



Reducing carbon emissions in Egyptian roads through improving the streets quality

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Abstract

The streetscape of any city reflects the natural built fabric of the street and adds to the experiential quality of that space. A sustainable streetscape ensures that the spaces are long-lasting and functional as a part of the greater sustainable eco-system. Over the past two centuries, mankind has increased the concentration of carbon dioxide (CO₂) in the atmosphere from 280 to more than 380 parts per million by volume, and it is still increasing every day. If Earth continues to emit carbon without control, the surface temperature is expected to rise by 3.4 °C by the end of this century. Climate change of that magnitude would likely have serious, long-lasting, and, in many cases, devastating consequences for the planet Earth. Egypt has become one of the biggest emitters of atmospheric pollutants from the transportation sector. The level of carbon emissions and its effect on air quality are placed high on the research agenda. The transportation sector has a great impact on increasing CO₂ emissions. The transportation and traffic sectors produce a quarter of the global CO₂ emissions due to the heavy use of fossil fuels. This research aims to study the effects of street shape and design on CO₂ production. This paper presents an analysis of road transportation in Egypt, taking Helmet EL-Zaitoun as the main case study, with a focus on energy demand and carbon dioxide (CO₂) emissions. Carbon emissions are measured using “Testo 315-3” as a measuring instrument to identify the relationship between street design and quality on the amount of carbon emissions produced. The results of this research suggest that street quality affects the amount of CO₂ emissions produced. A car moving at a constant speed will produce fewer CO₂ emissions than a car forced to start–stop every while because of external factors such as cracks in the roads occurring from bad streetscape elements. The presented research provides a set of guidelines to enhance the quality of the streetscape and design in order to reduce the amount of CO₂ produced in the streets.

Keywords Streetscape · Road pavement · Air pollution · Transportation and vehicles

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1 Introduction

Since the Industrial Revolution, a rapid increase in CO₂ has happened due to the consumption of fossil fuels (Wrigley, 2013). This has led to many problems in the global carbon cycle; this disturbance is basically leading to a planetary warming impact (Wrigley, 2013). Since carbon dioxide (CO₂) is a gas that absorbs and emits thermal radiation, it creates the “greenhouse effect,” along with other greenhouse gases (Eid et al., 2007; Galashev & Rakhmanova, 2013; IPCC, 2019; Moussa, 2019a, 2019b; Moussa et al., 2021).

Carbon dioxide is the primary cause of heat trapping which is known as “greenhouse gas,” responsible for global warming, in addition to other nitrogen and sulfur oxides responsible for various environmental impacts such as ozone depletion and climatic changes (Abdallah & El-Shennawy, 2013; IEA, 2018). The effects of global warming range from ecological, physical, and health impacts, including extreme weather events (such as floods, droughts, storms, and heatwaves); sea-level rise; altered crop growth; and disrupted water systems (IPCC, 2019; Ritchie & Roser, 2017). Over the past two centuries, mankind has increased the concentration of CO₂ in the atmosphere from 280 to more than 380 parts per million by volume, and it is still increasing every day (CDIAC, 2017).

Global carbon dioxide emissions increased from 0 in 1850 to 32,500 million metric tonnes in 2010, and it is expected to reach 39,000 million metric tonnes by 2030 (CDIAC, 2017). According to the statistics, almost a quarter of carbon emissions are produced by the transportation sector (Moussa, 2019b, 2021). The main concern of this research is that the level of air pollution in Egyptian roads is increasing due to the heavy use of fossil fuels in roads, poor street quality, and poor design of streetscapes. This research suggests that streetscape elements and design can help cities meet the environmental challenges of the planet, including climate change and global warming (Moussa, 2021; Rehan, 2013).

A successful urban development relies on the surrounding physical environment; streetscape is considered a major component of the urban fabric. Streetscapes describe the area where public and private interests combine to create the identity of a commercial district; they include a variety of elements, such as cars, parking and bike lanes, sidewalks, street furniture, bus stops, utility poles, trees and vegetation's, signage which have the ability to affect the place either positively or negatively.

This research tackles the effect of streetscape elements on CO₂ production by using an experimental method to investigate the effect of streetscape quality on CO₂ emissions production in Cairo. The study chooses a street in Cairo, Egypt, that can be divided into three zones according to the street's condition and elements to be the study area of this research. This research focuses on studying the effect of the quality of one streetscape element and one sub-element, which is road pavements, on the percentage of CO₂ emissions produced. By measuring the amount of CO₂ produced from vehicles passing through good pavements with high structural and finishing quality and pavements with cracked and irregular bumps, moreover, the presented research provides a set of guidelines to enhance the quality of the streetscape and design in order to reduce the amount of CO₂ produced. Achieving sustainable communities and cities by reducing carbon emissions using streetscapes and roads is the main concern of this paper.

Good streetscapes can be defined as those that are well-constructed, connected, and pedestrian-friendly (Abass & Tucker, 2020). Examples of good streetscapes can be found in Belmont, Grovedale, and Waurin Ponds suburbs (Abass & Tucker, 2020).

2 Research methodology

The presented research focuses on reducing the road’s carbon emissions through improving the street conditions and quality, which affect cars negatively and cause a lot of car accidents. The research will study the impact of street conditions on car speed, driving behavior, and the amount of carbon emissions released as shown in Fig. 1.

The procedures of this research consisted of different parts. The first location chosen is one where both a good and a bad streetscape exist. Road and sidewalk conditions and construction materials are used as an indicator to identify the quality of streetscape elements. A typical range of 2 represents a high-quality surface similar to that of airport runways and superhighways. While regular roads ranged from 3 to 6, where 3 represents good quality, while 6 represents that the road is in need of urgent maintenance, the more the number increases, the more the roughness increases. Rough roads limit the maximum speed while causing discomfort to the passengers. Fuel consumption increases by up to 3% for an average light commercial vehicle and by 4% for a medium-sized passenger car for an IRI value of 5 mm/m compared to a reference IRI D 2 mm/m surface. The roughness of roads affects travel time, leading to an increase in the fuel consumption of vehicles (Moussa, 2021).

