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Analysis of Mexico City transportation systems to address climate change, traffic, social equity, safety, and air pollution health risks

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This Master's Project

Analysis of Mexico City transportation systems to address climate change, traffic, social equity, safety, and air pollution health risks

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ABSTRACT

This research presents an analysis of Mexico City's transportation systems and how they impact climate change, traffic, social equity, safety, and health risks. The purpose of this research is to propose transportation and energy management strategies to the government of Mexico City to reduce the effects of climate change, traffic, social equity, safety, and health risks. The methodology used in the research includes a traffic analysis, environmental and social impact analysis across Mexico City transportation, an equity analysis, and a SWOT analysis of policies. Through the traffic analysis of the research found that traffic congestion occurs in the northwest region of Mexico City. Traffic is a major problem in Mexico City due to the increase in population since the year 2015. Traffic is considered the central problem of air pollution in Mexico City. The environmental and social impact analysis across Mexico City transportation found that low-socioeconomic status sectors tend to deal with more health, safety, and pollution problems in Mexico City. Through the equity analysis the research recommends that transportation electrification is convenient in the eastern and northeastern areas of Mexico City to reduce air pollution and improve the quality of the transportation modes in the vulnerable zones. Through the SWOT analysis the research found that the policy “Don’t Drive Today” is not bringing down emissions and is increasing the number of vehicles on the road. Recommendations for Mexico City to improve the policy are: 1) Creation of policies or incentives to make citizens invest in electric vehicles (EVs), 2) Carpooling systems, and 3) Intelligent Transportation Systems (ITS).

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CHAPTER 1: INTRODUCTION

Air quality in Mexico City in the latter 1980s and early 1990s was characterized as the worst of all mega-cities in the world (SEDESA, 2015). Since then, the Mexico City government has been trying to implement environmental policies to improve the city's air quality. However, Mexico City, the biggest city in North America, is still dealing with high levels of air pollution. Since the early 1990s, the city has not achieved emissions reductions as desired by the government.

Transportation systems help shape an area's economic health and quality of life, providing the infrastructure for people and goods' mobility (Chatziioannou et al., 2020). However, the transportation sector is the most significant contributor of air pollution emissions to Mexico City. Traffic is a big problem in Mexico City, especially during peak hours. According to the worldwide traffic index, Mexico City is the city with the most traffic congestion in North America, with drivers spending an average of 227 extra hours on the road each year (Castellanos, 2018). According to the TomTom traffic index, Mexico City's traffic congestion average during 2020 was about 36%. The average level of congestion of Mexico City's decreased from 2019 to 2020 due to the COVID-19 restrictions that the city faced throughout the year 2020. However, the level of congestion is still high in comparison to other cities in North America. Traffic is considered the central problem of air pollution in Mexico City. To control the traffic problem, new transportation systems, policies, and energy management strategies are needed. These transportation systems, along with insufficient policies, and limited renewable energy sources, cause Mexico City citizens to face climate change impacts, traffic, social inequity, safety concerns, and health risks. To control the traffic and related problems, government agencies need to implement improved transportation systems, policies, and energy management strategies

1.1 CONTEXT FOR THE TRANSPORTATION SECTOR IN MEXICO CITY

Inadequate transportation systems, policies, and energy strategies make Mexico City citizens face the challenges of climate change, traffic, social equity, safety, and health risks.

Mexico City is one of the most polluted and populated Cities in North America. Transportation accounts for around 60% of the total air pollution in Mexico City (Castellanos, 2018). The transportation systems have been evolving in Mexico City, but new strategies are needed to drastically decrease emissions from the transportation sector. Transportation systems are critical, especially in big cities like Mexico City. Transportation systems help change the population's health and quality of life (Chatziioannou et al.2020). One of the significant transportation modes in Mexico City is the subway.4.5 million commuters use the subway every day in Mexico City (Hernandez et al.2020). Mexico City's subway is the second most congested subway station globally (Lopez, 2018). The rate of safety and health exposure for the users of the subway increase with congestion. The overcrowded problem that citizens of Mexico City face using the subway can cause them exposure to safety risks like robbery and sexual assaults. 61% of the woman who travels in the Mexico City subway have reported a safety exposure issue. On the other hand, 51% of the men who have traveled in the subway have reported a safety issue (Magaloni, 2019).

Public transportation accounts for 58.1% of trips, followed by non-motorized transport and private cars 15% (Varela, 2015). Out of the 24 million daily trips made in public transportation in Mexico City, only 31% produce mass transport systems like the subway or the Mexico BRT system (Metrobus) (Varela, 2015). The large majority of the public transportation system trips made by the public, which accounts for 50.8%, are still characterized by low service quality, poorly regulated, and highly polluting microbuses (Varela, 2015). Mexico needs to bring down the pollution impacts of the public transportation and private transportation sector and reduce other synergetic problems like environmental injustice, health risks, safety impacts. The private sector, even though it only represents 15% of the total amount of usage of the transportation sector in Mexico City, includes around 4.7 million vehicles in Mexico City, which accounts for 81% of the total deaths in road traffic (Varela,2015). The private vehicle sector is also responsible for most of the traffic problems in Mexico City. In the Metropolitan area of Mexico City, approximately 6.3 million private vehicles travel daily (Mendoza, 2018). Most of the private vehicles are fossil-fuel cars. There are less than 1000 electric vehicles and 15,000 hybrid cars in Mexico City. (Mendoza,2018). The 6.3 million private vehicles travel approximately daily in Mexico City, the percentage of private vehicles and hybrid vehicles

compared to fossil fuel private vehicles is very low. Many countries are now banning fossil-fuel vehicles. The adoption of cleaner transportation systems in the private and public sectors of Mexico City is needed. This research aims to recommend to the government of Mexico City better transportation systems, transportation strategies, and policies from other big cities to reduce the pollution, social, health, and safety risks derived from the transportation sector.

1.2 CONTEXT FOR THE ENERGY SECTOR IN MEXICO CITY

The energy sector is crucial for the evolvement and economy of Mexico City. Due to suitable climate conditions and land, Mexico City can adopt private renewable energy investments like solar and wind energy projects to promote sustainability and green energy in the city. The current problem with Mexico City's energy sector is that in 2020 the Secretary of Energy created a new policy to reduce renewable energies like solar and wind and promote fossil-fuel industries. The new government's primary goal is to encourage the oil industry, build a refinery, and build an economy based on fossil-fuel plants.

The new rules imposed by the Secretary of Energy implement a series of limitations on creating power stations, limiting permits for creating renewable farms, and banning renewable energy projects in certain areas (Serrano et al. 2020). The new federal electric industry law affected around 28 solar and wind projects that were ready to operate and 16 under construction. The total foreign private investment lost by banning renewable energy projects in the country of Mexico was around 6.4 billion dollars (Serrano et al., 2020).

To lower air pollution and greenhouse gas emissions in Mexico City, the government needs to enable the renewable energy projects again and start banning the fossil-fuel industries. Green projects are needed in Mexico City to promote a sustainable future. The current government is prioritizing the oil sector because Mexico produces a lot of oil, but it also produces a lot of air pollution. This research will gather research from other developed cities to develop a comparative analysis of how many emissions Mexico City can reduce by adopting renewable energy projects. The comparative analysis will also compare the total costs of Mexico City to aim for renewable projects instead of fossil-fuel projects, which are a significant contributor to the entire economy of the country, not only Mexico City. The energy sector is also

a contributor to pollution to the air of Mexico City. The research aims to recommend better energy systems management strategies to Mexico City's government to promote clean energy projects in Mexico City and reduce the pollution in the city. The energy sector can help the transportation of Mexico City reduce emissions. This research analysis can optimally aim to develop a synergistic model between the transportation and the energy sector in Mexico City that can reduce the risk impacts of climate change, traffic, social equity, health, and safety in all the sectors of Mexico City.

1.3 INTRODUCTION TO THE ENVIRONMENTAL POLICY PROGRAM "DON'T DRIVE TODAY."

A government implements environmental policies to prevent or reduce the harmful effects of anthropogenic activities on the environment. Mexico City has implemented environmental policies like the program "Hoy No Circula," which in English translates to "Don't Drive Today" The environmental program "Don't Drive Today" was implemented on November 20, 1989, by Mexico's government due to the high record levels of ozone and other airborne pollutants in Mexico City (Davies, 2008). The program bans most drivers from using their vehicles one weekday based on the vehicle's license plate's last digit. Evidence from additional sources indicates that the program "Don't Drive Today" is not working, and the restrictions led to an increase in the total number of vehicles in circulation (Davies,2008). The "Don't Drive Today" policy is the only emissions reduction policy that Mexico City has adopted. The policy program's goal was to reduce fossil-fuel vehicles daily from the road to reduce emissions and improve air quality. Another goal of the policy was to promote public transportation, investment in EVs, and reduce traffic. This research aims to prove the inefficiencies of the current policy program. People are buying an extra car, the program is not bringing down the quality of air, traffic is not decreasing, and people are not investing in EVs or using more public transportation.

The car ban policy program has failed in Mexico City in producing a substantial reduction in pollution because the households are purchasing a second car, which is more often older and higher polluting than their current vehicle. With a different final digit of the license plate, the household can use the second car on restricted days (Guerra and Millard-Ball, 2017). The research will use the SWOT analysis method to identify and analyze the current strengths, weaknesses, opportunities, and threats of the current "Don't Drive Today" policy program. The

SWOT analysis in the research will be made by gathering qualitative data from the current policy program to help address the policy's problems and propose a better approach that will lead Mexico City to decrease the traffic pollution problem. The optimal goal of the research is to develop a strategy from the results of the SWOT analysis to improve the efficiency of the current program "Don't Drive Today" and design a policy that will be more helpful for the government of Mexico to control the levels of pollutants produced by the private vehicles.

CHAPTER 2: PROBLEM STATEMENT, RESEARCH QUESTIONS, AND METHODS

2.1 PROBLEM STATEMENT

The transportation sector is the major contributor to air pollution in Mexico City. Traffic is the central problem of pollution in Mexico City. The air pollution produced mainly by traffic development from the transportation systems in Mexico City brings social equity, health, and safety risks to Mexico City citizens. Low-socio economic status sectors tend to face high pollution levels in Mexico City (Lome-Hurtado et al., 2018). Most of the studies on environmental justice suggest that health impacts are more significant at high pollution levels (Hajat et al., 2016). Mexico City needs to adopt management and strategies to promote ecological justice across all communities in the city. Another problem derived from the transportation sector in Mexico City is exposure to health risks. Public transportation systems provide the ideal environment for the transmission of microorganisms as they carry many people daily. In Mexico City, urban systems transport approximately 4.5 million commuters every day (Hernandez et al., 2019).

The subway in Mexico City is the second busiest subway in the American Continent (Hernandez et al., 2019). Citizens who earn the minimum wage in Mexico City tend to use the subway more (Hernandez et al., 2020). This indicates that the groups with low socioeconomic status tend to use the subway more, which leads them to have a higher risk of health exposure by using the subway. Safety is another risk of exposure for the users of the public transportation systems in Mexico City. 61% of the woman who travels in the Mexico City subway have reported a safety exposure issue. 51% of the men who have traveled in the subway have reported

a safety issue (Magaloni, 2019). According to the Thomson Reuters Foundation survey, Mexico City has the most dangerous public transportation system for women out of the five worlds biggest commuter cities. The survey concluded that about three in every four women in Mexico City were not confident of using a public transportation system without the risk of sexual abuse, violence, or harassment (Thomas Reuters Foundation, 2018). According to the National Public Security System of Mexico City, the city averages 28 assaults per day on public transportation systems. Groups with low socioeconomic status tend to use more public transportation systems which means that the low-socioeconomic status groups are more vulnerable to experience safety risk exposures in Mexico City (Hernandez et al.,2020).

Pollution is another factor of exposure that the low-socioeconomic groups are at risk to face. To control the pollution primarily produced by the transportation and energy sectors, Mexico City needs to address the current environmental policies' problems.

The policy "Don't Drive Today" aiming to control the air pollution policy in Mexico City is not working. "Don't Drive Today" is not working, and the restrictions led to an increase in the total number of vehicles in circulation (Davies,2008). The government of Mexico City needs to start implementing environmental policies that will bring down pollution, improve air quality, and promote social equity to all the economic groups in Mexico City. The government of Mexico City needs to focus on policies that will aim to help the low-socioeconomic vulnerable groups. The qualitative research seeks to show that traffic is the central problem of air pollution. It also shows how groups with low socioeconomic status in Mexico City deal with more health risks, safety, and pollution impacts. Finally, it aims to show how the current environmental policies in Mexico City are not controlling the transportation systems' air pollution. The purpose of the research is to analyze the current transportation and energy management strategies of Mexico City using Case Study Comparative Traffic Analysis, Equity Analysis, and Swot Analysis. The research aims to develop a synergetic plan to reduce air pollution and expand renewable energy in the transportation sector while also addressing the transportation challenges of traffic, social equity, safety, and health risks in Mexico City.

2.2 RESEARCH QUESTIONS

This study's overall objective is to implement better environmental policies, transportation systems, and energy strategies to reduce the traffic problems in Mexico City and address climate change, social equity, health, and safety risks in Mexico City. To do so, the main research question for this study is:

How can Mexico City reduce air pollution and expand renewable energy in the transportation sector while also addressing the transportation challenges of traffic, social equity, safety, and health risks?

To help understand the current transportation challenges in Mexico City and to develop better environmental policies, I investigated the following sub-questions:

I. Why is traffic major air pollution and climate problem in Mexico City?

I. Why do groups with low socioeconomic status deal with more health risks, safety, and pollution impacts in Mexico City?

