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The role of street conditions and forms on the amount of carbon emissions released from vehicles

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ABSTRACT

In the last two decades, the percentage volume of carbon emissions has increased from 280 to more than 380 parts per million in the atmosphere; the problem is that it is still increasing daily in which it caused many environmental hazard that has been seen the last couple of years. The end of this century, it is expected that the uncontrolled amount of emissions emitted to the atmosphere will increase the surface temperature of plant earth by 3.4ºC. Worldwide, the percentage of carbon emissions in the atmosphere and its effect on air quality has been the main concern of scientist and researchers in the past decade. Egypt is one of the biggest emitters that surfer from atmospheric pollution; almost 24% of the atmosphere pollutants in Egypt are from the transportation sector due to the heavy use of fossil fuels. Reducing the roads carbon emissions through streets design and form is the main scope of this research. This research intends to control the amount of carbon emission released in air by vehicles through controlling vehicles speed and motion, which is affected by the street design and form. The present research analyzes the relation between carbon emissions and streets condition and forms, through measuring the amount of CO_2 and CO emission produced in one of the Egyptian roads from different types of vehicles in road with three different conditions. El-Shuhada Street has been chosen to be the study area of this research. The researcher used Testo 315-3 to measure the carbon emissions in the street and to identify the relation between CO_2 emission and street condition and form. The results reveled that straight routes with vehicle speeds ranging between 80 and 100 kn/h produce less carbon emissions than straight routes with street bumps and vehicle speed ranging between 26 and 19 km/h. Moreover, curved routes emitted more emissions than straight routes.

Keywords: Air pollution; Carbon emissions; Transport and vehicles; Street condition and form.

INTRODUCTION

More than 70% of global greenhouse gases emit from urban areas, which account for 60–80% of the global energy use (Fragkias et al., 2013; Moussa, 2018; Moussa 2019, HSU, 2020; Moussa, 2020). Given that the most of the subsequent constant growing of population will probably be in urban areas (UN, 2012); the major inquiry about urban planning is the way of designing streets and the size or population of a city affecting its energy use and carbon dioxide (CO2) emissions (Andrae, 2020). Nevertheless, energy consumption and carbon emissions emitted by urban transport have been specifically discussed in many cases: (i) transportations have a big ratio in the urban energy equilibrium, like the residential ratio (Lefèvre, 2010). (ii) Transportation is considered as the most difficult sector to reduce energy and emissions in urban areas (Banister, 2011). (iii) The number of vehicles consuming energy is constantly increasing. (iv) In addition, there are the extensive flexibility and long routes of transportations infrastructure. The growing population exposed a huge pressure on the city's urban infrastructure especially the transport infrastructure. Transportations are considered the main resource of greenhouse gas emissions: the carbon emissions emitted from transportations sector are about 30% of the total emission produced in developed countries and about 23% of the total carbon emissions emitted globally (Moussa, 2021).

This research highlights the importance to connect network structure, which connects people and places with CO2 emissions. This kind of connection shall give more knowledge about how cities are arranged and how their energy could be used proficiently. Cities' energy usage and carbon emissions depend on several elements such as local climate, urban form, population and building density, technology, average income or wealth, and transportation network (Steadman, 2014).

Recently, many researchers addressed the urban form and urban transport energy usage connected to carbon emissions (Breheny, 1995; Anderson et al., 1996; Banister et al., 1997; Makido et al., 2012; Moussa, 2021 and many other).

There is a superliners relation between carbon emissions and city size. A study made by Fragkias et al. (2013) and Oliveira et al. (2014) shows that that bigger cities may not emit more emissions than smaller cities. Moreover, larger cities may create more CO2 per capita than smaller cities; it all depends on the population density and transportation network design (Oliveira et al., 2014).

The geographical characteristics of the road affect the amount of fuel consumed, which affects the amount of carbon emitted in the atmosphere. For example, driving a car uphill requires more power to overcome gravity than driving on a flat road. On the other hand, driving a car downhill requires less power that consumes less fuel. Road grade has an important effect on vehicle carbon emissions (Fontaras et al., 2017).