Measurements of the study areas are carried out to be able to know their length and width. Then the calculation of the number of vehicles crossing by is conducted regarding their type at different times of the day. By doing so, it is possible to know the average number of vehicles crossing each day by multiplying the total average of each type of vehicle by 3. Furthermore, the basic amount of CO₂ emissions that should be produced by one vehicle is estimated using the previously provided information and is included in the data collection. After that, the research calculated the actual CO₂ emissions from vehicles using the "Testo 315-3" meter. By knowing the amount of emissions from just one vehicle, it is possible to calculate the total CO₂ emissions occurring in each study area over the whole day.

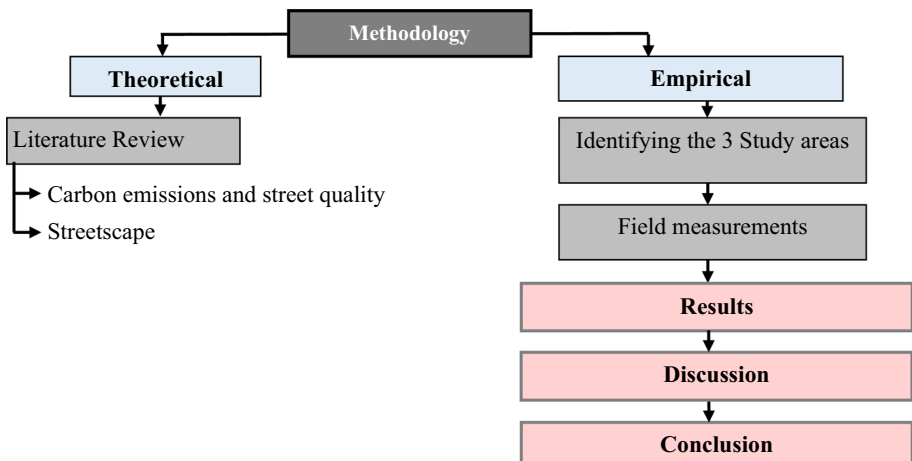


Fig. 1 Research methodology

3 Literature sections

In 2019, the transportation sector accounted for approximately 32% of total emissions in Egypt (Mansour et al., 2019; Moussa, 2019b). Egypt is ranked number 10 as the country with the fastest greenhouse gas emissions (Hegazy et al., 2017; Moussa et al., 2020).

The fact that the utilization of fuel in transportation sector containing more than 1.5% sulfur is limited by law at urban regions or adjoining local locations, around 4 million tonnes overwhelming oil (2.5–3% S) is utilized by industry and power control stations. Nearly 52% of this sum is utilized at Cairo's energy stations. Substantial oil and gaseous petrol are the real energy sources utilized for control purposes in Cairo, representing 60% and 40% separately. Table 1 summarizes the amount of energy consumed in Egypt by different sectors and the type of energy used (Hegazy et al., 2017).

As shown in Table 1, a poorly designed streetscape has a significant impact on energy consumption and carbon emissions in Egyptian streets. Moreover, Egypt has recently been undergoing rapid urbanization and industrialization (Hegazy et al., 2017; Solban & Moussa, 2019, 2021).

3.1 Transport sector and CO₂

Egypt is considered the largest Arab country, with more than 100 million people, which makes it the second most populous country in Africa (CEDARE, 2016). Between the years 2003 and 2004, the number of people using the roads for transport was around 115.6 billion passengers per km, while freight transport was around 43.1 billion tons/km. The transportation sector in Egypt has a huge share of the country's greenhouse gases, and the reason is the use of fossil fuels. The transportation sector emitted around 29.16% of the overall energy consumption and around 31.6 million tonnes of CO₂ emissions, which is approximately 26% of the total energy-related CO₂ emissions by the year 2004. Since the Egyptian population grows by 2% annually, this increase directly affects the consumption of transportation and, consequently, energy consumption (CEDARE, 2016). Table 2 shows Egypt's main transport indicators; it indicates the passenger traffic.

3.2 Vehicle stock in Egypt

As to vehicle stock in Egypt, in 2013, the number of authorized vehicles in Egypt was 7.04 million, and most of them are in the capital, Greater Cairo. Around half of all vehicles in Egypt are autos, particularly 3.83 million autos. Figure 2 depicts the distribution of various types of vehicles (Hegazy et al., 2017).

The number of vehicles consuming diesel fuel is 33%, as verified by the Central Agency for Public Mobilization and Statistics of Egypt (Campas, 2013), most of which are considered heavy-duty vehicles (Mansour et al., 2019).

3.3 Effects of CO₂ emissions

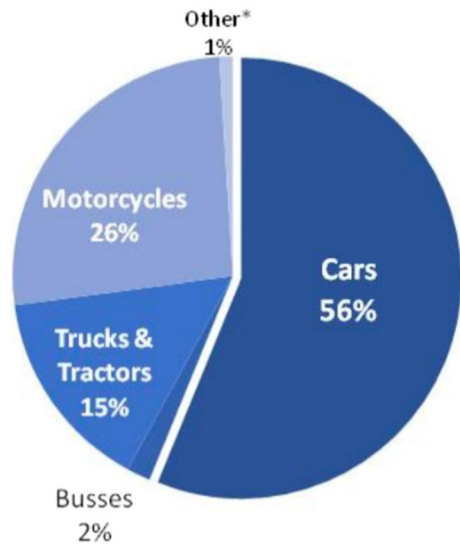
The high concentration of CO₂ in the atmosphere affects the planet's average temperature. Over the past century, the average surface temperature of the Earth has increased by about 0.74 °C. If Earth continues to emit carbon without control, the surface temperature

Table 1 The type and amount of energy consumed by different sectors in Egypt (Hegazy et al., 2017)

Energy source	Sulfur content %	Transportation	Electricity	Industry	Commercial, residential and others	Total
Fossil fuel						
Petrol	0.05	1173	–	–	–	1173
Kerosene	0.15	–	–	6	241	247
Diesel and solar (furnace fuel)	0.9	962	–	993	–	1955
Mazout (heavy fuel oil)	2.7	–	2083	1890	–	3973
Natural gas	–	0.5	1528	286	344	2158.5
Electricity (GWH)	152	–	6540	14,168	20,860	

Table 2 The indicators of different transportation types in Egypt (CEDARE, 2016)

Type of transportation	Indicator	2002–2003	2003–2004
Railways	Passenger/km (million)	46,185	76,090
	Ton/km (million)	38,444	4758
	Railway length (km)	9432	9467
Roads	Passenger/km (million)	113,570	115,845
River transport	Ton/km (million)	309	2375
Pipeline transport	Million tons	6489	6680

Fig. 2 Percentage of different vehicles types in Egypt (Hegazy et al., 2017)

is expected to rise by an additional 3.4 °C by the end of this century. Climate change of that magnitude would likely have serious consequences for life on Earth (Abdallah & El-Shennawy, 2013).