I. What policies can help Mexico City address these multiple challenges in the transportation sector?

2.3METHODS

This research conducted a literature review across peer-review literature, transportation, and energy action plans. The traffic analysis will help identify the most congested area of traffic in Mexico City. The study gathered traffic data from 2017, 2018, 2019, and 2020 in Mexico City. The comparative traffic analysis of the four years aims to show how the traffic has been changing in Mexico City and identify the peak hours of congestion in Mexico City. The traffic analysis will gather quantitative data from the TomTom traffic index platform to gather information for the research recommendations to reduce the traffic problems in Mexico City. The traffic analysis will also review an article on solutions for urban traffic implemented in developing countries in the Asia-Pacific regions. The traffic analysis will help the research answer the sub-question: Why are traffic significant air pollution and climate problems in Mexico City?

To conduct this research, by reading several peer-reviewed articles, I was able to identify the environmental risks produced by the transportation sector. The ecological risks that identify are climate change, social equity, health, and safety risk. With the qualitative data that I gathered, I noticed how the low-socioeconomic groups tend to deal with environmental justice by having more exposure to health, safety, and pollution risks than other economic groups. An equity analysis will help the research aim the sub-question of: Why do groups with low-socioeconomic status deal with more health risks, safety, and pollution impacts in Mexico City?

The equity analysis will gather information from a geospatial and demographic analysis made in Mexico City. The geospatial analysis reviewed provides evidence of environmental injustice for a population with deprivation economic condition living in a location with higher PM10 levels. With the equity analysis, the research will aim to identify the vulnerable low-socioeconomic groups. By identifying the vulnerable economic groups in Mexico City, the research will aim to develop transportation strategies to help lower the health, safety, and pollution risk impacts of the groups with low socioeconomic status. The research recommendation will be implemented first in the geographical locations where the low-socioeconomic vulnerable groups are located.

The final method the research utilized is SWOT analysis to identify the strengths, weaknesses, opportunities, and threats of the environmental policies in Mexico City. The SWOT analysis will focus on the environmental program "Don't Drive Today." The SWOT analysis focuses on gathering the program's weaknesses and threats to recommend better traffic and related issues in Mexico City. The SWOT analysis framework will help to evaluate the current environmental policies in Mexico City and develop strategic planning to overcome the weaknesses and strengths. A comparative analysis will complement the SWOT analysis to gather recommendations and strategies implemented in other cities to reduce traffic and environmental risks in Mexico City. The SWOT analysis will also study a case study of the city of Beijing of how costly are the driving restrictions policies for a country.

CHAPTER 3: TRAFFIC ANALYSIS

Traffic is the main problem of air pollution in Mexico City. To identify why traffic is significant air pollution and climate problem in Mexico City, a traffic analysis was conduct to identify the types of pollution contaminants derived from traffic. The peak hours and the traffic-congested zones are also placed in this traffic analysis. Identifying the peak hours and traffic congestion zones is important for the government of Mexico City to see in which zones and at what hours they need to implement the traffic management strategies. The traffic analysis gathered information from the year 2017 to the year 2020. The traffic analysis goal was to identify the main air pollution and climate problems derived from traffic in Mexico City to develop recommendations and traffic management strategies to reduce traffic in the most congested zones.

3.1 WHY IS TRAFFIC A MAJOR AIR POLLUTION AND CLIMATE PROBLEM IN MEXICO CITY?

Mexico City suffers from high levels of atmospheric pollution, which its majority comes from traffic congestion in the urban areas (Mahady et al. 2020).In 2017 Mexico City's urban center was ranked as the city with the worst traffic in the world (Mahady et al., 2020). Internal combustion vehicles, especially heavy-duty vehicles, are responsible for most greenhouse gas pollution, particulate matter, and a significant portion of the ozone pollution in Mexico City (Mahady et al. 2020). Mexico City can achieve meaningful greenhouse gas reductions by replacing the internal combustion vehicles representing nearly all the vehicles on the road in Mexico City with EVs (Castellanos, 2019). Mexico's population now in 2021 is estimated to be at 21,918,936 people. Mexico City has grown by 0.63% annually since the year 2015. These population estimates come from the latest revision of the UN World Urbanization Prospects. The rapid urban growth and the constant expansion of the Metropolitan Area in Mexico City are forcing thousands of people to use their vehicles daily, optimally increasing traffic (Estrada et al., 2019). Mexico City is an excellent example of a Megapolis where traffic is an everyday problem (Hernandez-Hernandez et al., 2019). In 2017 a total of 5,471,904 vehicles were registered in Mexico City, 5,000,454 were cars, 32,245 were buses, 83,354 were cargo vehicles, and 347,851were motorcycles (Estrada et al.2019). Buses are the most common source of public transportation in Mexico City. The problem with the buses in Mexico City is that most public bus companies do not have private lanes to avoid being congested in traffic with the personal vehicles of the citizens in Mexico City. Traffic congestion on the road not only increases fuel

consumption but it leads to an increase in carbon dioxide emissions and air pollution (Bharadwaj et al.2016). Traffic congestion results in more travel time, and energy consumption causes pollution, decreases productivity, and imposes societal costs. During traffic congestion, vehicles spend more time on the road, crawling and undergoing numerous acceleration and deceleration events, leading to increased emissions in Mexico City (Bharadwaj et al.2016). The traffic congestion increases the emissions of pollutants like carbon monoxide (CO), carbon dioxide (CO2), volatile organic compounds (VOCs), nitrogen oxides (NOx), and particular matter (PM), among other pollutants associated with traffic congestion (Bharadwaj et al.2016). The population and urban growth in Mexico City are bringing more traffic congestion and climate change impacts. Figure 1 below shows a graph of population growth in Mexico City. The traffic congestion affects the three pillars of sustainability of Mexico City: the environment, the economy, and society.

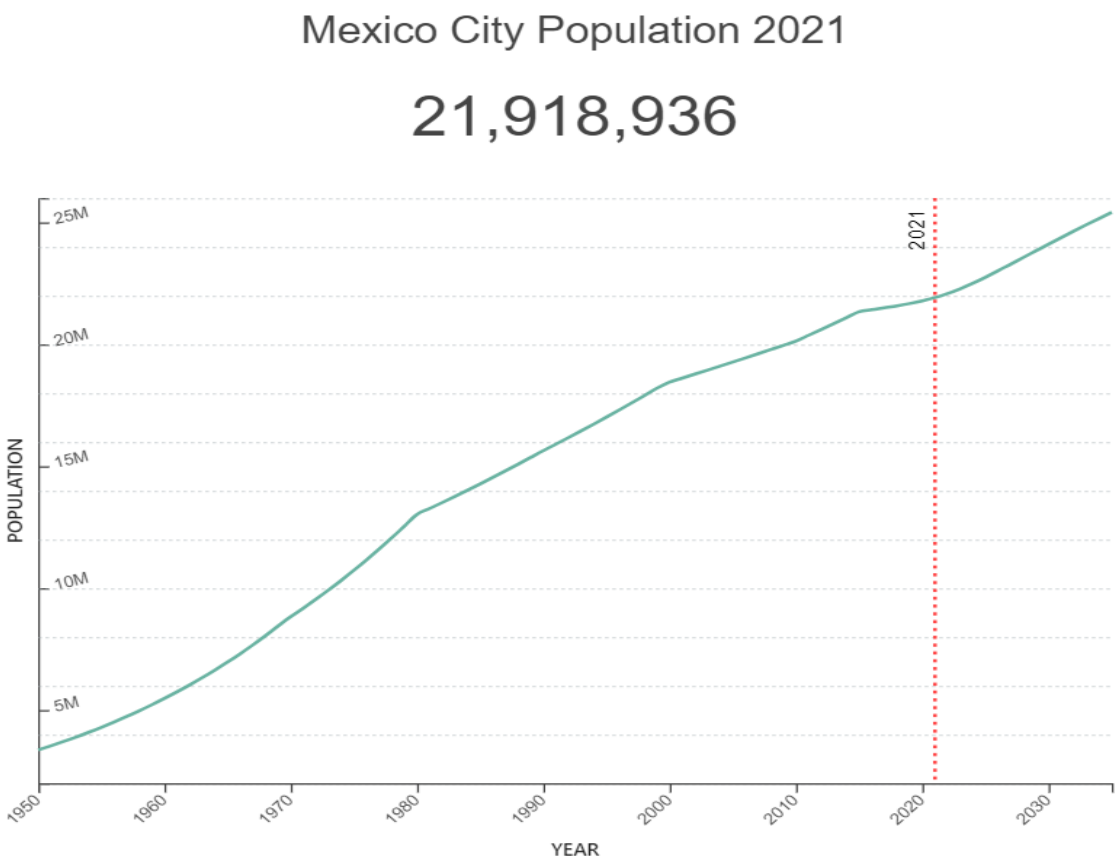

Figure 1. Graph showing the patterns of population growth in Mexico City (Source: World Population Review)

3.2 LITERATURE REVIEW: TRAFFIC ANALYSIS OF MEXICO CITY

The rapid urban growth in Mexico City has made it one of the most crowded globally, with close to twenty million people; the metropolitan areas are constant in expansion, forcing thousands of people to use their vehicles daily. The heavy traffic in Mexico City causes a daily loss of 3.3 million person-hours, which costs 33 billion pesos, according to a study by The Mexican Institute for Competitiveness (Estrada et al.2016). According to the worldwide traffic index, Mexico City is the city with the most traffic congestion in North America, with drivers spending an average of 227 extra hours on the road each year (Castellanos, 2018). Traffic is considered the central problem of air pollution in Mexico City. Due to traffic, air pollutants' levels have exceeded the maximum exposure limits established by the World Health Organization (Estrada et al.2016). Traffic is causing air pollution, smog, and degradation in Mexico City (ICLEI Case Study, 2019). The Mexico City Metropolitan area figures among one of the most congested cities worldwide in 2016. Air quality experts estimated that traffic was causing bad air quality equaled to smoking forty cigarettes a day, affecting children who breathe faster than adults (ICLEI Case Study, 2019). The program "Today Don't Drive" was created to reduce traffic in Mexico City. Evidence from additional sources indicates that the program "Today Don't Drive" is not working, and the restrictions led to an increase in the total number of vehicles in circulation (Davies,2008). The Policy Program is not reducing vehicles; it is incrementing the number of vehicles on the road instead of increasing traffic. Two factors that contribute to traffic are the government transport policies and the disproportionate growth in the number of vehicles on the road in Mexico City (Perez-Espinoza et al.2018). It is essential to identify the peak hours, main areas of accidents in Mexico City, and the traffic zones to manage traffic. The traffic peak hours have been identified in the morning between 6:00 am, and 9:00 am, in the afternoon between 12:00 pm and 4:00 pm, and finally between 6:00 pm and 9:00 pm (Perez-Espinoza et al.2018). Figure 2 below the main vehicular traffic areas are identified; the most significant traffic congestion occurs in the northwest zone in Mexico City (Perez-Espinoza et al.2018).

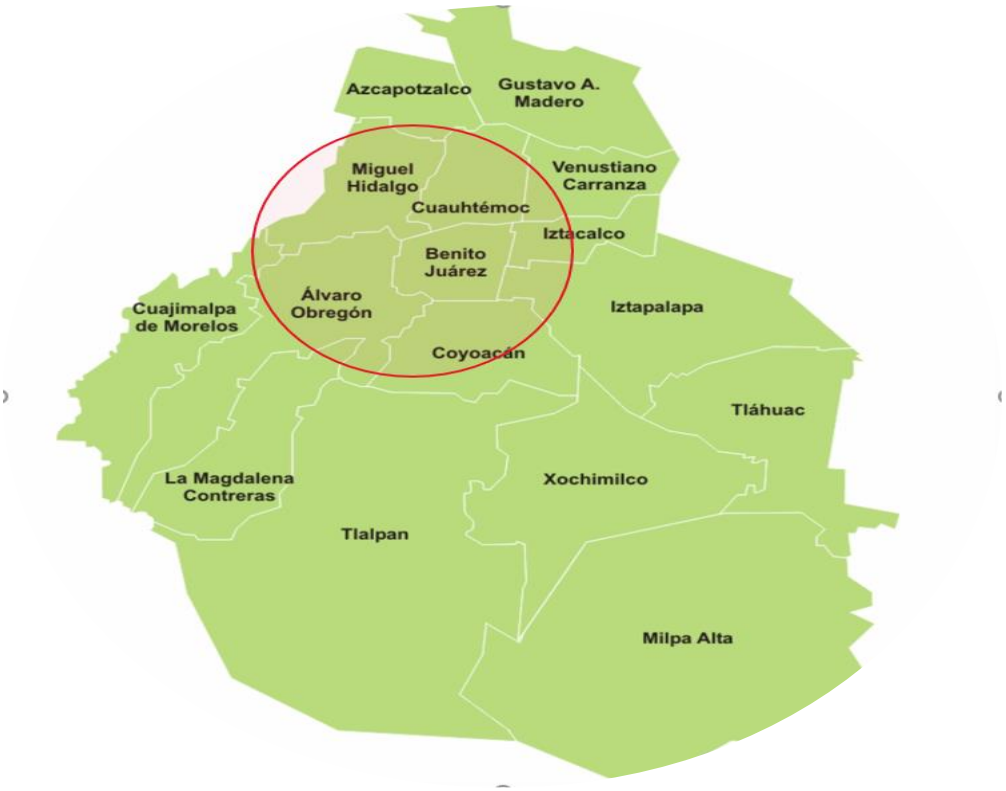

Figure 2. Geographic identification of the traffic congestion in the northwest zone in Mexico City (Modified from Perez-Espinoza et al.2018).