Road roughness depends on the road condition and construction materials of the road and is used as an indicator for maintenance. A typical range of 2 represents high quality surface similar to that of airport runways and superhighways. While regular roads ranged between 3 and 6, where 3 represents good quality and 6 represents the road in need for urgent maintenances, the more the number increases, the more the roughness increases. Rough roads limit 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 the time leading in increasing the fuel consumption of vehicles (Fontaras et al., 2017).

As a result, many studies tackled this issue of traditional street design and its effect of carbon emission. The design framework for nature integrated streets studies suggests that much more can be achieved within a city if streets are given the sustainable design elements, which are absent in traditional streets. Much can be achieved by adding the nature integrated elements of green walls, green roofs, and green balconies to building envelopes. Considerable benefit is also possible by adding elements to the existing urban streets and road reserves: tree pits, street trees, linear gardens, pocket parks, bioswales, rain gardens, daylighting streams, and nature elements integrated with street furniture. The value of all of these is great when it comes to carbon emissions reduction (Mohajeri, 2015; Moussa & Mahmoud, 2017; Moussa el al., 2020)

STUDY METHODS

An empirical method is used in this research for testing and examining the influence of streets condition and form on the amount of CO_2 emissions produced. In the case study, a street with different form and condition has been chosen to be the study area of this research. Testo 315-3 ambient CO-/CO_2 instrument was used to measure the CO and CO_2 emissions released in air, which occurs in the area with different street form. The data collected in the study areas were taken in different timings during a day in normal working days and weekends in which it represents the traffic density during the week. The data collection process was set to collect as much information needed about the status of the street regarding number and type of vehicles crossing by throughout the day.

Study Area

El-Shuhada Street has been chosen as the study area of this research, because it is one-way street that consists of different form and conditions, which serve the main scope of this research. El-Shuhada Street was previously named Mubarak Street, named after President Mubarak; after the Egyptian revolution in January 2011, the name was changed to El-Mosher Street; then, in June 2013, the street name was changed to El-Shuhada Street, which means Martyrs. El-Shuhada Street is the main street rote in El-Sherouk city, which is located in Cairo, Egypt. El-Shuhada Street is a crowded street connecting Suez-Cairo desert road with Ismailia-Cairo desert road as shown in figure (1).

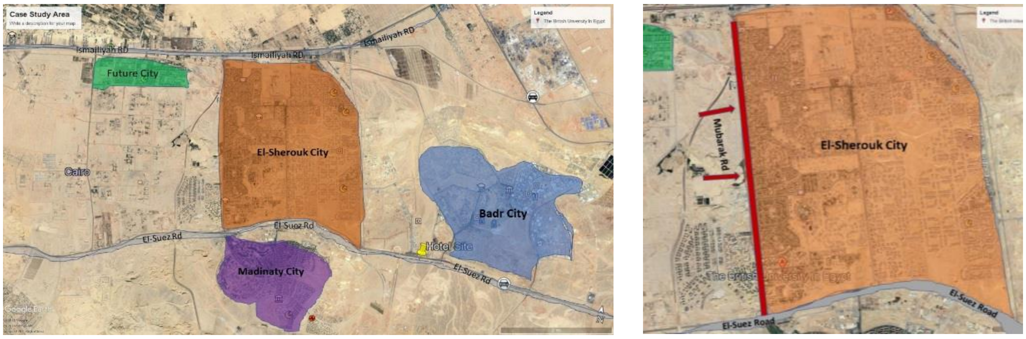


Figure 1. The research Study Area El-Shuhada Street.

El-Sherouk city is one of the most crowded new suburbs in Cairo, and El-Shuhada Street is the main route in this suburb, and it is the most crowded street due to its geographic location, which links two main high roads, and it includes the most important facilities in this suburb such as "the British University in Egypt (BUE)" and "El-Sherouk Academy" as shown in figure 2.

Figure 2. Important facilities in El-Shuhada Street.

The hypothesis of this research states that the road designer can control the amount of CO_2 and CO emissions released from street by controlling the speed of vehicles in this road. The speed of vehicle can be controlled using the street condition and form.