The continuous rise in temperature and climate change is expected to have far-reaching, long-lasting and, in many cases, devastating consequences for planet Earth, such as increasing the sea level, droughts, floods, intense storms, forest fires, water scarcity, and the appearance of cardiorespiratory diseases. There is also another risk: the continued warming will push the planet to "extreme weather events." Other than hot and cold extreme weather conditions, it can also affect hurricane formations, percentage of lightning, and rainstorms (Bradford & Pappas, 2017). Air contamination can cause negative effects on humans when it gathers noticeably all around us in sufficiently high concentrations. Many people live in territories where urban brown haze, contamination, and poisonous toxins pose well-being concerns. Along with the previously mentioned negative effects, human health may be negatively affected by: irritation of the eyes, nose, and throat blockage, chest problems; heavy breathing; asthma; increased risk of heart attack; and many other health problems (McMichael et al., 2003; Ziska et al. 2009). Despite the evidence of dangers caused by climate change, efforts to limit carbon emissions remain insufficient, ineffective,

and in most countries non-existent (Chandler et al., 2002). Given the current carbon emissions circumstances and the best available scientific evidence, carbon emissions need to be reduced by almost 80% of the total percentage by the year 2050 (DOE 2010; Abdallah & El-Shennawy, 2013).

4 Streetscape

Streetscape refers to urban transportation route design. It recognizes that streets are places where people engage in various activities, including but not limited to motor vehicle travel. “Streetscape” is a word used to describe the natural and built fabric of the streets. It can also be defined as the quality of the design of the street and its visual effects (RRM, 2007). It focuses on how the paved area is designed, furnished, and treated. Buildings and street surface with their fixtures, such as bus stops, signage, and plantation, are examples of streetscape. Moreover, a sustainable streetscape ensures that the spaces are long lasting and functional as a part of the greater eco-system by implementing technologies that can manage storm water runoff and reduce carbon footprints occurring from roads (Greenberg, 2009). Streetscape quality and elements contribute to the amount of emissions produced from streets. Well-designed and constructed streetscape elements help in reducing transportation emissions, which is the main scope of this research. That is why the streetscape is one of the main factors that affect the success of the city’s urban design. Successful urban development relies on the surrounding physical environment. Streets are considered a major component of the urban fabric, which has the ability to affect the place either positively or negatively. The streets are the main element that connects places. However, their design influences where people are supposed to stop. Attributes that define a good and sustainable streetscape can vary from adding green elements such as trees to improving pedestrian environments that encourage people to walk (Jennings, 2012).

Green streetscapes are those that adhere to well-established standards of sustainable design. Whether designing a new pedestrian environment for an existing street or redeveloping a new street, first, the street geometry should be established. Second, utility solutions. Third, the cities and municipal traffic engineering departments must follow the standards for major street alignments and planning documents that describe street hierarchies and land use (Jennings, 2012).

Architects, landscape architects, and engineers should synchronize all of the controlling factors to establish a design that is functional, safe, and appealing. However, good streetscapes require a higher level of coordination between project designers and municipal representatives (Spellman, 2012).

4.1 Streetscape elements

Streetscape elements are placed in public or communal areas to maintain decorative and functional aspects (Housing, City Planning and Environmental Management Department, 2007). Many streetscape designers, architects, and urban designers considered streetscape elements as aesthetic, healthy, and points of attraction in their designs, and that was a result of what the researchers achieved through their research path while trying to understand the amazing effect of streetscape elements on human health, social life, spirit, economy, environment, and psychology of human actions (Moussa & Dewidar, 2020). This helped people

Table 3 Classification for streetscape elements

Source	Streetscape elements
Streetscape elements (2001)	(1) Street Paving, (2) Sidewalks, (3) Curbs and Curb Ramps, (4) Street Lighting, (5) Seating, Benches and Bus Shelters, (6) Fountains, (7) Public Art, (8) Kiosks, (9) Tree Grates, (10) Planting Pots and Planters, (11) Trash Receptacles, (12) Bicycle Racks, (13) Bollards, (14) Utility Accessories, (15) Newspaper Racks
Fukahorin and Kubota (2003) Daley (2003)	(1) Road paving, (2) Street furniture, (3) Vegetation, (4) Roadside buildings (1) Lighting, (2) Trees and Plantings, (3) Sidewalk Pavement, (4) Roadway Pavement, (5) Street Furniture, (6) Community Identifiers, (7) Parking, (8) Traffic Control Devices, (9) Signage
Avenue (2010)	(1) Parking, (2) Corners, (3) Utilities, (4) Sidewalk Furniture, (4) Trees, (5) Medians, (6) Hanging baskets, (7) Street swales, (8) Rain Gardens, (9) Street lighting, (10) Paving, (11) Benches and Seating, (12) Bicycle racks, (13) Bollards, (14) Flowerstands, (15) Kiosks and Gateway Monuments, (16) Newsracks, (17) Parking Meters, (18) Public art, (19) Sidewalk Restrooms, (20) Traffic and parking signs, (21) Trash Receptacles, (22) Wayfinding signage
City of Milwaukee (2011)	(1) Lighting, (2) Tree and Plant Materials, (3) Planters, (4) Sidewalk Pavement, (5) Street Furniture
Rehan (2013)	(1) Sidewalks, (2) Street corners, (3) Trees and landscape strips, (4) Rain garden, (5) Planters, (6) Street furnishing, (7) Benches, (8) Lighting, (9) Trash receptacles, (10) Signage, (11) Bus shelter, (12) Medians, (13) Curbs, (14) Bicycle facilities, (15) Crossing, (16) Public art, (17) Cafe spaces
City of Cheyenne (2017)	(1) Sidewalks, (2) Street Corners and Curb Extension, (3) Trees and Landscape Strips, (4) Planters, (5) Seating, (6) Trash/Ash Receptacles, (7) Public Art, (8) Screening, (9) Fences, Railings, and Walls, (10) Cafe Spaces, (11) Special Event Spaces, (12) Alley and In-Fill Spaces, (13) Fixtures/Utility Zone, (14) Utilities, (15) Lighting
City of Toronto (2019)	(1) Paving, (2) Street Trees, (3) Medians, (4) Lighting, (5) Street Furniture (Seating, Benches and Bus Shelters)