Road traffic accidents are among the principal causes of traffic congestion; studies about high traditional road accidents in urban zones represent a very high inversion of time and money (Angeles Perez et al.2018).In 2015 there were 12,321 road traffic accidents in Mexico City, causing 315 deaths (Angeles Perez et al.2018). The traffic analysis shows that the roads with the most significant number of accidents in Mexico City are: Paseo de la Reforma, Presidente Manuel Avila Camacho, Av. Constituyentes, and Adolfo Lopez Mateos; these roads present the major amount of accidents that coincide with the reality they have the highest vehicular traffic in Mexico City (Angeles Perez et al.2018). All of the roads with traffic accidents are in the northwest zone in Mexico City.

The traffic analysis in this study gathered data from the TomTom Traffic Index, which oversees providing detailed insights on traffic congestion levels in over 400 cities worldwide for the past ten years. The TomTom Traffic Index delivers daily data on traffic congestion in Mexico

City. The traffic analysis shows traffic congestion in Mexico City for four different years 2017, 2018, 2019, and 2020. The traffic analysis in this study provides hours traveled by car, km traveled on the road, the world rank of Mexico City in traffic congestion per year, the percentage of congestion level, rush hours, and time lost by people during the traffic congestion period. The TomTom traffic index comes from a study of over 600 million drivers who use TomTom tech in navigation devices. The data coverage that the traffic analysis cover comes from the total kilometers/miles of GPS data from actual driven trips used in Mexico City. The traffic analysis in this study will also identify the rush hours during the weekdays during the morning and evening times.

2017

In 2017, Mexico City was in the 8th position in ranking the most traffic-congested cities globally and the 1st position as the most traffic-congested cities in North America (TomTom Traffic Index, 2017). The congestion level in Mexico City was 52%; the amount of data covered in that percentage was 1,079,752,968 km (TomTom Traffic Index, 2017). The traffic level of congestion means that a 30-minute trip took 52% more time than it would during Mexico City baseline uncongested levels of congestion. In 2017 the best day with minor traffic was April 14, with average daily congestion of 8%.In 2017 the worst day with most traffic was December 8, with average daily congestion of 80% (TomTom Traffic Index, 2017).48% of the total traffic congestion in the year 2017 occur on highways, the other 53% of the traffic congestion on the road occur in non-highway streets (TomTom Traffic Index, 2017). In Figure 3 below, the morning and evening weekdays rush hours, the traffic analysis identifies which days were the best to avoid during rush hour in Mexico City during 2017. As shown in Figure 3 below, the most congested days during the morning rush hours were Tuesdays, and the least congested days in Mexico City during the morning rush hours were Fridays in the year 2017. Friday was the day to avoid the evening rush hour during the evening rush hour because it was the most congested day, and Monday was the least crowded day during the morning rush hour in Mexico City during 2017. The time lost during the rush hour per trip in Mexico City during 2017 is around 23 minutes per every 30 minutes trip in the morning and 26 minutes per every 30 min trip in the evening (TomTom Traffic Index, 2017). A driver in Mexico City during the year 2017 spent around 188 extra hours on the road, which is equivalent to 7 days and 20 hours. The extra driving

time that a driver spent on the road during rush hour in 2017 is equal to the time it takes to plant 189 trees to benefit the environment (TomTom Traffic Index, 2017). In Table 1 below, the study identified the weekly traffic congestion by the time of day in Mexico City during 2017. The purpose of Table 1 is to show the percentage level of traffic congestion at each time during every weekday. The percentages marked with red represent the rush hours times and days of traffic congestion in Mexico City. The worst time to avoid in the year 2017, according to Table 1, was Thursday from 7 pm to 8 pm. Traveling after 8 pm on Thursdays could save a driver around 5 hours per year for a 30 minutes commute during 2017 in Mexico City (TomTom Traffic Index, 2017).

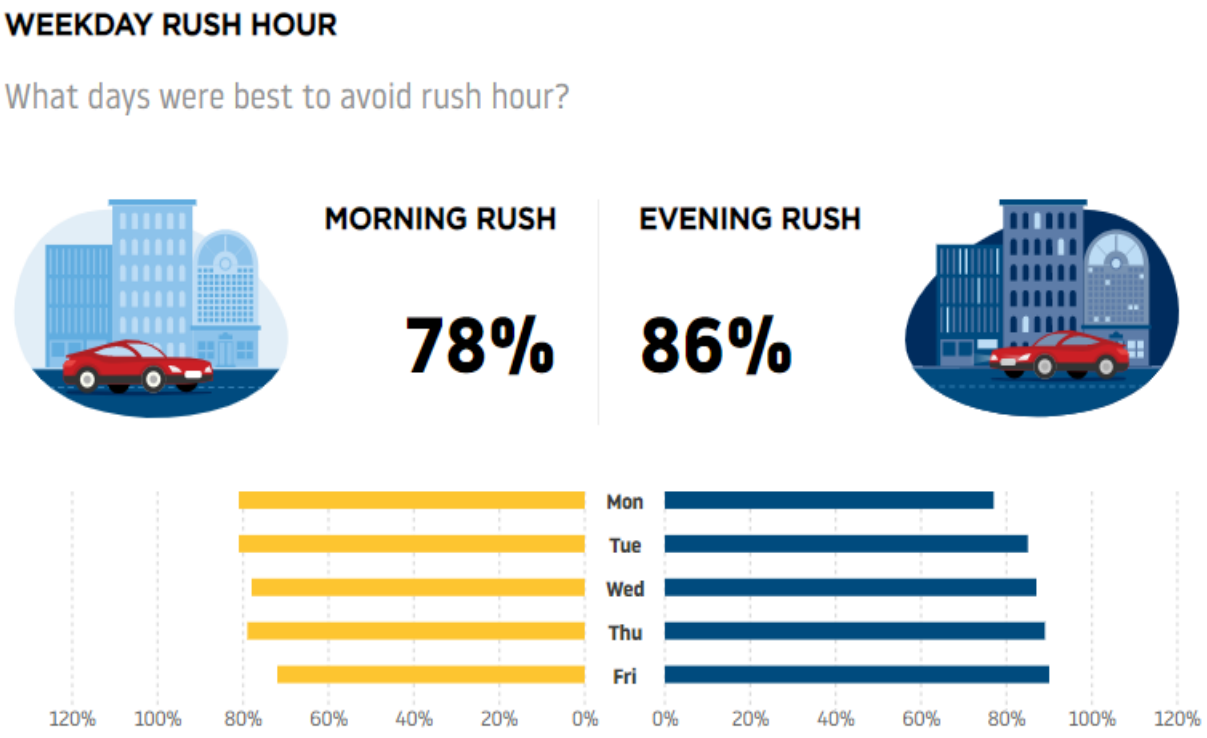

Figure 3. Identification of the % of traffic congestion in Mexico City during morning and evening weekdays rush hour in 2017 (Source: TomTom Traffic Index).

Table 1. Identification of the rush hour during the weekdays in Mexico City in 2017 (Source:TomTom Traffic Index).

WEEKLY TRAFFIC CONGESTION BY TIME OF DAY

What time was rush hour in Mexico City?

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
12:00 AM	8%	0%	0%	2%	4%	5%	11%
	4%	0%	0%	0%	0%	0%	5%
02:00 AM	2%	0%	0%	0%	0%	0%	2%
	0%	0%	0%	0%	0%	0%	0%
04:00 AM	0%	0%	0%	0%	0%	0%	0%
	0%	13%	10%	9%	9%	9%	1%
06:00 AM	1%	43%	41%	38%	38%	35%	5%
	1%	68%	67%	64%	65%	58%	10%
08:00 AM	4%	81%	81%	78%	79%	72%	19%
	9%	66%	69%	68%	69%	63%	26%
10:00 AM	14%	46%	53%	54%	55%	52%	31%
	18%	39%	47%	49%	50%	50%	34%
12:00 PM	22%	39%	47%	50%	51%	53%	41%
	27%	44%	54%	56%	57%	63%	49%
02:00 PM	31%	52%	63%	66%	66%	80%	56%
	28%	50%	60%	62%	63%	90%	52%
04:00 PM	23%	44%	52%	55%	55%	81%	40%
	23%	53%	60%	63%	64%	76%	29%
06:00 PM	28%	77%	85%	87%	89%	87%	28%
	31%	83%	91%	92%	96%	89%	30%
08:00 PM	29%	64%	72%	72%	77%	72%	28%
	24%	38%	46%	46%	51%	52%	23%
10:00 PM	15%	19%	26%	26%	31%	37%	20%
	6%	6%	10%	11%	14%	23%	14%

2018

In 2018, Mexico City was the 9th position in the TomTom Index Traffic ranking of the most traffic-congested cities globally and the 1st position traffic-congested city in North America (TomTom Traffic Index, 2018). The congestion level in Mexico City was 52%, the same as the

year 2017; the amount of data coverage in that percentage was 1,078,786,118 km (TomTom Traffic Index, 2018). In 2018 the best day to travel with minor traffic was December 25, with average daily traffic congestion of 9%.In 2018 the worst day to travel with the most traffic was November 14, with average daily congestion of 82% (TomTom Traffic Index, 2018). 49% of the traffic congestion in the year 2018 occurred on highways, 53% of the traffic level road congestion occurred in non-highways (TomTom Traffic Index, 2018). In Figure 4 below, the morning and evening weekdays rush hours, the traffic analysis identifies which days were the best to avoid during rush hour in Mexico City during 2018. As shown in Figure 4 below, the most congested days during the morning rush hours were Tuesdays, and the minor traffic-congested days during the morning rush hours were Fridays in 2018. During the evening rush hour, Friday was the day to avoid the evening rush hour because it was the most traffic-congested day. Monday was the least traffic-congested day during the evening morning rush hour in Mexico City during 2018. The time lost during the rush hour traffic-congestion per trip in Mexico City in 2018 is around 25 minutes per every 30 minutes trip in the morning rush hour and 26 minutes per every 30 minutes trip during the evening rush hour (TomTom Traffic Index, 2018). A driver in Mexico City during the year 2018 spent around 193 extra hours on the road, which is equivalent to 8 days and 1 hour. The extra driving time that a driver spent on the road during rush hour in 2018 is equal to the time it takes to plant 193 trees to benefit the environment (TomTom Traffic Index, 2018).In Table 2 below, the study identified the weekly traffic congestion by the time of day in Mexico City during the year 2018. The purpose of Table 2 is to show the percentage level of traffic congestion at each particular time during every weekday. The percentages marked with dark red represent the rush hours and days of traffic congestion in Mexico City. The worst time to avoid driving in the year 2018, according to Table 2, was Thursday from 7 pm to 8 pm. Traveling after 8 pm on Thursdays during the year 2018 could save a driver around up to 5 hours per 30-minute commute (TomTom Traffic Index, 2018).

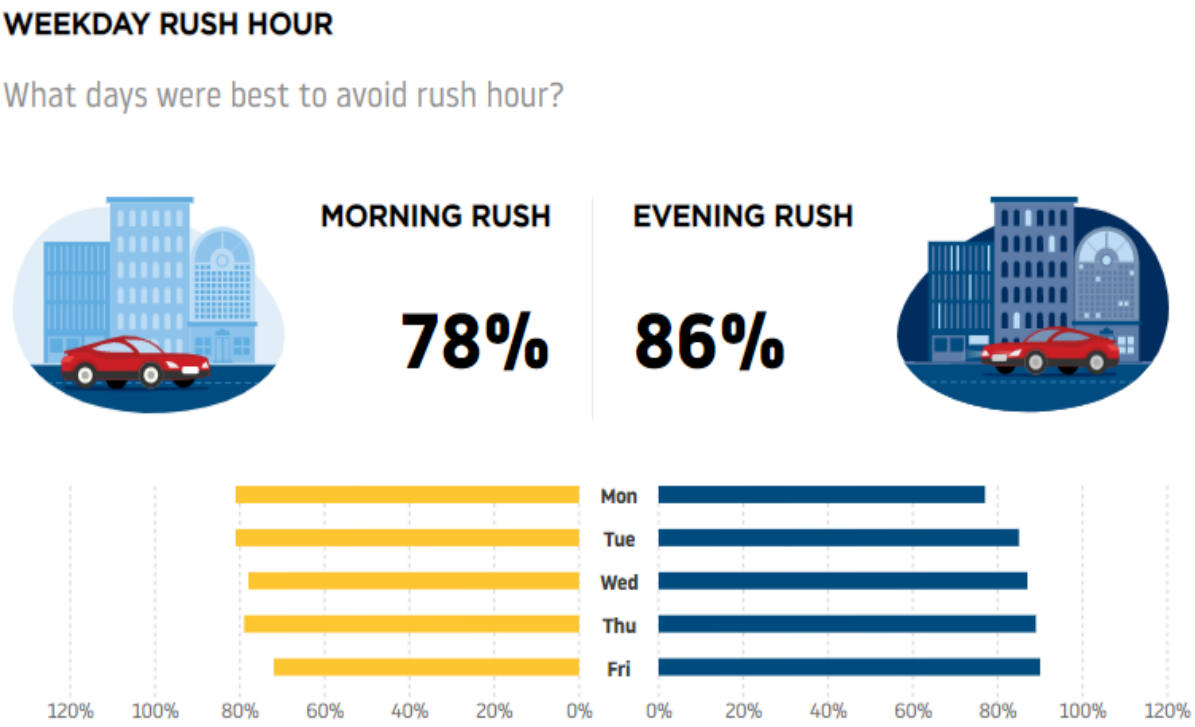

Figure 4. Identification of the % of traffic congestion in Mexico City during morning and evening weekdays rush hour in 2018 (Source: TomTom Traffic Index).

Table 2. Identification of the rush hour during the weekdays in Mexico City in 2018 (Source: TomTom Traffic Index).

WEEKLY TRAFFIC CONGESTION BY TIME OF DAY

What time was rush hour in Mexico City?