This research classified the street conditions into three conditions: high speed road, moderate speed road, and low speed road. The high speed road represents highway roads where the speed of vehicle exceeds 120km/h and the road is designed with no obstacles such as street bumps and U-turns. Moderate speed represents roads where the speed of vehicles ranges between 50 and 10km/h, and it may have some obstacles such as curved road, bridge, or U-turns. Finally, low speed road represents roads where the speed of vehicles ranges between 20 and 40 km/h, and these are roads with obstacles such as intersections, street bumps, traffic control lights, pedestrian path, and high traffic density roads.

The study area was chosen because it represents the three types of street conditions. El-Shuhada Street was divided into three zones according to the street condition and form as shown in figure 3. Zone one represents high speed road. Zone two represents low speed road due to the many street bumps existing, which were added in front of the two universities for all the students to path the road. Zone three represents moderate speed road due to the high curved road existing, which forces the vehicles to slow down as shown in figure 3.

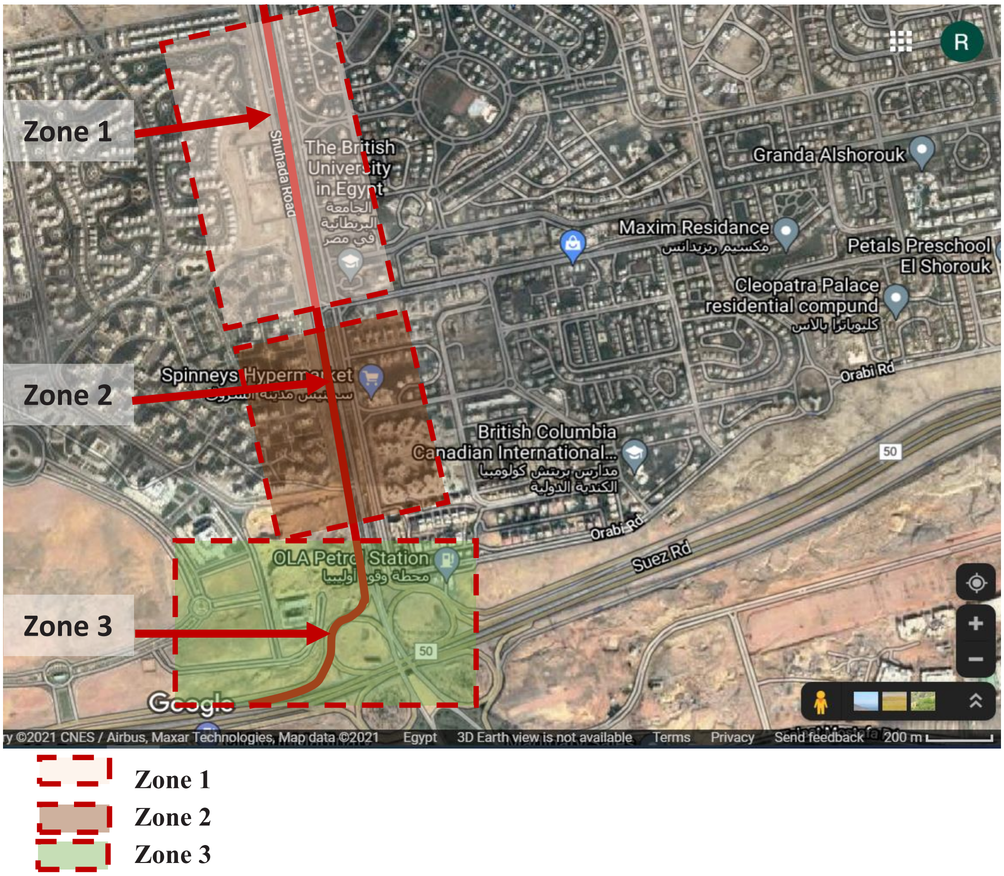


Figure 3. Three study area zones.

Figure 4. Real life photos for the street condition in each zone.

Figure 5. Three CO_2 measuring instrument Testo 315-3.

Equipment

Two measuring equipment devices were used in this research. The first is a German equipment called "Testo 315-3," which is shown in figure 5 and will be used in this research to measure the amount of CO_2 and CO emissions produced from different type of vehicles in the three locations allocated in the study area. During the measurement, Testo 315-3 shows the optical and audible signals immediately whether the variably adjustable limit values have been exceeded. The second equipment is the "Speedometer," which is used to measure the speed of each vehicle type in each zone.