think more about the importance of streetscape elements. Many researchers classified the streetscape elements differently through time, as shown in Table 3 (Fig. 3).

The framework of streetscape elements used in this research was collected from the elements presented in Table 3. This framework summarizes all the elements that are described in Table 3 by different researchers, and these elements are: (1) paving (crossings, road paving, sidewalks, street corners, parking, curbs), (2) vegetation (trees, landscape strips, planting pots, and planters), (3) street squares (medians), (4) lighting, (5) street furniture (trash receptacles, seating, benches, bus shelters, signage, newspaper racks, bicycle racks, traffic control devices, telep. booths), (6) rain drainage, (7) cafe spaces, (8) kiosks, (9) fountains, (10) fences, railings, and walls, (11) public art.

4.2 Streets and CO₂ emissions

A street is considered one of the main streetscape elements, and it is basically the main element used in designing cities and neighborhoods. In previous years, governments paid less attention to the reduction of CO₂ emissions, which could be achieved by reducing traffic congestion in the Egyptian streets. Previous studies conducted by Fontaras et al. (2017) and

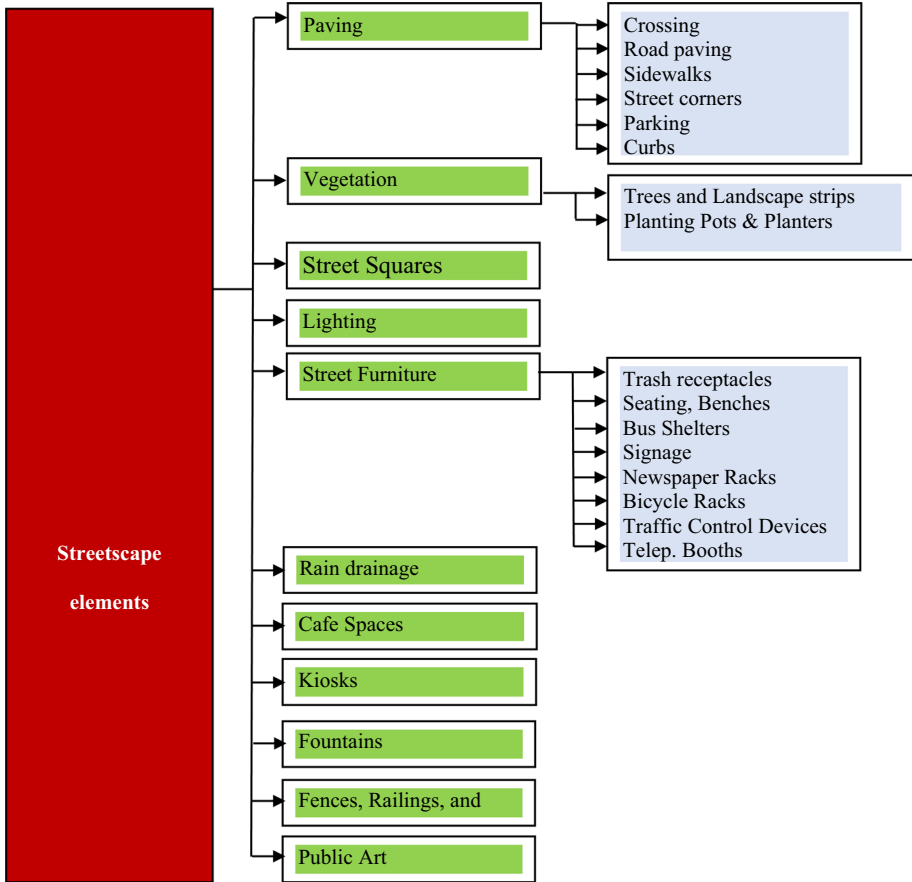


Fig. 3 Breakdown of streetscape elements

Makido et al. (2012) proved that when congestion increases, CO₂ emissions automatically increase. Therefore, guidelines and rules should be set and followed in order to reduce traffic congestion.

Many websites now provide a tool for calculating the average amount of emissions produced by various vehicle types. Table 4 presents the average emissions produced by different types of vehicles in Lit/km. The footprint link ("<https://comcar.co.uk/emissions/footprint/?clk=1>") is one of the links that is used to measure the average amount of CO₂

Table 4 Mass emission of different vehicle type (Brookes, 2017)

Type of vehicles	V	RD (km)	AV (L/km)
Bus	7800	250	0.25
Taxi	82,358	185	0.1
Private car	2,400,000	43	0.1
Motorcycle	560,000	40	0.04

emissions produced from every Lit/km driven by each type of vehicle. Table 4 shows that cars produce around 0.24 kg of CO₂ emissions per mile, a bus produces around 0.60 kg of CO₂ emissions, while motorcycles produce around 0.10 kg of CO₂ emissions in 1 km. However, some vehicles could differ depending on their weight, power, and other factors.