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
12:00 AM	8%	0%	0%	0%	2%	4%	11%
	4%	0%	0%	0%	0%	0%	4%
02:00 AM	1%	0%	0%	0%	0%	0%	1%
	0%	0%	0%	0%	0%	0%	0%
04:00 AM	0%	0%	0%	0%	0%	0%	0%
	0%	16%	12%	12%	11%	11%	1%
06:00 AM	1%	46%	44%	43%	42%	40%	7%
	2%	71%	71%	70%	68%	64%	11%
08:00 AM	5%	81%	84%	83%	82%	77%	21%
	10%	63%	70%	72%	72%	66%	28%
10:00 AM	14%	43%	53%	56%	57%	54%	32%
	18%	36%	47%	49%	50%	50%	36%
12:00 PM	22%	37%	46%	49%	51%	54%	42%
	28%	43%	52%	56%	58%	64%	52%
02:00 PM	31%	50%	60%	64%	67%	82%	59%
	30%	48%	57%	61%	65%	93%	55%
04:00 PM	24%	42%	49%	54%	56%	85%	42%
	23%	51%	58%	63%	65%	80%	33%
06:00 PM	27%	75%	84%	87%	90%	90%	31%
	30%	79%	89%	92%	95%	91%	31%
08:00 PM	29%	59%	69%	71%	74%	74%	29%
	24%	35%	43%	46%	48%	54%	24%
10:00 PM	15%	17%	22%	25%	28%	38%	20%
	7%	5%	8%	10%	13%	22%	14%

2019

In 2019, Mexico City was the 13th position in the TomTom Index Traffic ranking of the most traffic-congested cities globally and the 1st position traffic-congested city in North America

(TomTom Traffic Index, 2019). The congestion level in Mexico City was 52%, the same as the years 2017 and 2018; the amount of data coverage in that percentage was 1,478,195,001 km (TomTom Traffic Index, 2019). In 2019 the best day to travel with minor traffic was April 19, with average daily traffic congestion of 8%.In 2019 the worst day to travel with the most traffic was October 17, with a high level of traffic congestion of 86% (TomTom Traffic Index, 2019). 48% of the traffic congestion in 2019 occurred on highways, 54% of the traffic level road congestion occurred in non-highways (TomTom Traffic Index, 2019). In Figure 5 below, the morning and evening weekdays rush hours, the traffic analysis identifies which days were the best to avoid during rush hour in Mexico City during 2019. As shown in Figure 5 below, the most congested days during the morning rush hours were Tuesdays, and the minor traffic-congested days during the morning rush hours were Fridays in 2019. During the evening rush hour, Friday was the day to avoid the evening rush hour because it was the most traffic-congested day. Monday was the least traffic-congested day during the evening morning rush hour in Mexico City during 2019. The time lost during the rush hour traffic-congestion per trip in Mexico City in 2019 is around 25 minutes per every 30 minutes trip in the morning rush hour and 26 minutes per every 30 minutes trip during the evening rush hour (TomTom Traffic Index, 2019). A driver in Mexico City during the year 2019 spent around 195 extra hours on the road, which is equivalent to 8 days and 3 hours. The extra driving time that a driver spent on the road during rush hour in 2019 is equal to the time it takes to plant 196 trees to benefit the environment (TomTom Traffic Index, 2019).In Table 3 below, the study identified the weekly traffic congestion by the time of day in Mexico City during the year 2019. The purpose of Table 3 is to show the percentage level of traffic congestion at each time during every weekday. The percentages marked with dark red represent the rush hours and days of traffic congestion in Mexico City. The worst time to avoid driving in the year 2019, according to Table 3, was Thursday from 7 pm to 8 pm. Traveling after 8 pm on Thursdays during the year 2018 could save a driver around up to 5 hours per 30-minute commute (TomTom Traffic Index, 2019).

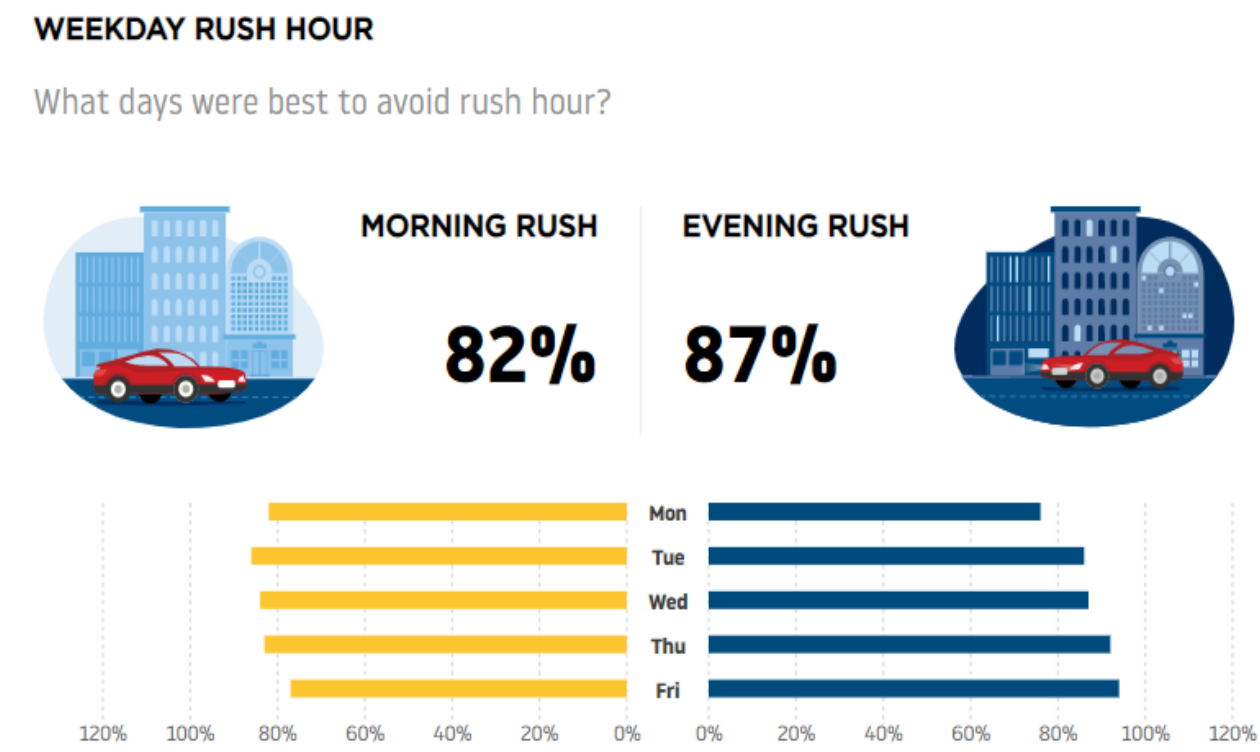

Figure 5. Identification of the % of traffic congestion in Mexico City during morning and evening weekdays rush hour in 2019 (Source: TomTom Traffic Index).

Table 3. Identification of the rush hour during the weekdays in Mexico City in 2019 (Source: TomTom Traffic Index).

WEEKLY TRAFFIC CONGESTION BY TIME OF DAY

What time was rush hour in Mexico City?

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
12:00 AM	7%	1%	0%	1%	2%	5%	8%
	3%	0%	0%	0%	0%	0%	3%
02:00 AM	1%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%
04:00 AM	0%	0%	0%	0%	0%	0%	0%
	0%	15%	13%	12%	12%	11%	1%
06:00 AM	2%	46%	45%	43%	43%	39%	7%
	2%	71%	72%	69%	69%	63%	13%
08:00 AM	6%	82%	86%	84%	83%	77%	24%
	10%	64%	71%	71%	71%	66%	31%
10:00 AM	15%	43%	54%	55%	56%	53%	35%
	19%	36%	47%	49%	51%	50%	39%
12:00 PM	24%	37%	47%	49%	51%	54%	44%
	29%	44%	53%	55%	58%	65%	54%
02:00 PM	32%	50%	61%	64%	67%	84%	62%
	29%	49%	58%	61%	66%	94%	57%
04:00 PM	25%	43%	51%	54%	58%	86%	44%
	25%	53%	60%	63%	67%	80%	33%
06:00 PM	30%	76%	86%	87%	92%	91%	33%
	32%	77%	88%	89%	96%	89%	33%
08:00 PM	30%	56%	67%	69%	76%	71%	31%
	24%	34%	43%	44%	50%	51%	26%
10:00 PM	15%	17%	22%	24%	29%	34%	20%
	7%	6%	8%	10%	14%	20%	13%

2020

In 2020, Mexico City was the 29th position in the TomTom Index Traffic ranking of the most traffic-congested cities globally and the 1st position traffic-congested city in North America (TomTom Traffic Index, 2020). Mexico traffic congestion decreased in 2020 in comparison to the years 2017,2018 and 2019. However, in this study, it has to be noticed that during the year 2020, the covid-19 pandemic was the main reason for the decrease in traffic congestion in Mexico City. The congestion level in Mexico City was 36%, which decreases by 16% compared

to 2019. In 2020 the month with the least congested traffic flow was May, with an average congestion level of 10%. February was the month with the most congested traffic flow, with average daily traffic congestion of 56% (TomTom Traffic Index, 2020). The most traffic congestion in 2020 occurs on February 14, with average daily congestion of 82% (TomTom Traffic Index, 2020).In the year 2020, Mexico City experience 139 days with low traffic, which is unusual in the city (TomTom Traffic Index, 2020).

In Figure 6 below, the traffic analysis shows how congested Mexico City was during rush hour throughout 2020 in comparison to the year 2019. The traffic analysis identifies a monthly change in traffic congestion between the years 2019 and 2020. As shown in Figure 6 below, the most congested month in 2020 during the morning rush hours was January, and the lower traffic-congested month during the morning rush hours was May. During the evening rush hour, January was the month with high levels of traffic congestion. May was the month with the lowest traffic congestion in Mexico City during the evening rush hour (TomTom Traffic Index, 2020). Overall, during the morning weekday rush hour, the level of congestion was 50%. During the evening weekday rush hour, the overall congestion level was 59% (TomTom Traffic Index, 2020). The level of traffic congestion decreases by 32% in comparison to the year 2019 in the morning rush hour, and it decreases 28% compared to the overall traffic congestion level during the evening weekday rush hour of the year 2019. The time lost during the rush hour traffic-congestion per trip in Mexico City in 2020 is around 15 minutes per every 30 minutes trip in the morning rush hour and 18 minutes per every 30 minutes trip during the evening rush hour (TomTom Traffic Index, 2020). A driver in Mexico City during the year 2020 spent around 124 extra hours on the road, which is equivalent to 5 days and 4 hours (TomTom Traffic Index, 2020). In Table 4 below, the study identified the weekly traffic congestion by the time of day in Mexico City during the year 2020. The purpose of Table 4 is to show the percentage level of traffic congestion at each time during every weekday. The percentages marked with dark red represent the rush hours and days of traffic congestion in Mexico City. The worst time to avoid driving in the year 2020, according to Table 4, was Friday from 7 pm to 8 pm. Traveling after 8 pm on Fridays during the year 2020 could save a driver around up to 4 hours per year per 30-minute commute (TomTom Traffic Index, 2020).

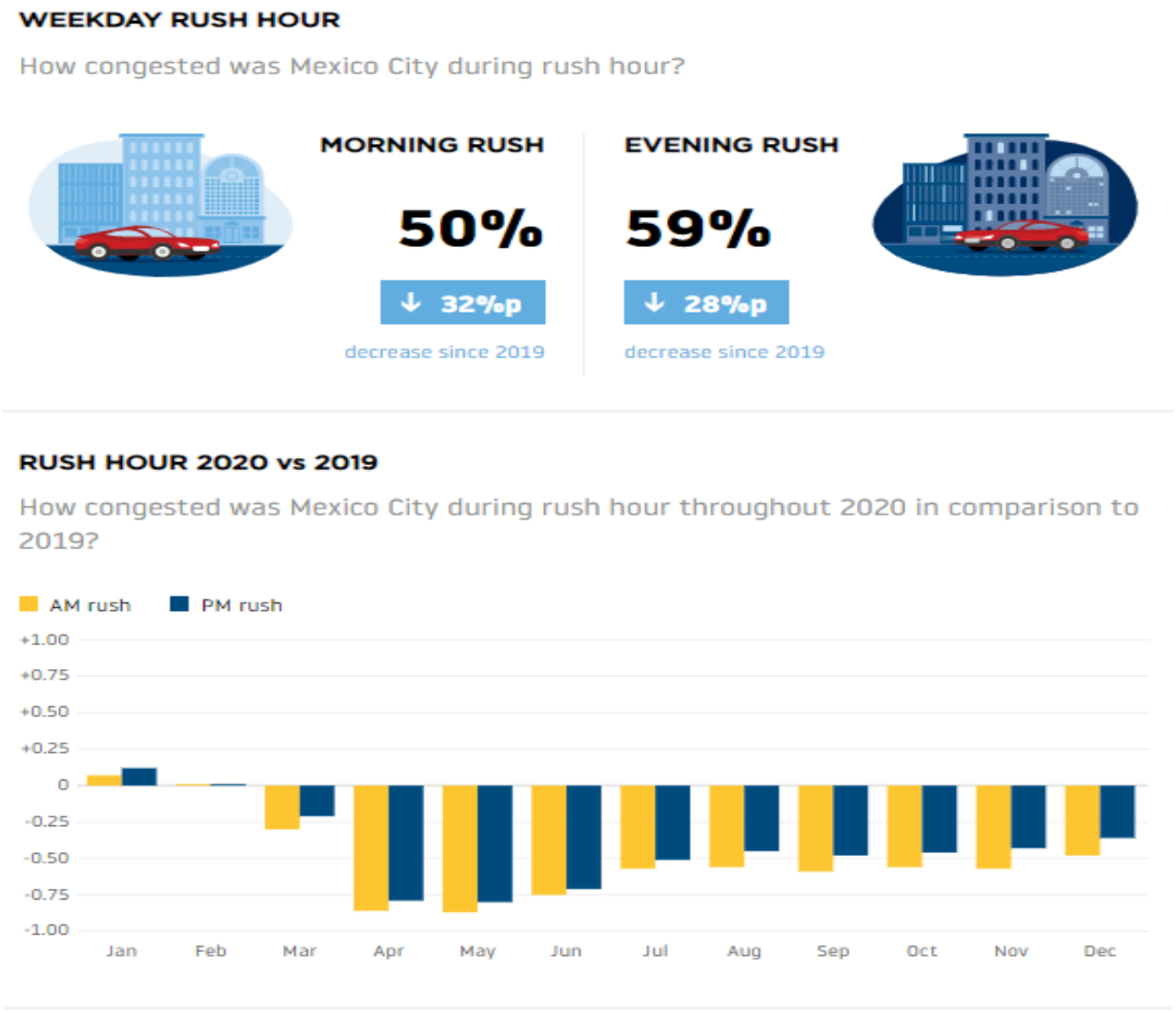

Figure 6. Graph showing traffic congestion levels during the morning and evening weekday rush hour from the year 2020 compared to 2019 (Source: TomTom Traffic Index).