Data Collection

The data collected in this research is divided into two parts: the first part is the traffic density passing through the study areas, and the second part is the amount of CO_2 and CO emissions produced by different types of vehicles.

The types of vehicles were classified as big vehicles, small vehicles, and motorcycles. The big vehicles represent truck, bus, minibus, microbus, and crain. Small vehicles include all types of cars such as SUV, 4x4, hatchback, and sedan, as shown in table 1. Table 1 represents the average traffic density in El-Shuhada Street/day. In order to calculate the average traffic density/day, the researchers conducted a field survey in four days/week; every day the number and type of vehicles were counted and recorded four hours/day. These four days represent working days, last day in the week, first day in the week, and weekend, where Friday is the weekend in Arabian countries such as Egypt, Thursday is the last day in the week, and Saturday is the 1st day in the week, and many private firms take Saturday as the 2nd weekend in the week, in which the traffic density in Saturday is much lower than Monday, which is considered as a working day to all public and private firms.

Table 1. The number of vehicles passing through the study area in working days and weekends.

Study Area	**Date**	**hours**	**Small vehicles**	**Big vehicles**	**Motor cycle**
(Zone 1, Zone 2 and Zone 3)	Saturday 12/06/2021	9:00-10:00 am	1890	880	780
		4:00-5:00pm	2704	960	520
		9:00-10:00 pm	1610	50	80
		4:00-5:00 am	170	1	3
	In Saturday, Average number of vehicles/ hour		1,593.5	472.75	345.75
	Monday 14/06/2021	9:00-10:00 am	2390	1280	780
		4:00-5:00pm	3404	1660	63
		9:00-10:00 pm	1819	36	55
		4:00-5:00 am	70	0	0
	In Monday, Average number of vehicles/ hour		1,920.75	744	224.5
	Thursday 17/06/2021	9:00-10:00 am	2690	1403	530
		4:00-5:00pm	3201	2520	39
		9:00-10:00 pm	1923	41	65
		4:00-5:00 am	54	1	2
	In Thursday, Average number of vehicles/ hour		1,967	991.25	636

	Friday 18/06/2021	9:00-10:00 am	990	22	6
		4:00-5:00pm	954	41	12
		9:00-10:00 pm	513	4	3
		4:00-5:00 am	47	0	0
	In Friday, Average number of vehicles/ hour		626	16.75	5.25
Average number of cars / Hour			1526	556	27
Average number of cars / day			36,643.5	13,348.5	7,269

Based on table 1, table 2 represents the width and length of each zone in the study area, the average number of cars passing daily through the street, the vehicles speed, and the basic amount of CO_2 and CO emissions that should be produced from 1 vehicle in each zone. To calculate the average number of vehicles/day, the research calculated the average number of vehicles passing through the street/hour, by adding the number of vehicles in each hour and dividing them by 4, which represents the 4 hours recorded. After that, the researchers added the average number of vehicles/hour passing through the street in the 4 days and then dividing them by 4 and multiplying them by 24, which represents the number of hours/day.

Table 2. Study area properties divided into street dimensions, type and number of vehicles passing through.

Study Area	**Street dimensions**		**Average vehicle Speed**	**Type of vehicle**	**Average Number of vehicle crossing/ hour**	**Basic Amount of CO_2 produced per 1 vehicle/ distance**	**Basic Amount of CO produced per 1 vehicle according to vehicle speed**
	Length	**width**					
Zone 1	950 m	15m	100±80 km/h	Big Vehicle	556	0.387 t	0.22 ± 0.09 g km^{-1}
				Small Vehicle	1526	0.298 t	0.22 ± 0.09 g km^{-1}
				Motorcycle	27	0.264 t	0.22 ± 0.09 g km^{-1}
Zone 2	440 m	15 m	26 ± 19 km/h	Big Vehicle	556	0.179 t	0.86 ± 0.26 g km^{-1}
				Small Vehicle	1526	0.178 t	0.86 ± 0.26 g km^{-1}
				Motorcycle	27	0.122 t	0.86 ± 0.26 g km^{-1}
Zone 3	600 m	7 m	55 ± 40 km/h	Big Vehicle	556	0.244 t	0.83 ± 0.05 g km^{-1}
				Small Vehicle	1526	0.236 t	0.83 ± 0.05 g km^{-1}
				Motorcycle	27	0.206 t	0.83 ± 0.05 g km^{-1}