Researchers often use the average speed of vehicles to measure the performance of traffic (Brookes, 2017). A previous study conducted by Brookes (2017) also shows that if we take a large number of car trips and apply them to an emission model for a passenger car, a histogram for CO₂ emissions will be conducted as in Fig. 5, which illustrates that emissions can differ from one trip to another depending on many aspects in California (Brookes, 2017).

By comparing the values presented in Fig. 4 with the different average speeds, a U-shaped pattern will be presented as shown in Fig. 5. The graph presented in Fig. 5 illustrates different key factors, such as very low average speeds, which represent start–stop driving behavior. This causes the vehicle to not travel a far distance. Therefore, the emission rate per km is high compared to smooth traffic. Besides, the graph also illustrates that when a vehicle moves at a very high speed, it emits a high CO₂ emission rate. The moderate speed of a car should be between 60 and 100 km/h (Brookes, 2017).

5 Empirical section

When time passes, the number of vehicles on the roads will increase. If the countries did not develop their infrastructure by developing the roads and streets, the road congestion will increase, which will consume more fossil fuel and will increase the percentage of CO₂ emissions (Moussa et al., 2021; Moussa, 2020). Consequently, traffic congestion mitigation packages need to lower CO₂ emissions. Since the vehicles' speed and density affect the amount of CO₂ produced, site measurements were taken in this research to measure the amount of CO₂ produced in two streets. The first "El-Horeya" street is well designed and in good condition,

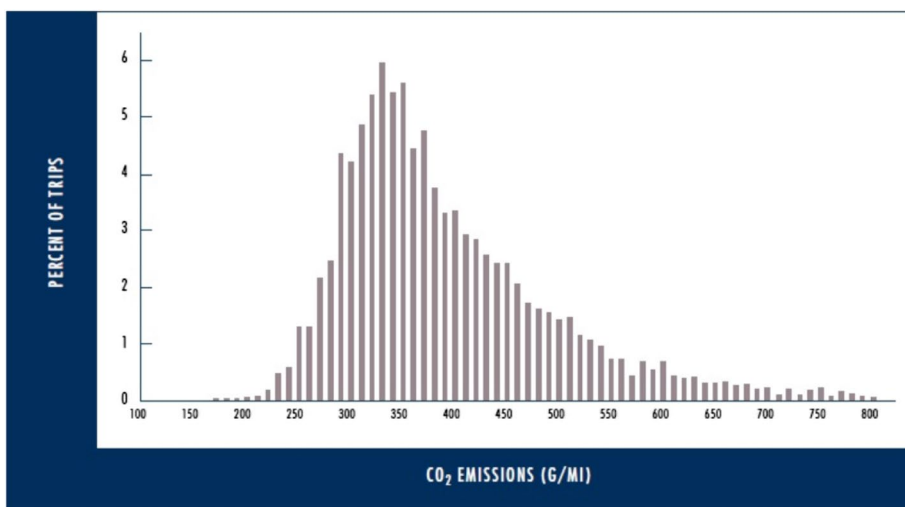


Fig. 4 Percentage of trip and amount of emissions produced (Barth & Boriboonsomsin, 2009)

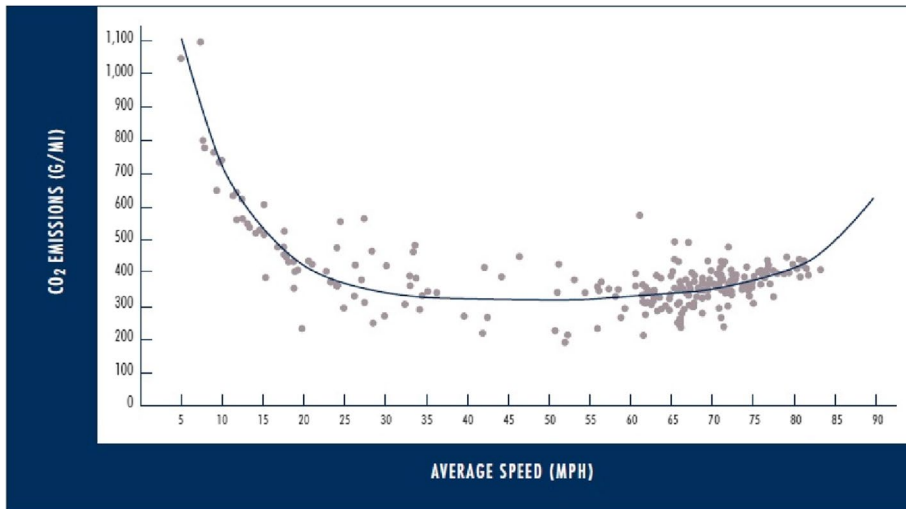


Fig. 5 The relation between CO₂ emission and average speed (Barth & Boriboonsomsin, 2009)

while the second street "El-Helmeya Bridge" lacks the appropriate streetscape design and in bad condition with cracks and irregular street bumps.

5.1 Study methods

An empirical method is used in this research for testing and examining the influence of street design on the amount of CO₂ produced. In this paper, a street with good road pavement was chosen, and another one with bad road pavement has been chosen and compared. The research used an observational survey to collect streetscape data and identify the street quality. Moreover, the research used the "Testo 315-3" ambient CO-/CO₂ measuring instrument to measure the CO-/CO₂ emissions in the research study area with good road pavement and bad road pavement conditions, to measure the amount of CO₂ emissions produced in the roads with different conditions and to compare the effect of road pavement conditions on CO₂ emissions which is the main scope of this research.

The activity of the vehicle will be measured by an electrochemical sensor for CO measurement and a shock-resistant infrared CO₂ sensor. The instrument used (Testo 315-3) is equipped to resist external influences by virtue of its robust design and the optionally available TopSafe. During the measurement, optical and audible signals show immediately whether the variably adjustable limit values have been exceeded (Testo 315-3, 2021).

Testo 315-3 is used to test the amount of CO₂ that occurs in the area with road pavement and compare it with the amount of CO₂ produced by good road pavement. The data collected in the study areas were taken at different timings and dates during normal working days and weekends to collect as much information as needed about the status of the street regarding the number of vehicles crossing the street throughout the day.