Table 4. Identification of the rush hour during the weekdays in Mexico City in 2020 (Source: TomTom Traffic Index).

WEEKLY TRAFFIC CONGESTION BY TIME OF DAY

What time was rush hour in Mexico City?

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
12:00 AM	3%	0%	0%	0%	0%	0%	4%
	0%	0%	0%	0%	0%	0%	0%
02:00 AM	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%
04:00 AM	0%	0%	0%	0%	0%	0%	0%
	0%	5%	6%	5%	4%	5%	0%
06:00 AM	0%	25%	28%	27%	26%	25%	4%
	0%	39%	44%	43%	42%	39%	8%
08:00 AM	4%	46%	52%	51%	50%	48%	16%
	8%	40%	46%	46%	46%	46%	23%
10:00 AM	11%	31%	39%	39%	39%	41%	27%
	14%	28%	36%	36%	37%	40%	30%
12:00 PM	18%	30%	36%	37%	38%	42%	35%
	21%	33%	40%	41%	42%	49%	42%
02:00 PM	23%	36%	43%	45%	47%	60%	48%
	21%	36%	42%	43%	46%	65%	44%
04:00 PM	18%	33%	38%	39%	41%	61%	34%
	18%	36%	42%	43%	45%	59%	26%
06:00 PM	23%	50%	57%	57%	60%	69%	27%
	26%	50%	58%	58%	61%	69%	27%
08:00 PM	23%	35%	41%	42%	45%	53%	23%
	16%	19%	23%	24%	27%	35%	17%
10:00 PM	10%	9%	12%	12%	15%	22%	13%
	4%	2%	3%	4%	6%	12%	8%

3.3 COMPARATIVE ANALYSIS

The traffic analysis gathered data from the years 2017, 2018, 2019, and 2020. Comparing the traffic flow of the four years, the patterns from the years 2017,2018 and 2019 are very similar. The level of traffic congestion in the years 2017, 2018, and 2019 was 52%. The percentage of congestion in the year 2020 was 36% (TomTom Traffic Index, 2020). The traffic level of congestion means that a 30-minute trip took 52% more time than it would during Mexico City baseline uncongested conditions in the years 2017, 2018, and 2019. In the year 2020, the

traffic level of congestion was 36%. It means that a 30-minute trip took 36% more time than it would during Mexico City baseline uncongested conditions. The 36% can be converted into a simple calculation. First: .36 x 30 mins = 10.8 mins extra average travel time. Second: 30 mins + 10.8 mins = 40.8 mins of total average travel time. Compared to the past three years, the traffic congestion of the year 2020 decreased by 16%. In Figure 7 below, we can show a comparison of the monthly traffic congestion levels from the years 2019 and 2020. In January and February in the year 2020, it offers a similar pattern of high levels of traffic congestion compared to the year 2019. In March is detected in the traffic analysis, how 2020 traffic starts to decline compared with the traffic congestion of 2019. On March 30, 2020, the authorities of Mexico City declared a state of emergency because of the ease of the COVID-19 pandemic. The COVID-19 pandemic that the world faces in the year 2020 is the primary reason why there was a significant decline in traffic congestion from 2020 compared to 2019, which has similar traffic congestion patterns to the year 2017 2018.

In the worldwide overall ranking from the TomTom Traffic Index, Mexico has been lowering traffic from year to year in comparison to other countries; however, in the four years, Mexico was rank as the city with the highest level of traffic congestion in North America (TomTom Traffic Index, 2020). The evening rush hour seems to be more crowded than the morning rush hour in the four years in which the study gathered the data. The most congested hour to drive in 2017, 2018, and 2019 was Thursday's from 7 pm to 8 pm. In 2020, the most crowded hour to drive was on Fridays from 7 pm to 9 pm. According to the UN World Urbanization Prospects population in Mexico City has been increasing by 0.63% since 2015. The population growth has maintained the same traffic congestion patterns from the year 2017 to the year 2020. The COVID-19 pandemic reduced traffic congestion in the year 2020 in Mexico City by around 16% compared to 2017, 2018, and 2019.

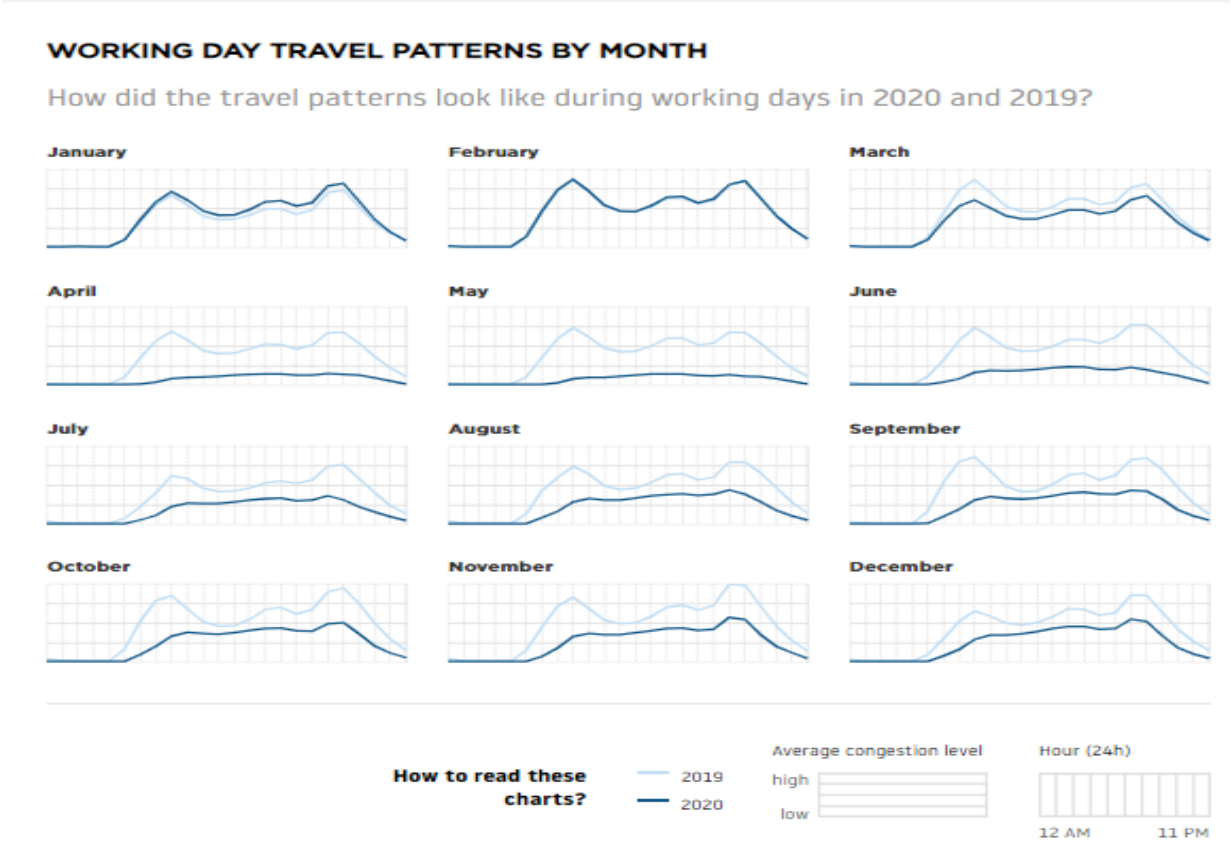

Figure 7. Comparison of traffic congestion patterns from the year 2019 and 2020 (Source: TomTom Traffic Index, 2020)

CHAPTER 4: ENVIRONMENTAL AND SOCIAL IMPACT ANALYSIS ACROSS MEXICO CITY TRANSPORTATION

To promote environmental justice in Mexico City, the people need a good environment and a good society. The ecological and social impact analysis complements the traffic analysis to identify the number of pollutants from each transportation mode in Mexico City. The study also identified the types of social communities that tend to use more public transportation and the most common mode of transport used by the citizens in Mexico City. The transportation sector in Mexico City needs to be modernized. Old transportation systems tend to provide more pollution to the environment. The environmental and social impact analysis across Mexico City identifies and reduces the emissions from each transportation zone in Mexico City.

4.1 MODERNIZING TRANSPORTATION IN MEXICO CITY

Mexico City is one of the biggest cities in the world. In Mexico City, there is a lot of tourism, business, politics, and education. With millions of people traveling daily, the private and public sectors of Mexico City can be congested, and the citizens can face delays. According to Claudia Sheinbaum, the Head of the Mexico City Government, "The subway has to be modernized; we can no longer continue with one that is 40 years old and has not undergone a major modernization and maintenance process". Most of the public transportation systems in Mexico City are around five decades old. Mexico City government needs to develop strategies to modernize the transportation systems in Mexico City. Mexico City has an aging infrastructure and lacks rapid transit transportation. Lack of rapid transit infrastructure makes traffic worst (Harbering et al. 2020). Mexico City also needs to modernize the public infrastructure to improve the filters and cleaning of the current public transportation systems of Mexico City. The overcrowding in the public transportation systems is causing many health hazards, especially among low-socioeconomic groups in Mexico City. The modernization of public transportation will bring new infrastructure, filters, and cleaning, reducing the number of bacteria's in the current systems. Most trips are made in public transportation systems in Mexico City, characterized by low service quality, poorly regulated, and highly polluted systems (Varela, 2015). Before using the methodology to show results on which strategies the Mexico City government needs to reduce traffic. It is crucial to identify the type of public transportation system that Mexico City currently has and how it regulates and funds each public transportation system.

Table 5 below shows all the public transportation systems in Mexico City and which organization oversees operating and financing each public transportation system. In Mexico City, more employers are located in the central areas and business districts that are hard to reach by public transportation; this issue causes overcrowding of people in the current public transportation systems and a significant increase in traffic (ICLEI Case Study, 2019). The increase in congestion on public transportation and on the road, combined with increased industrial activities, has contributed to air pollution and air quality degradation in Mexico City (ICLEI Case Study, 2019). Figure 8 and Figure 9 below show the mode of transportation that people in Mexico City prefer to use the most. Figure 8 refers to Mexico City, and Figure 9 refers

to the Metro area of Mexico City. Figure 8 and Figure 9 are based on a land area consisting of around 1,485 km^2. Approximately 8,985,339 in Mexico City and the Metropolitan Area is 7,866 km^2 with a population of roughly 20,892,724 people (ICLEI Case Study, 2019).

Table 5. Public Transportation Systems in Mexico City (ICLEI Case Study, 2019).

System	ECOBICI	Peseros	Bus	Metro	Metrobús	Tren ligero	Trolebús	Tren Interurbano Toluca – Valle de México
Type	Bike-sharing system	Microbuses	Buses	Subway	BRT	LRT	Trolleybuses	Train
Authority	Secretaría de Movilidad (SEMOVI)	Individual concessions	Red de Transporte de Pasajeros (RTP)	Sistema de Transporte Colectivo	Metrobús	Servicio de Transportes Eléctricos		Under construction (federal government's budget)
	Publicly funded		Decentralized state-owned companies					

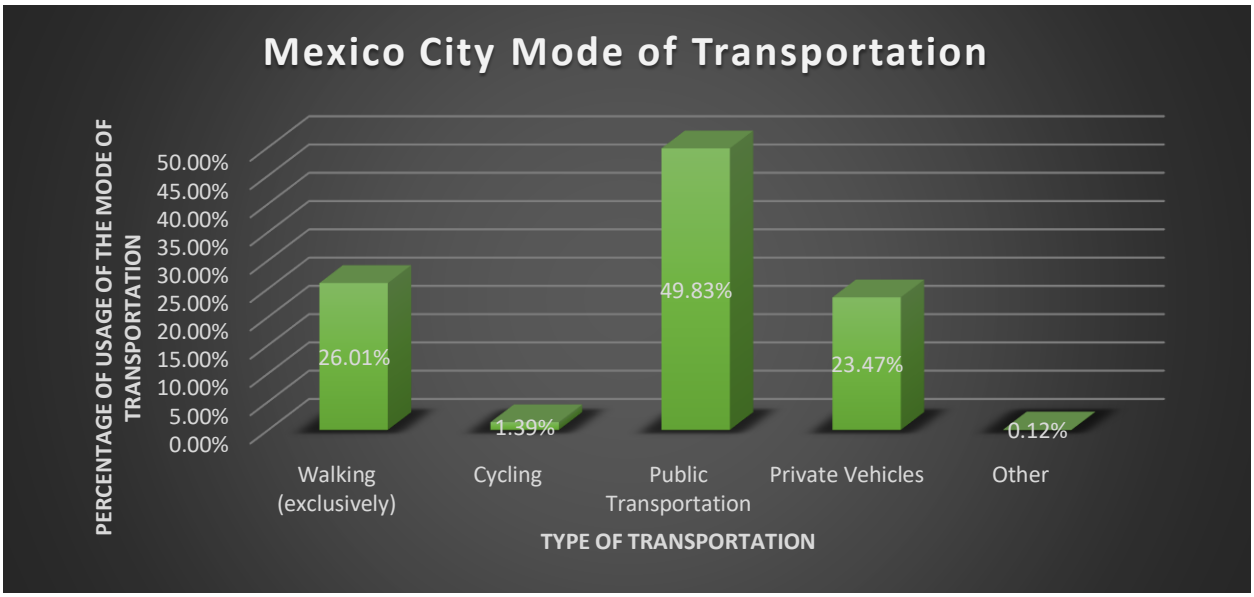

Figure 8. Mexico City % of the usage of the types of transportation (Modified from ICLEI Case Study, 2019)