Research Procedures

The procedures that took place in this research can be summarized as follows:

1- First, choosing the site location with different form and with high, moderate, and low conditions.
2- Conducting several field observational surveys to identify the street conditions and properties such as length and width of study areas.
3- Counting the types and number of vehicles crossing the street, four hours in 4 days a week, to calculate the average vehicle density per hour.
4- Calculating the amount of CO2 and CO emissions produced from each zone according to the literature
5- Conducting three field measurements during the field observational survey, one measurement for each zone, using "Testo 315-3" to measure the amount of CO2 and CO emissions in the street every 5 min for an hour and considering the average readings as the measurement for specific hour in specific zone

RESULTS

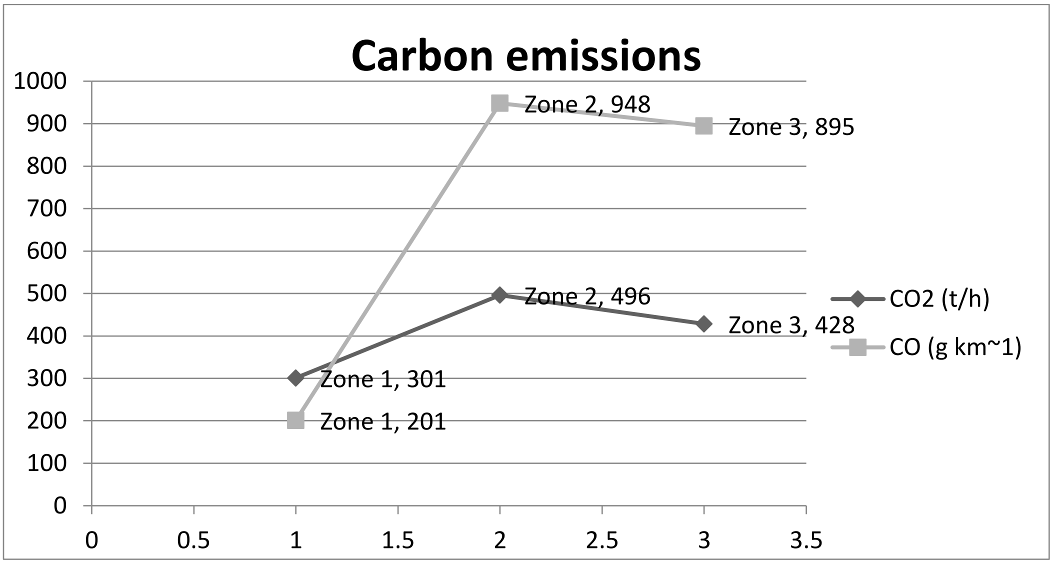
In table 2, according to the literature and the researches that were provided by Vlieger (2000) and My climate (2021), the current research calculated the amount of CO2 and CO emissions that should be produced in each zone/hour depending on the zone length, vehicle speed, and type of vehicles. The results of the empirical work are proving that Street form and condition affect the vehicle speed, which affects the amount of burned fuel that the vehicle consumed and produces carbon emissions as shown in table 3.

Table 3. the amount of CO_2 and CO emissions produces from different types of vehicles in each zone