Fig. 6 The study area and the landmarks surrounding the area

5.2 Study area

The street linking "El-Mataraya" square and "Ibn el Hakam" square was chosen to be the study area of this research. The coordinates of the study area are $30^{\circ}06'47.1''N$ $31^{\circ}18'50.0''E$, which is located in Cairo, Egypt. The total length of the study area is 1,341 m. The study area is divided into 3 small areas as shown in Fig. 6, each with an average of 450 m (Fig. 7).

The street links between "El-Mataraya" square and "Ibn el Hakam" square were chosen because it consists of both well road pavements and poor road pavements, which serves the main goal of this research (Fig. 6). El-Horeya and El-Helmeya Bridge Street contains a part where cars can move easily without start–stop; however, it is considered a congested area at the middle of great Cairo city. On the other hand, the street contains parts with bad road pavements (El-Helmeya Bridge), which represent study area 2, where cars are forced to slow down because of cracks, while the rest of the study areas (1 and 3) have road pavements in good condition (Fig. 7).

The main purpose of this bridge is to transport cars from "El-Horeya Street" to "El-Helmeya" square. They are all main parts of the same main street. The study area is divided into three main sectors: Study area 1 starts from "El-Mataraya" square and ends at the beginning of "El-Helmeya Bridge," with a total length of 467 m. Study area 2 starts from "El-Helmeya Bridge" and ends when the bridge ends, with a total length of 421.5 m, while study area 3 starts from the ends of study area 2 and ends in "Ibn el Hakam" square with a total length of 471 m (Fig. 8).

6 Results

Field surveys were conducted in this research to identify the geographical information of the study area and to calculate the number, type, and speed of vehicles crossing the three study areas during working days and weekends. The field surveys revealed that the average number of vehicles crossing the three streets daily is 6600, as shown in Table 5. Moreover, the speed of vehicles has been affected by the road pavement conditions since the maximum speed of vehicles on roads with good pavement conditions reached 70 km/h, while



Fig. 7 The length of the three study area roads

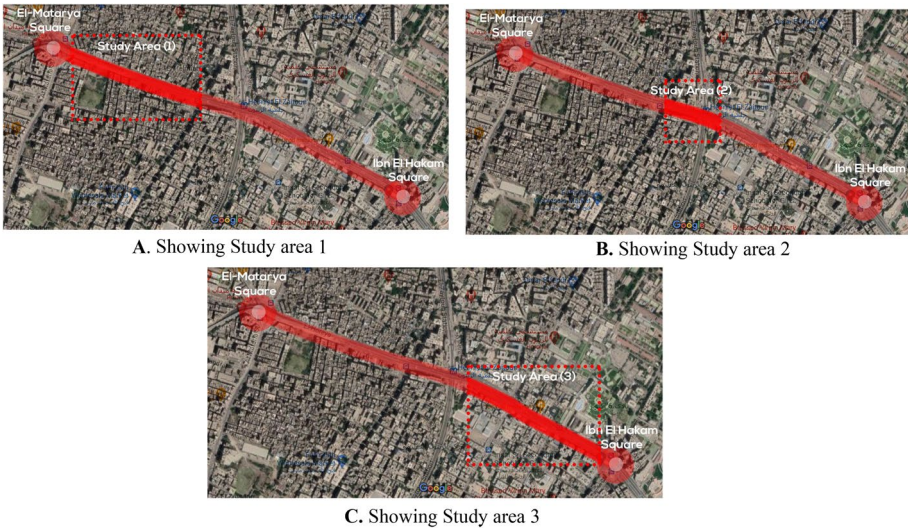


Fig. 8 The three streets in the case study

the maximum speed of vehicles on El-Helmeya Bridge is 38 km/h, which is the bad road pavement condition with cracks and irregular street bumps. The field survey counted the number, type, and speed of vehicles crossing each study area four times a day. Each time, the number of vehicles was counted for two hours, for a total of eight hours a day. As shown in Table 4, it is possible to know the average number of vehicles crossing the study area in a day by multiplying the total average of each type of vehicle by 3.

Table 6 presents the length and width of each study area together with the average daily traffic density and the basic amount of CO₂ emissions produced by 1 vehicle in each study

Table 5 Observing the number and type of vehicles in the 3 study areas

Study area/date	Hours	Small vehicles (Cars)	Big vehicles (bus, mini bus, micro bus and trucks)	Motorcycle	Max speed/1 vehicle (km/h)
El-Mataraya square to El-Helmeya bridge (study area 1)					
	9:00–11:00 am	1560	480	480	70
	4:00–6:00 pm	1800	960	960	
	9:00–11:00 pm	1920	360	480	
	4:00–6:00 am	240	0	120	
Average number of cars in 8 h		1380	450	510	
Average number of cars/day		4140	1350	1530	
El-Helmeya bridge (study area 2)					
	9:00–11:00 am	1680	600	600	38
	4:00–6:00 pm	1920	960	960	
	9:00–11:00 pm	1080	240	240	
	04:00–06:00 am	120	0	120	
Average number of cars in 8 h		1200	450	480	
Average number of cars/day		3600	1350	1440	
El-Helmeya bridge to Ibn el Hakam square (Study area 3)					
	9:00–11:00 am	1800	600	240	70
	4:00–6:00 pm	2160	960	720	
	9:00–11:00 pm	1920	240	360	
	04:00–06:00 am	240	0	120	
Average number of cars in 8 h		1530	450	360	
Average number of cars/day		4590	1350	1080	

Table 6 The amount of CO₂ produced from different types of vehicles in good streets conditions