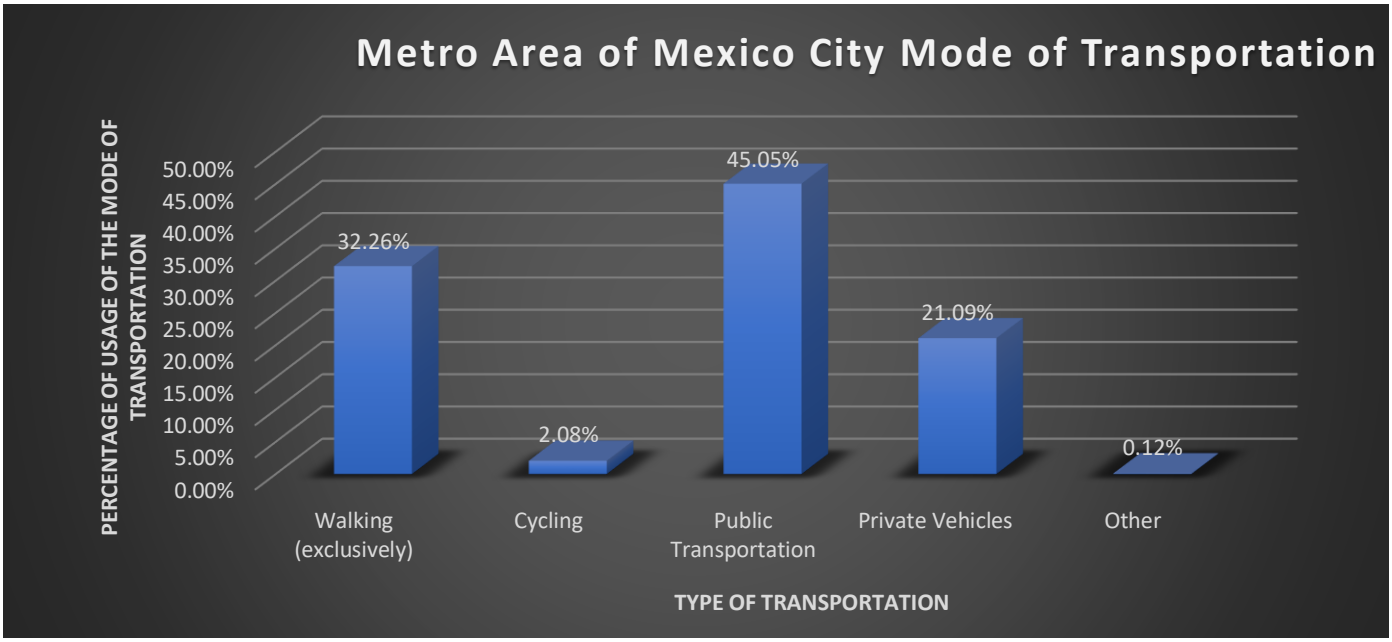

Figure 9. Mexico City Metro Area % of the usage of the types of transportation (Modified from ICLEI Case Study, 2019)

According to the book "THREE REVOLUTIONS," written by Daniel Sperling, automated steering vehicles, shared carpooling systems, and electric cars can reduce climate change risks and bring a better future to a city. Automation in the transportation sector can

modernize the transportation systems, but Google estimates that automation could eliminate at least half of 1.2 million crash fatalities worldwide (World Health Organization, 2013). It is predicted that automated transportation systems would reduce accidents by 80% by 2040 (Center for Automotive Research, 2012). According to the literature review, automotive transportation systems can reduce traffic accidents, reduce traffic, pollution, and safety exposure in Mexico City. Carpooling can be another transportation alternative to reduce traffic and air pollution (EPA, 2017). Carpooling apps provide an estimated reduction of 0.58 tons of CO2 per household member per year reported in North America (Q et al. 2020). Electric vehicles in another source of modernizing the private transportation sector. EVs are one of the most convenient alternatives to replace fossil-fuel cars. However, it is not suitable for the citizens to adopt that alternative in Mexico due to high prices and poor infrastructure. Education can also play a massive role in making the citizens of Mexico City adopt EVs. Higher education of individuals found to be positively associated with adopting an electric vehicle (Harbering et al.2020).

4.2 CARBON EMISSIONS FROM THE TRANSPORTATION SECTOR IN MEXICO CITY

Mexico City suffers from high levels of atmospheric pollution (Mahady et al .2020). Most high levels in a metropolitan city like Mexico City come from the transportation and energy sectors. The pollutants caused by the transportation sector in Mexico City damage the citizens' respiratory and cardiac systems in Mexico City (Mahady et al.2020). Internal combustion vehicles are responsible for most greenhouse gas pollution and particulate matter pollution in Mexico City (Mahady et al.2020). In Figure 10 below, the amount of CO2 emissions per transportation system is shown in Mexico City. Vehicles are the transportation mode with the most significant contributions of CO2 emissions in Mexico City. Cars are the most common transportation method used in Mexico City. To reduce emissions, a good alternative can be the usage of EVs. By replacing EVs on the roads instead of internal combustion vehicles, Mexico City can reduce a significant amount of atmospheric pollution, especially in congested urban areas (Marshall et al., 2014).

In Mexico City, fossil-fuel vehicles are also responsible for 53% of particulate matter (PM10), 56% of particulate matter (PM2.5), 86% of nitrogen oxides (NOx), 86% of carbon monoxide (CO), and 17% of volatile organic compounds (VOC) emissions (Mahady et al.,

2020). Figure 11 below shows the number and type of emissions produced by fossil-fuel vehicles. Zero-emissions vehicles on the road are needed in Mexico City to reduce the pollutants caused by fossil-fuel vehicles. Another problem with the transportation emissions in Mexico City is the air emission produced by the buses. The buses alone in Mexico City are responsible for 22% of PM10, 32% of PM2.2, and 23% NOx (Mahady et al. 2020). Figure 12 below shows the number and type of emissions produced by buses in Mexico City. An alternative for buses can be Intelligent Transportation Systems (ITS). ITS can reduce intersections, promote speed control, autonomously reduce travel time, and improve capacity management. ITS can reduce the citizens' travel time by 25% in a city and reduce greenhouse emissions (Knupter et al., 2018).

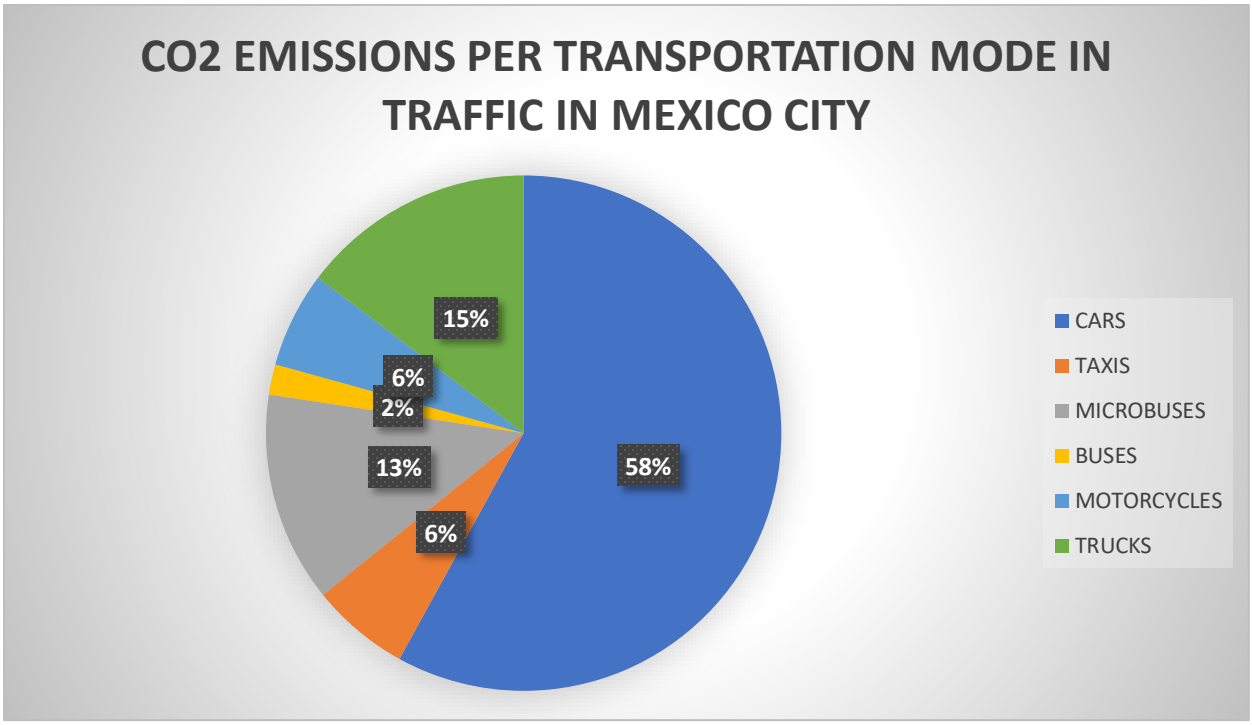

Figure 10. CO2 emissions per transportation mode in Mexico City (2007)

Modified from (Varela, 2015)

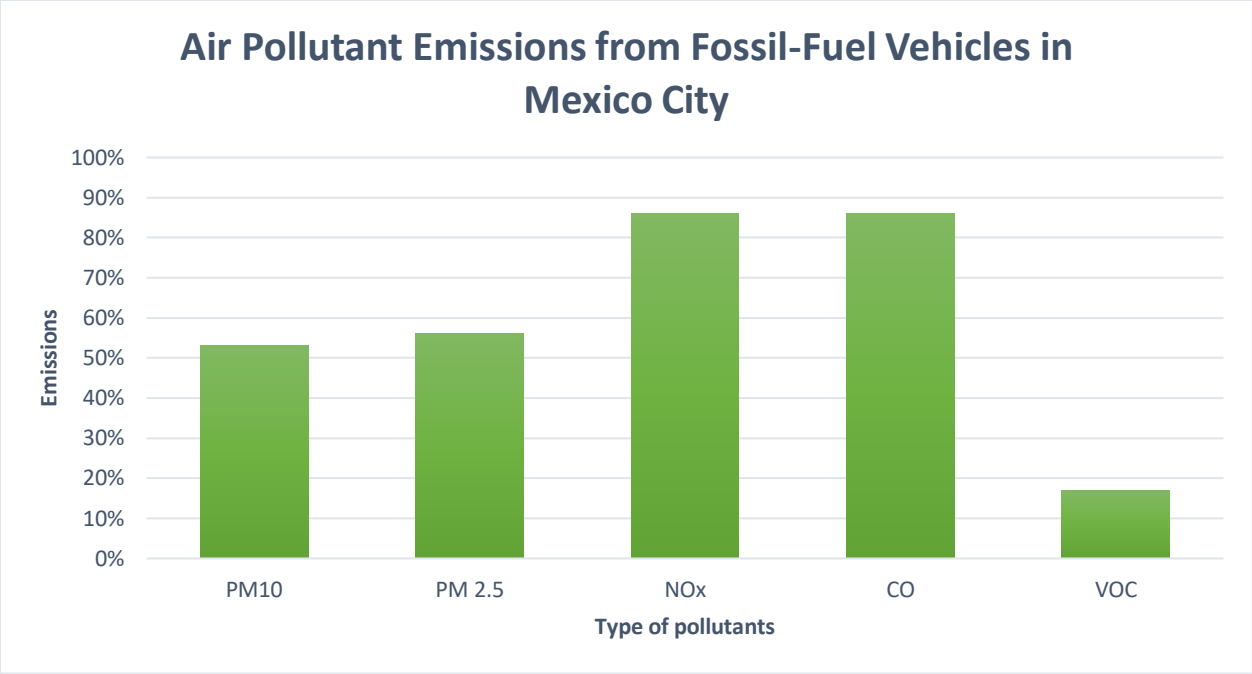

Figure 11. Percentage and type of emissions produced by fossil-fuel vehicles in Mexico City (Modified from. Mahady et al.2020)

