraq.

Evans, R. L., 2007. Fueling our future, an introduction to sustainable energy. *Cambridge University Press - UK*. Doi:10.1017/CBO9780511807015

Iraqi Ministry of Planning, 2023. Electricity indicators report. Iraqi Ministry of Electricity- Statistics, p5. https://cosit.gov.iq/documents/industrial/water&electric

Foster, J. B., 2000. *Marx's ecology: Materialism and nature*. NYU Press-USA. Doi:10.2307/3341498

Ghassemi, A., 2001. Handbook of pollution control and waste minimization. *CRC Press - USA*. Doi:10.1142/8699

Gladek, E., van Odijk, S., Theuws, P., Herder, A., 2014. Circular buiksloterham/tranditioning Amsterdam to a Circular City. *Metabolic, Studiodots & DELVA Landscape Architects*. Doi:10.13140/RG.2.1.2926.5120

Golubiewski, N., 2012. Is there a metabolism of an urban ecosystem and ecological critique. *Ambio*, *41*(7), pp. 751-764. Doi:10.1007%2Fs13280-011-0232-7

Harvey, M., Pilgrim, S., 2011. The new competition for land: Food, energy, and climate change. *Food policy*, *36*, pp. 40-51. Doi:10.1016/j.foodpol.2010.11.009

IEA, Energy Policies of Countries, 2005. *Review*. https://www.iea.org/reports/energy-policies-of-iea-countries-2005-review

Kennedy, C., Pincetl, S., and Bunje, P., 2011. The study of urban metabolism and its applications to urban planning and design. Environmental pollution, 159(8-9), pp. 1965-1973. Doi:10.1016/j.envpol.2010.10.022

Khitoliya, R.K., 2004. Environmental pollution management and control for sustainable development. *S. Chand and Company, New Delhi*, 309. Doi:10.54536/ajec.v1i2.602

Le Nechet, F., 2012. Urban spatial structure, daily mobility and energy consumption: a study of 34 european cities. Cybergeo: *European Journal of Geography*. Doi:10.4000/cybergeo.24966

Ma, C., Ju, M. T., Zhang, X. C., Li, H. Y., 2011. Energy consumption and carbon emissions in China. *Procedia Environmental Sciences*, pp. 1-9. Doi:10.1016/j.proenv.2011.03.001

Malmodin, J., Lundén, D., 2018. The energy and carbon footprint of the global ICT and E&M sectors 2010–2015. *Sustainability*, *10*(9). Doi:10.3390/su10093027.

Newman, D. M., Heptinstall, J., Matelon, R. J., Savage, L., Wears, M. L., Beddow, J., Mens, P. F., 2008. A magneto-optic route toward the in vivo diagnosis of malaria: preliminary results and preclinical trial data. *Biophysical journal*, *95*(2), pp. 994-1000. Doi:10.1529/biophysj.107.128140

Obaid, Z., 2023. Activating the role of spatial planning in the urban security system, M.Sc. thesis in *Urban and Regional Planning at university of Baghdad in Iraq*.

Pandey, D., Agrawal, M., 2011. Carbon footprint: current methods of estimation. *Environmental monitoring and assessment*, *178*, pp. 135-160. Doi:10.1007/s10661-010-1678-y

Pincetl, S., Bunje, P., & Holmes, T., 2012. An expanded urban metabolism method: toward a systems approach for assessing urban energy processes and causes. *Landscape and urban planning*, *107*(3), Elsevier, pp. 193-202. Doi:10.1016/j.landurbplan.2012.06.006

RenSMART, 2024. The Energy Information Source. https://www.rensmart.com/Calculators/KWH-to-CO2

Restrepo, J. D. C., and Morales-Pinzón, T., 2018. Urban metabolism and sustainability: precedents, genesis and research perspectives. *Resources, Conservation and Recycling*, *131*, pp. 216-224. Doi:10.1016/j.resconrec.2017.12.023

Saguin, K., 2019. Urban metabolism. *The Wiley Blackwell Encyclopedia of Urban and Regional Studies*, pp. 1-5. Doi:10.1002/9781118568446.eurs0378

Salim, A., 2008. Sustainable architecture levels. *Journal of Engineering*, 14(04), pp. 560–583. Doi:10.31026/j.eng.2008.04.04.

Sawant, S., Babaleshwar, B., 2015. A New Method of Assessment and Equations on Carbon Footprint. J. Appl. *Geology and Geophysics*, 3, pp. 52-59. Doi:10.9790/0990-03415259

Shaheen, B. R., 2016. Environment friendly Eco-City. *Journal of Engineering*, *22*(2), pp. 1-20. Doi:10.31026/j.eng.2016.02.11

Twidell, J., 2021. Renewable Energy Resources, USA. Doi:10.4324/9780429452161

UK Government GHG Conversion Factors for Company Reporting, UK-GHG, 2020. https://assets.publishing.service.gov.uk/media/62aed8f6d3bf7f0af9463486/ghg-conversion-factors-2022-full-set.xls

UNEP, 2018. Urban Metabolism For Resource-Efficient Cities. https://resourceefficientcities.org/wp-content/uploads/2017/09/Urban-Metabolism-for-Resource-Efficient-Cities.

UN-HABITAT, 2008. Energy Consumption in Cities. https://unhabitat.org/topic/urban-energy

Wiśniewski, P., and Kistowski, M., 2017. Carbon footprint as a tool for local planning of low carbon economy. *Rocznik Ochrona Środowiska*, P. *19*. Doi:10.12912/23920629/66984.

Wolman, A., 1965. The metabolism of cities. *Scientific American*, *213*(3), PP. 178-193. Doi:10.1038/scientificamerican0965-178

Yıldırım, H. H. Y., Gültekin, A. B., Tanrıvermiş, H., 2017. Evaluation of cities in the context of energy efficient urban planning approach. In *IOP Conference Series: Materials Science and Engineering,* IOP Publishing, (Vol. 245, No. 7, p. 072051). Doi:10.1088/1757-899X/245/7/072051