Street name	Length (m)	Width (m)	Type of vehicle	Average number of vehicle crossing per day	Basic amount of CO ₂ produced per 1 vehicle/distance	Basic amount of CO ₂ that should be produced per day	Components of study area	Streetscape elements existing in study areas	Number of elements
El-Mataraya square to El-Helmeya bridge (study area 1)	550	12	Car	4140	132 g/CO ₂	546.48 kg/CO ₂	1-Medical centers and hospitals	Traffic lights	2
			Bus	1350	330 g/CO ₂	445.5 kg/CO ₂	2-Sidewalk	Light bulbs	30
			Motorcycle	1530	55 g/CO ₂	84.15 kg/CO ₂	3-Lighting	Square	1
							4-Paved road		
							5-Square on one end		
El-Helmeya bridge (study area 2)	200	6	Car	3600	48 g/CO ₂	172.8 kg/CO ₂	6-Advertising billboards	Kiosks	2
			Bus	1350	120 g/CO ₂	162 kg/CO ₂	1-Lightings	Light bulbs	10
			Motorcycle	1440	20 g/CO ₂	28.8 kg/CO ₂	2-Fence		
			Car	4590	60 g/CO ₂	275.4 kg/CO ₂	(1) Charitable hospital	Traffic lights	1
El-Helmeya bridge to Ibn el Hakam square (study area 3)	250	12	Bus	1350	150 g/CO ₂	202.5 kg/CO ₂	(2) Sidewalk	Light bulbs	14
			Motorcycle	1080	25 g/CO ₂	27 kg/CO ₂	(3) Lighting	Speed bumps	1
							(4) Paved road	Squares	2
						(5) Squares	Kiosks	1	

Table 7 Amount of carbon emissions produced from the GPS devices “Testo 315–3”

Name of street	Type of vehicle	Number of vehicles	Basic amount of CO ₂ produced per 1 vehicle/distance	Amount of CO ₂ produced per 1 vehicle	Basic amount of CO ₂ that should be produced per day	Total amount of CO ₂ produced from all vehicles in a day	Total amount of CO ₂ produced from all vehicles in a month
El-Mataraya Square to El-Helmeya bridge (study area 1)	Car Bus Motorcycle	4140 1350 1530	132 g/CO ₂ 330 g/CO ₂ 55 g/CO ₂	171 g/CO ₂ 396 g/CO ₂ 57 g/CO ₂	546.48 kg/CO ₂ 445.5 kg/CO ₂ 84.15 kg/CO ₂	707.94 kg/CO ₂ 534.6 kg/CO ₂ 87.21 kg/CO ₂	84,930 kg/CO ₂ 84,930 kg/CO ₂ 10,464 kg/CO ₂
El-Helmeya bridge (study area 2)	Car Bus Motorcycle	3600 1350 1440	48 g/CO ₂ 120 g/CO ₂ 20 g/CO ₂	58 g/CO ₂ 170 g/CO ₂ 23 g/CO ₂	172.8 kg/CO ₂ 162 kg/CO ₂ 28.8 kg/CO ₂	208.8 kg/CO ₂ 229.5 kg/CO ₂ 33.12 kg/CO ₂	25,680 kg/CO ₂ 27,540 kg/CO ₂ 3972 kg/CO ₂
El-Helmeya bridge to Ibn el Hakam square (study area 3)	Car Bus Motorcycle	4590 1350 1080	60 g/CO ₂ 150 g/CO ₂ 25 g/CO ₂	93 g/CO ₂ 202 g/CO ₂ 29 g/CO ₂	275.4 kg/CO ₂ 202.5 kg/CO ₂ 27 kg/CO ₂	426.87 kg/CO ₂ 272.7 kg/CO ₂ 31.32 kg/CO ₂	51,210 kg/CO ₂ 32,700 kg/CO ₂ 3758.4 kg/CO ₂

area. Moreover, the amount of CO₂ emissions produced by different types of vehicles is shown in Table 6.

The model and year of the vehicles can make a difference in the amount of CO₂ emissions produced, but in this research the model and year of the vehicles have been neglected because it is almost impossible to identify all the models and years of the average 6600 vehicles crossing the three study areas. Instead, the vehicles have been classified into three clusters. The first cluster is the small vehicles, which includes all types of cars (small and big), and the second cluster is the big vehicles, which includes buses, trucks, and microbuses. The third and final cluster is the motorcycles, as shown in Table 6.

The results of the empirical method are presented in Table 7. Table 7 presents the basic amount of CO₂ emissions produced per 1 vehicle/distance, which was collected from the literature section, and then compared with the amount of CO₂ produced per 1 vehicle as measured by Testo 315-3. In addition, the research calculated the amount of emissions produced in each study area by multiplying the amount of emissions produced from 1 vehicle/cluster with the total number of vehicles crossing the street in a day.

The result clearly proves that road pavement design has a significant effect on the amount of CO₂ emissions produced by vehicles.

According to the data presented in Table 7, it is clear that vehicles produced CO₂ emissions more than expected and planned. Looking at study area (1), the CO₂ emissions from cars have increased by 23% more than expected, emissions from buses increased by 17%, and motorcycle emissions increased by 4%. In study area (2), cars produced an average of 18% more than planned, buses produced 30% more, and motorcycles produced 14%. Lastly, the cars in study area (3) have experienced a 36% increase in emissions from cars, 25% from buses, and 14% from motorcycles.

A driving trip consists of idling, accelerating, cruising, and decelerating. All these actions produce a certain amount of CO₂ emissions from burning fossil fuel. The vehicle driver's effect the amount of CO₂ emissions produced from the way they drive (Barth & Boriboonsomsin, 2009). A car moving in a constant speed smoothly will produce less CO₂ emissions than a car that is forced to start-stop every while because of external factors such as cracks in the roads occurring from bad streetscape elements. A smooth trip consists of moderate speed that should be between 60 and 100 km/h.

However, in this research, it is proven that the elements of streetscape in this specific case study have a huge effect on CO₂ emissions since the results in the case study show that an increase of 23% for cars, 17% for buses, and 4% for motorcycles of carbon emissions existed in (study area 1), together with 18% for cars, 30% for buses, and 14% for motorcycles in (study area 2), while 36% for cars, 25% for buses, and 14% for motorcycles in (study area 3). These percentages were concluded by collecting the data regarding the number of cars crossing in the 3 study areas where held in 4 different timing of the day: from 9 am till 11 am, from 4 pm till 6 pm, from 9 pm till 11 pm, and from 4 am till 6 am. These timings consist of only one-third of the day. The average number of each vehicle was conducted and then was multiplied by 3 in order to know the total amount of vehicles crossing the area throughout the whole day. The basic amount of CO₂ emissions that should be produced in each study area was calculated by multiplying the amount of emissions each vehicle produced in (L/km) by the number of cars crossing. However, the increase in emissions is considered to be a big increase and should be taken in account in order to improve the streetscape elements within the study areas. Keep in consideration that in study area 1 and 2 there was no traffic light that would

influence the traffic flow. That ensures that the main reason of congestion within this area is because the poor streetscape elements exist.