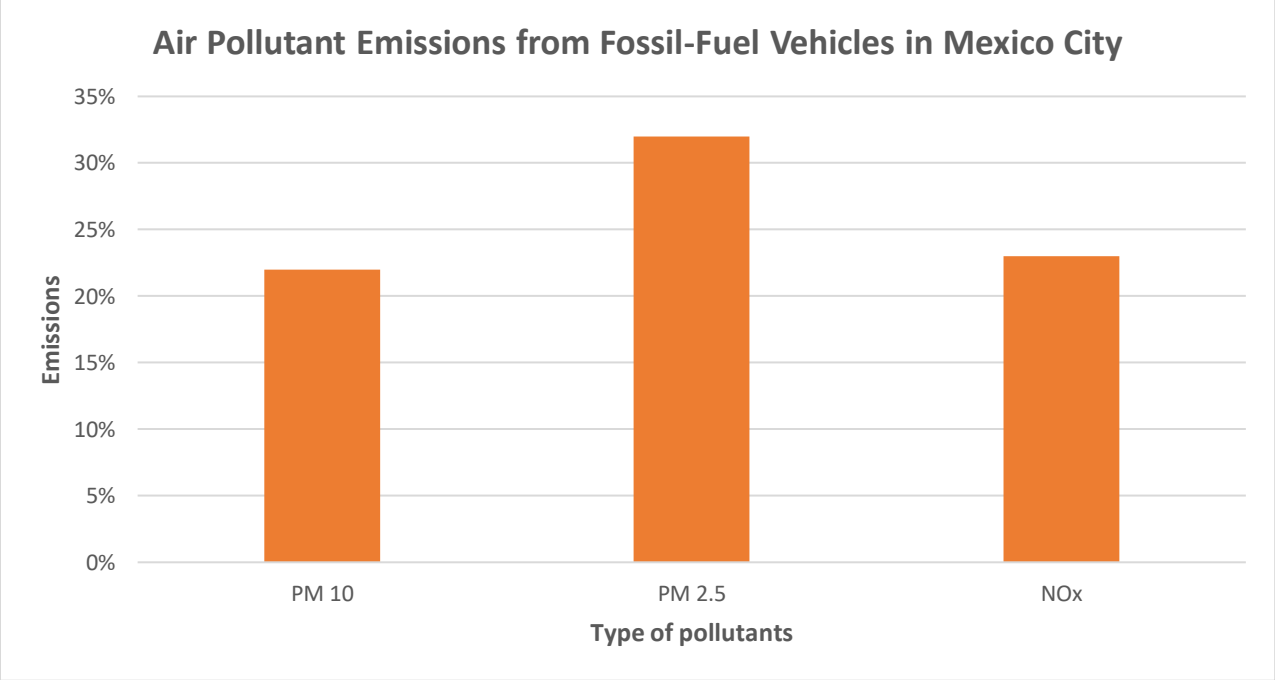

Figure 12. Percentage and type of emissions produced by buses on the road in Mexico City (Modified from. Mahady et al.2020).

4.3 TRANSPORTATION IMPACTS ON SOCIAL EQUITY

Groups with low socioeconomic status are exposed to more pollution and health impacts in Mexico City (Lome-Hurtado et al., 2020). This research aims to promote environmental justice and examines why low-socioeconomic vulnerable groups are the most exposed to pollution and health impacts. Mexico City should be interested in ecological justice because, under the Mexican constitution, all citizens should have the right to live in a healthy environment with equal protection of the environmental rights for all the citizens in Mexico. Environmental justice is defined as "fairness, regardless of race, color, national origin or income in the development of laws and regulations that affect every natural surrounding of a city" (California Environmental Protection Agency, 2019).

In Mexico City, indigenous communities have faced discrimination for hundreds of years due to race, national origin, color, and income. The racism towards indigenous communities has led them to migrate geographically to Mexico City's low-socioeconomic regions. The indigenous communities have a similar level of risk compared to the low-socioeconomic groups of Mexico City on getting exposed to health, safety, and air pollution risks (Mahady et al.2020). Asthmatic and older people are particularly vulnerable to air pollution in Mexico Cities (Mahady et al.2020). Low-socioeconomic groups tend to be more exposed to safety and health risks because they use more public transportation. Citizens who earn the minimum wage in Mexico City tend to use the subway (metro) more (Hernandez et al., 2020). The subway (metro) can assemble a repository of harmful bacteria that transmit infectious diseases (Hernadez et al., 2019). Mexico City subway (metro) is one of the most densely populated places. Hernandez et al. (2019) estimate that humans can emanate 10^6 particles per hour; thus, passengers in the Mexico City subway release a total of 9.2 x10^12 bacteria particles every day. By using the subway more frequently, low-socioeconomic groups are more exposed to safety and health risks.

4.4 TRANSPORTATION IMPACTS ON SAFETY AND HEALTH RISKS

Mexico City's subway is the second most congested subway station globally (Lopez, 2018). The rate of safety and health exposure for the users of the subway increase by being very crowded. The overcrowded problem that citizens of Mexico City face using the subway can cause them exposure to safety risks like robbery and sexual assaults. 61% of the woman who

travels in the Mexico City subway have reported a safety exposure issue. On the other hand, 51% of the men who have traveled in the subway have reported a safety issue (Magaloni, 2019). Worldwide, women are more likely than men to be exposed to unwanted sexual behavior while on public transportation (Romero-Torres, Cecato. 2020). Poor transit safety is a major social issue in Mexico City. Reuters' survey revealed that the transportation system of Mexico City was considered the second most dangerous in the world (TRF,2014). University students in Mexico City show the highest sexual victimization rates in buses and the second-highest victimization rate in the subway (Romero-Torres, Cecato. 2020). There is a slight difference in victimization between buses and the subway for women but not for men. In public buses, 92.1 percent of women and 65.4 percent of men have declared victims of at least one sexual assault, while in the subway, 88% of women have declared victimization and 64.9 percent of men (Romero-Torres, Cecato. 2020). The public transportation systems in Mexico City are dangerous for the communities, and they need to address the safety impacts in the public transportation sector.

For private vehicles, the safety exposure risks are robbery and road accidents. The main areas of Mexico City accidents are identified in the traffic zones (ICLEI Case Study, 2019). According to the Mexican Institute of Statistics and Geography (INEGI), In 2015, they reported 12,321 traffic accidents, causing 315 deaths in Mexico City, placing the traffic accidents by private vehicles as one of the leading causes of mortality in the city (Angeles Perez et al.2018). Freight transport is also impacting health risk hazards in Mexico City. Diesel vehicles are significant contributors to air pollution in Mexico City's effects (Evans et al. 2020).

Emissions within Mexico City lead to exposures and health risks in the city, especially PM 2.5, responsible for significant health risks of cardiopulmonary diseases and lung cancer (Evans et al.2020). Airborne pollutants in Mexico City have been linked to respiratory infection, chronic respiratory illness, and aggravation of existing cardiovascular diseases (Davies, 2008). Air pollution caused by fossil fuel combustion caused severe public health problems in most major metropolitan cities like Mexico City (Schifter et al., 2012). In Mexico, in 2008, there were 14,000 deaths due to poor air quality because of fossil-fuel vehicle pollution (Chatziioannou et al., 2020). The most apparent health problems are caused by air pollution (Chatziioannou et al.2020). The most common air pollutants in Mexico City are ozone, sulfur dioxide, nitrogen oxides, and particulate matter (Scfifter et al., 2012). There is a considerable health risk exposure

in public transportation due to the number of people who traveled daily in public transit in Mexico City. The subway can assemble a repository of harmful bacteria that transmit infectious diseases. Mexico City subway (metro) is one of the most densely populated places; it has been estimated that humans can emanate 10^6 particles per hour. In Mexico City, it is estimated to release a total of 9.2 x 10^12 bacteria particles in the subway of Mexico City every day (Hernandez et al., 2019). Public transportation systems are the ideal environment for the transmission of microorganisms as they carry many people daily. In Mexico City, the subway has more than 4 million o users daily, totaling 1,647,475,013 billion users annually (Hernandez et al., 2019). Due to the large number of people who travel daily in the subway, Mexico's citizens are exposed to high levels of bacteria by using the subway. The most common bacteria in Mexico City's subway are the Propionibacterium, Corynebacterium, Streptococcus, and Staphylococcus (Hernandez et al., 2019). Renovation of infrastructures and new transportation strategies to avoid massive agglomeration in Mexico City's public transportation systems are needed.

CHAPTER 5: EQUITY ANALYSIS

Low-socioeconomic status groups deal with more health risks, safety, and pollution impacts in Mexico City. The purpose of the equity analysis was to identify in which zones the low-socioeconomic groups are located in Mexico City and why they face more health risks, safety, and pollution impacts in Mexico City than other socio-economic groups. To promote environmental justice, the government of Mexico City needs to address the social and ecological problems that the low-socioeconomic groups are facing in Mexico City. By analyzing a geospatial and demographic analysis of Mexico City, this equity analysis was able to identify in maps the vulnerable zones with high levels of pollutants, health, and safety risks. The goal of the equity analysis is to provide strategies and recommendations for the government of Mexico City to reduce the health risks, safety, and pollution impacts in the low-socioeconomic sectors to promote environmental justice, which is a social right for all the communities in Mexico City.

5.1 LITERATURE REVIEW: WHY DO GROUPS WITH LOW-SOCIOECONOMIC STATUS DEAL WITH MORE HEALTH RISKS, SAFETY, AND POLLUTION IMPACTS IN MEXICO CITY?

Megacities around the world have significant problems with air pollution (Molina and Molina, 2004). Mexico City is an example of excessive urban growth and severe environmental pollution, with over 20 million people, over 40,000 industries, and over four million vehicles (Calderon-Garciduenas and Torres-Jardon, 2012). Neighborhoods with proximity to main roadways, unpaved roads, dumps, and factories are most affected by pollution and health impacts (Calderon-Garciduenas and Torres-Jardon 2012). Children with low socioeconomic status in Mexico City have emotional and social needs, which are also related to the significant rise of crime and violence in their neighborhoods in a country where 52 million people have incomes below the poverty line (Calderon-Garciduenas and Torres-Jardon 2012). Children with low socioeconomic status tend to live closer to unpaved roads and proximity to the roadways with more pollution in Mexico City (Calderon-Garciduenas and Torres-Jardon 2012). Low-Socio economic status children tend to live in poor environments than the children in the middle and high class in Mexico City.

Mexico City suffers from high levels of atmospheric pollution (Mahady et al.2020). Mexico's constitution states the right of all persons to an environment suitable for their development and well-being (Mahady et al., 2020). In the past years, the government has prioritized urban development to improve the transportation infrastructure of the municipalities of Chimalhuacan, Chalco, Valle de Chalco, and Ecatepec. (Mahady et al.2020). In the areas of Nicolás Romero,Tlanepantia de Baz, Ecatepec, Naucalpan, Chimalhuacán and Valle de Chalco more than 80% of the citizens fill insecure during their travels in that particular zones (Magaloni, 2019).These municipalities are regions with high social marginalization; the cost of insecurity or safety affects the low-socioeconomic status communities of Mexico City (Magaloni, 2019). Most of the studies on environmental justice show that groups with low socioeconomic status are more likely to face higher levels of air pollution (Lome-Hurtado et al., 2018). People with low socioeconomic status tend to use more public transportation due to the low tariffs. They cannot afford a private vehicle and tend to live or work in the regions of Mexico City in which they are higher health safety and pollution risks. 52% of the total population of Mexico City corresponds

to the low-socioeconomic status group (Bolanos, 2020). The subways and buses are old, which is typical of commuting from low-socioeconomic status groups. Most trips made by the low-socioeconomic status groups are made in public transportation systems in Mexico City, characterized by low service quality, poorly regulated, and highly polluted systems (Varela,2015). The low-socioeconomic sectors are exposed to bacteria like Propionibacterium, Corynebacterium, Streptococcus, and Staphylococcus, especially using the subway (Hernandez et al., 2019).

5.2 GEOSPATIAL ANALYSIS AND IDENTIFICATION OF VULNERABLE GROUPS IN MEXICO CITY

A geospatial analysis study from Mexico City for PM10 and Ozone shows a significant positive spatial autocorrelation in the concentration levels of both pollutants in Mexico City (Lome-Hurtado et al., 2019). Figure 13 below shows the spatial distribution of the PM10 and ozone levels in Mexico City. The darker red shading indicates the highest concentration of PM10 and ozone in Mexico City (Lome-Hurtado et al., 2019). In figure 13a it illustrates that the higher levels of PM10 are identified in the north of Mexico City; in the south of the city is faced with low levels of PM10 (Lome-Hurtado et al.,2019). Figure 13b shows the ozone concentration levels; the south area of Mexico City presented higher ozone concentration levels. The north area raised low levels of ozone concentration (Lome-Hurtado et al., 2019). The pollutants are negatively correlated (Lome-Hurtado et al., 2019) in the spatial analysis reviewed by this study. Particulate pollution is found in Mexico City due to traffic. Ozone is not emitted directly into the Mexico City environment but is formed through reactions emitted from combustion engines (Lome-Hurtado et al., 2019). There is less traffic in the suburban or peri-urban areas, and ozone is more significant in that area (Lome-Hurtado et al.,2019). The suburban or peri-urban areas are in the south of Mexico. The high-socioeconomic sectors are located at the center-west of Mexico City, where the purchasing power is higher than any other locations in the city (Lome-Hurtado et al., 2019). Households of the low-socioeconomic sectors are located in the north, center-east, and south of Mexico City (Lome-Hurtado et al., 2019).In Figure 13c, the red color identifies the more poor households in Mexico City; the green color identifies the less deprived families in Mexico City (Lome-Hurtado et al., 2019). In Figure 14, another map with the location of the vulnerable population and housing groups in Mexico City is shown. The definition of each color

in Figure 14 is as follows: the blue on the map refers to the not vulnerable communities, the green refers to the vulnerable population, the yellow color refers to the vulnerable housing communities, and finally, the red refers to vulnerable people and housing in Mexico City.