Study Area	Street dimensions		Average vehicle Speed	Type of vehicle	Average Number of vehicle crossing/ hour	According to literature				Testo 315-3	
	Length	width				Basic Amount of CO_2 produced per 1 vehicle/ distance	Basic Amount of CO produced per 1 vehicle according to vehicle speed	Basic Amount of CO_2 that should be produced per hour	Basic Amount of CO that should be produced per hour	Average Amount of CO_2 that should be produced per hour	Average Amount of CO that should be produced per hour
Zone 1	950 m	15m	100±80 km/h	Big Vehicle	556	0.387 t	0.22 ± 0.09 g km^{-1}	215.172 t/h	86.18 g km^{-1}	301.7 t/h	201.8 g km^{-1}
				Small Vehicle	1526	0.298 t	0.22 ± 0.09 g km^{-1}	454.748 t/h	236.53 g km^{-1}		
				motorcycle	27	0.264 t	0.22 ± 0.09 g km^{-1}	7.128 t/h	4.185 g km^{-1}		
Zone 2	440 m	15 m	26 ± 19 km/h	Big Vehicle	556	0.179 t	0.86 ± 0.26 g km^{-1}	99.524 t/h	311.36 g km^{-1}	496 t/h	948.6 g km^{-1}
				Small Vehicle	1526	0.178 t	0.86 ± 0.26 g km^{-1}	271.628 t/h	854.56 g km^{-1}		
				motorcycle	27	0.122 t	0.86±0.26 g km^{-1}	3.294 t/h	15.12 g km^{-1}		
Zone 3	600 m	7 m	55 ± 40 km/h	Big Vehicle	556	0.244 t	0.83 ± 0.05 g km^{-1}	135.664 t/h	244.64 g km^{-1}	428.97 t/h	895. 6 g km^{-1}
				Small Vehicle	1526	0.236 t	0.83 ± 0.05 g km^{-1}	360.136 t/h	671.44 g km^{-1}		
				motorcycle	27	0.206 t	0.83 ± 0.05 g km^{-1}	5.562 t/h	11.88 g km^{-1}		

In Table 3, it is clear that vehicles produced carbon emissions more than expected and planned due to the high traffic density in this road. It was noticed that the readings that were collected from Testo 315-3 in each zone are different than the calculated emissions; this is due to the differences in fuel type and purity used by different vehicles, vehicle type with different burning capacity (Toyota, Mercedes Benz, BMW, Honda, etc.), year of manufacture, vehicle accessories, and driving behavior (Fontaras et al., 2017). These variables were not considered in the observational survey due to the difficulties in collecting such data for every vehicle crossing the street.

According to Table 3, zone 2 produced the maximum amount of emissions where vehicles speed ranged between 26 and 19 km/h due to the six street bumps exiting in this route, which force the drivers to slow down. The best results were seen in zone one where vehicles speed ranged between 100 and 80 km/h as shown in figure 6.



In zone 1, the carbon emissions from cars have increased by 18% than expected, emissions from buses increased by 17%, and the motorcycle emissions increased by 4%, while in zone 2, cars produced an average of 36% more than planned, buses produced 30% more, and motorcycles produced 14%. In addition, in zone 3, cars experienced 26% increase in emissions from cars, 25% from buses, and 14% from motorcycles as shown in table 3.

CONCLUSION

In conclusion, street form and conditions have huge effects on the amount of carbon emissions produced from vehicles. Traffic congestions lead to an increase in the vehicles' fuel consumption that may be severe under low speed urban driving conditions and in heavy traffic, increasing the number of vehicles crossing the street affects fuel consumption in several ways. It reduces the average and maximum speed of the trip; it increases the accelerations and decelerations transient operation of the vehicle, which may cause traffic congested conditions that are characterized by vehicle standstills, low vehicle speeds, and increased engine idling. The decline in vehicles speed, consequently, increases the amount of carbon emissions produced by the slow movement of all types of vehicles. The impact of traffic on vehicle fuel consumption is not uniform; it depends on the geographical area and the characteristics of the vehicle fleet. The street congestions force the vehicle drivers to start or stop the vehicle, which causes the vehicle to produce more carbon emissions than smoother driving. Proper street design will lead to less emissions in the air, which is reflected back on humans through polluting the environment and causing sever health effects for all creatures. Decreasing the amount of carbon emissions will affect the Egyptian atmosphere since only the transportation sector hold an average of 32% of the total emissions in Egypt.

RECOMMENDATION

Urban designers and planners can control the amount of carbon emissions produced from street through controlling the vehicle speed. Vehicle speed can be controlled by setting designing guidelines for streets that control the vehicle speed and produce low carbon emissions. As proved in this research, vehicle speed ranging between 80 and 100 km/h produced fewer amounts of emissions. Accordingly, it is recommended to design streets that preserve this speed and remove the street bumps, which force the drives to slow down for assisting the pedestrians to cross the roads, which can be replaced with pedestrian tunnels or bridges.

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