7 Discussion and recommendation

Egyptians are suffering from many chronic diseases due to the high level of pollution and poor medical services (Guirguis and Moussa, 2019). Chronic respiratory diseases are one of the main current leading national causes of death in Egypt (World Health Organization, 2021). According to previous research, almost 78% are suffering from problems in their respiratory system due to the high percentage of air pollution (Guirguis and Moussa, 2019). In 2020, the amount of CO₂ emissions released in Egypt was 269.5 million tonnes. Over the last 50 years, CO₂ emissions in Egypt grew substantially from 25 to 269.5 million tonnes, rising at an increasing annual rate that reached a maximum of 15.83% in 1976 and then decreased to -4.53% in 2020 (Knoema 2021). The Egyptian government set a new strategy to reduce their emissions and preserve the environment. The government started to think green by generating energy using renewable sources and converting cars to move with natural gas instead of benzene as an approach to reduce road emissions (Maged et al., 2022; Moussa, 2021).

Egypt has a high population density, and most people depend on private cars as their basic means of transportation (Moussa, 2021). Moreover, Egypt has a poor traffic management system; this is probably the most important cause of congestion. In addition to limited parking capacity, few traffic signals, random stops by cars and minivans, no proper pedestrian crossings, and U-turns are examples of poor traffic management. As for maintenance, there is no regular maintenance schedule applied on Egyptian roads (Nakat et al. 2014). Approximately 47 billion LE, or 8 billion USD, are wasted every year due to congestions; this is expected to increase to 105 billion LE by 2030; the economic costs that the Egyptians paid due to traffic congestion are summarized in Table 8 (Nakat et al. 2014).

Table 8 The economic costs of congestion in 2010 in Cairo, Egypt (Nakat et al. 2014)

Cost component	Value	Annual cost (million USD)	Annual cost (billion LE)	Percent of total cost (%)	Annual cost per capita (USD)
Delay	2.2B h	2443	14.7	31	125
Reliability	1.4B h 78	1526	9.2	19	78
Fuel	1.9B L	1094	6.6	14	56
CO ₂	7.1B kg	63	0.4	0.8	3
Safety	0 Fatalities – 3100 Injuries 34,800 PDOs	–92	–0.5	–1	–5
VOC	N/A	371	2.2	4	19
Other emissions	44 Million kilograms	1478	8.8	19	75
Agglomeration/productivity	N/A	875	5.2	10	45
Suppressed demand	N/A	204	1.2	3	10
Housing demand	N/A	10	0.1	0.2	0.5
Total	N/A	7972	47.7	100	406

Since roads are one of the most important streetscape elements, applying a proper strategy for maintaining streetscape elements is essential in order to achieve a uniform character for the neighborhood (Albalate & Fageda, 2019). The general importance of designing and maintaining streetscape elements is to provide constant and proper roads and sidewalks, drainage systems, lighting features, trees, paving, etc. (Avenue, 2010). Pavements are considered the major streetscape element since all types of vehicles use them as a means of transportation; the more efficient the pavement is, the easier and smoother the traffic flows, as proven by the results. Using concrete as a pavement material would be a good choice for the study area. Since the voids in the concrete pavement give the surface a better, coarser appearance compared to the standard impervious concrete (Tompkins et al., 2009), the voids, together with low mortar, reduce the strength compared to standard concrete. Besides, there are no heavy-duty vehicles crossing by in this area.

Sidewalks are essential in every street and neighborhood. The more efficient the sidewalk is, the more sustainable the city will become since people will have the chance to walk instead of using their car to move to a nearby location. A proper sidewalk should contain frontage for shops in the region, thoroughways for pedestrians to walk, furnishing zones for plantations, an edge for lighting, and an extension for cars to park. Parking facilities should exist in private zones in order not to interfere with traffic flow. However, some streets and neighbors allow cars to park on the edge of the street (Rehan, 2013). Since it is not possible to make private parking in the area, it is acceptable for cars to park parallel to the sidewalk only. As for the squares, they already exist at both ends of study area 1 and study area 2, which eases the traffic flow. Lighting should occur along the entire road every 35 m at maximum in order to enhance the safety environment. All types of street furniture, such as trash receptacles, benches, bus shelters, signage, and kiosks, should be in good shape and condition, as well as a sufficient storm water management system (Javadi, 2016). This 1 km was chosen because it represents both good and bad street quality, which influences CO₂ emissions. Most Egyptian main streets are in good quality, but the sub-streets, especially in old Cairo, are in very bad shape and condition. That is why almost 35% of emissions produced in Egypt is from transportation sectors (Tkachenko et al., 2019). According to the presented study, Egypt needs to develop a strategy for regular road maintenance in order to reduce carbon emissions, which have a negative impact on public health and contribute to climatic change, among other environmental hazards.

8 Conclusion

In conclusion, streetscape elements, particularly the road pavements sub-element, have a significant impact on the amount of emissions produced by vehicles. Street quality controls the vehicles' speeds, and it affects the amount of CO₂ emissions produced as well as the amount of street congestion. This congestion causes the driver to start-stop the vehicle, which causes the vehicle to produce more CO₂ emissions than smoother driving. Regular maintenance of streetscape elements (road pavements sub-element) will decrease the amount of traffic congestion that occurs, which will lead to a decrease in the emissions emitted into the air that reflect back onto humans, polluting the environment and causing severe health effects for all creatures. In addition, applying strategically planned for streets and road maintenance in developing countries will decrease traffic congestion and a massive decrease in CO₂ emissions will occur in developing countries, which will affect the global emissions produced by the transportation sector.

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