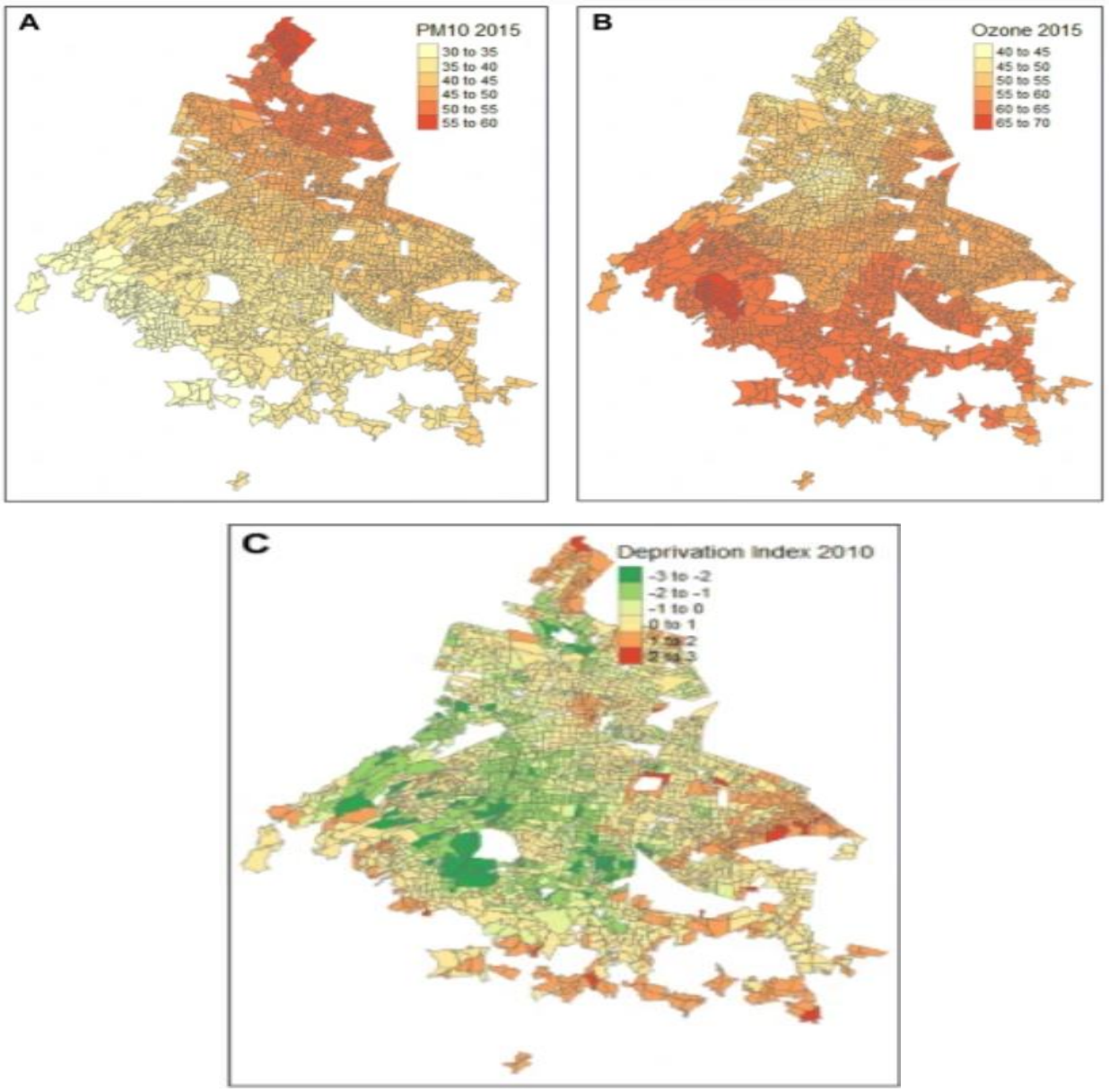

Figure 13. Spatial distribution of the PM10 and ozone levels in Mexico City (Modified from Lome-Hurtado et al.,2019)

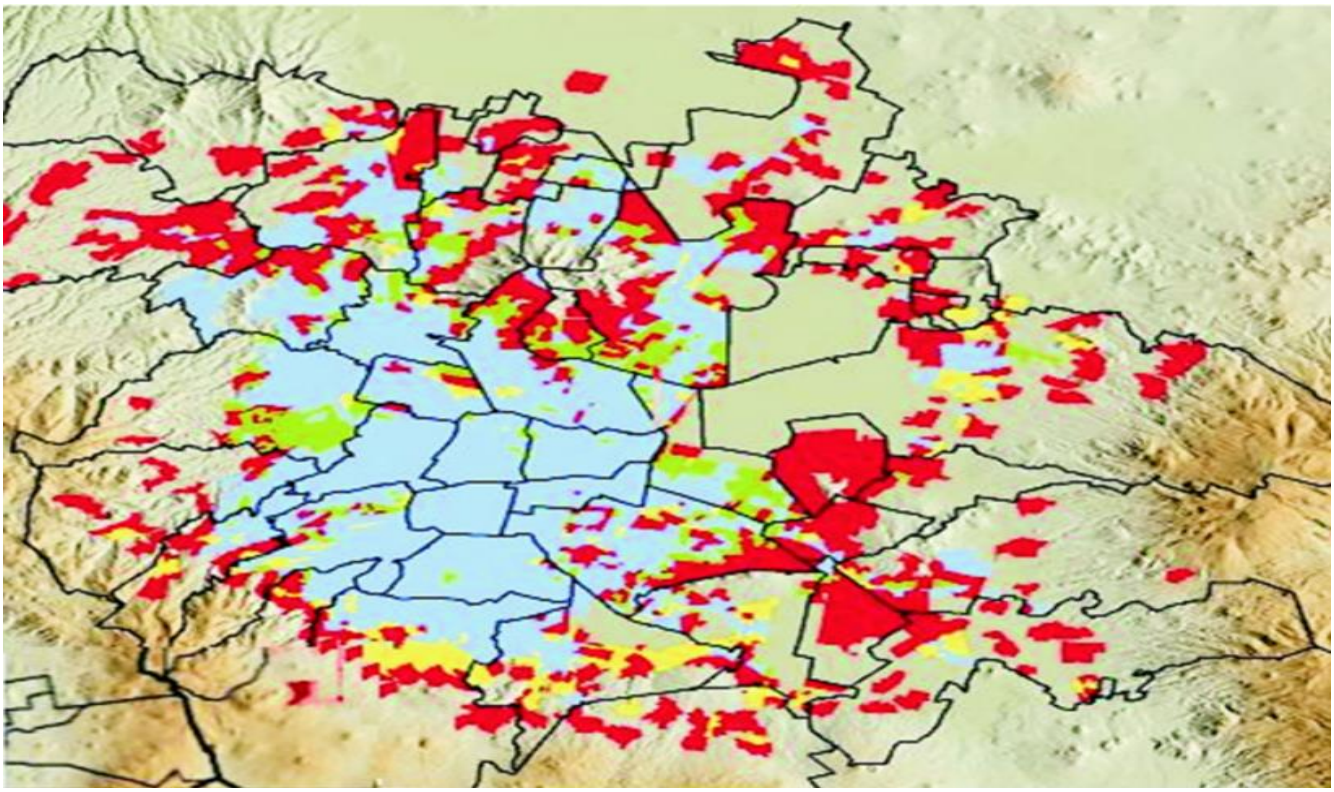

Figure 14. Map with the location of the vulnerable population and housing groups in Mexico City (Calderon-Garciaduenas and Torres-Jardon, 2012)

5.3 DEMOGRAPHIC ANALYSIS

Mexico City's population, according to the UN Urbanization Prospects, is now estimated to be 21,918,936. Mexico City is the capital of the country of Mexico. According to the world population review, Mexico City is considered the largest Spanish-speaking city in the world. Mexico City's area comes to a total of 1,485 square kilometers (573 square miles) (World Population Review, 2021). The biggest municipalities in Mexico City, excluding Mexico City are: Ecatepec (1.6 million people), Nezahualcoyotl (1.1 million people), Naucalpan (833,000 people), Tlalnepantla de Baz (664,000 people), Chimalhuacan (602,000 people), Ixtapaluca (467,000 people), Cuautitlan Izcalli (533,000 people) and Atizapan de Zaragoza (490,000 people). The high-socioeconomic sectors are located at the center-west of Mexico City, and the low-socioeconomic sectors are in the north, center-east, and south of Mexico City (Lome-Hurtado et al., 2019). In the areas of Nicolás Romero,Tlanepantia de Baz, Ecatepec, Naucalpan, Chimalhuacán and Valle de Chalco more than 80% of the citizens fill insecure during their

travels in that particular zones (Magaloni, 2019).In Mexico City, people with indigenous ancestry inhabit middle and lower-class neighborhoods. People with European ancestry or white people inhabit the wealthier zones. According to the geospatial analysis, the people who live in the lower-socioeconomic areas tend to have more health, safety, and pollution impacts than the lower-class communities. 52% of the total population of Mexico City corresponds to the low-socioeconomic status group (Bolanos, 2020). According to the OECD, the low-socioeconomic status groups are the groups with a salary below 5,356 pesos per month, around $267 per month. The mid-socioeconomic status groups are the groups with a salary range between 5,346 pesos and 14,256 pesos, between $267 and $712 per month. The high-socioeconomic groups are the groups with salaries higher than $712.

CHAPTER 6: SWOT ANALYSIS OF POLICIES

In 1989 the policy program “Don’t Drive Today” was introduced by the government of Mexico City to reduce traffic and air pollution emissions. The policy program has failed since then. Depending on the last digit of the license plate of the vehicles of the citizens of Mexico City, the cars are not permitted to circulate one day per week from 5 am to 10 pm. The policy program also bans each vehicle on one Saturday per month to try to reduce emissions during the weekends. The SWOT analysis of the “Don’t Drive Today" program identified the strengths, weaknesses, opportunities, and threats of the policy program to provide recommendations to reduce traffic and air emissions, which is the optimal goal of this policy.

The federal electric industry law was introduced in Mexico in the year 2021. The law is intended to boost and prioritize the fossil fuel sector over the renewable energy sector in Mexico City. By implementing the new electric industry federal law, the federal government of the country of Mexico sees the fossil fuel industry as a potential opportunity to promote economic growth. The new federal electric industry law is already impacting foreign renewable energy projects implemented and planned in Mexico City in recent years. The SWOT analysis of the federal electric industry law identified the strengths, weaknesses, opportunities, and threats of the new federal law to provide energy management recommendations to reduce environmental impacts in Mexico City derived from the fossil fuel industry.

6.1 LITERATURE REVIEW: OVERVIEW OF THE CURRENT POLICIES IN MEXICO CITY

The study will analyze two central environmental policies in Mexico City. The "Don't Drive Today," a local program implemented in Mexico City to reduce emissions and take the local citizen's fossil-fuel vehicles out of the road once per week. The "Don't Drive Today" program began in 1989 and restricted private cars from driving once per week in Mexico City-based on the last digit of the license plate (Guerra and Millard-Ball, 2017). According to the "Don't Drive Today" official website, the policy is an urban program restricting vehicles circulating in Mexico City and reducing environmental pollution levels. The program applies to all the delegations in Mexico City and the other 18 municipalities in Mexico. The program works base on two-vehicle restrictions rules. Every vehicle registered IS ban from getting into the road once per week from Monday to Friday. Every car registered in Mexico City cannot circulate on the road two Saturdays per month Saturdays. Depending on the level of pollution of the vehicle and the pollution levels of Mexico City, some registered cars are banned from traveling all the Saturdays of the month. Every registered vehicle in Mexico City, depending on the last digit of the license plate, has a color that identifies which day of the week the car cannot be on the road. The program can determine the level of pollution of each vehicle registered in Mexico City by the holograms. According to the Secretary of the Environment in Mexico City (SEDEMA), the program hours are from 5 am to 10 pm. The SEDEMA also states that the money fine that the citizens need to pay can round from 1,737.60 pesos to 2,606.4 pesos between $86 to $130 us dollars. The program only gets suspended during official festivities days from Mexico City or when the meteorological conditions are favorable for the atmosphere of Mexico City. According to the official website of the program "Don't Drive Today," depending on the ozone levels of pollution, the government of Mexico City can increment the days of not circulating to the registered vehicles in Mexico City.

Driving restrictions tend to be politically more palatable than congestion changing and other pricing-based policies to reduce traffic and pollution (Guerra, and Millard-Ball, 2017). The program "Don't Drive Today" is economically costly for the government (Guerra and Millard-Ball, 2017). Driving restrictions programs may seem like a reasonable approach for addressing the complex problem of urban air pollution (Davies, 2008). Whereas it was hoped that the driving restrictions programs would cause drivers to substitute low-emissions transportation

modes, there is no evidence of increased ridership in public transportation systems (Davies,2008). There is evidence of increased automobile registration and sales increase the number of higher emitting vehicles on the road (Davies,2008). Three empirical studies show that the "Don't Drive Today" program encouraged households to purchase second cars to avoid restrictions (Guerra and Millard-Ball, 2017). Car bans have failed to produce a substantial reduction in pollution. Families buy a second car, often older and higher, polluting with a different digit in the license plate (Guerra and Millard-Ball, 2017). Households are rescheduling their travel routines to avoid a car ban restricted day (Guerra and Millard-Ball,2017). It estimated that after implementing the "Don't Drive Today" program, weekend and weeknight pollution increased relative to weekday pollution in Mexico City (Guerra and Millard-Ball, 2017). Many households, particularly the poorer ones, do not use their car every day and may not be unaffected by a ban even when the ban applies. This is particularly true for older, lower quality cars that are likeliest to be the highest polluters (Guerra and Millard-Ball, 2017). A strength of the "Don't Drive Today" program is increasing biking in Mexico City. There is an overall increase in bike-share trips in Mexico City during contingency days (De Buen Kalman, 2021). The "Don't Drive Today" program gives an environmental alert when pollution is high in Mexico City. The warning emitted by the program is increasing the bike-share trips during the early morning and evening peak hours (De Buen Kalman, 2021).

The new government administration introduced the new federal electric industry law in Mexico. The federal electric industry law is another policy reviewed by the SWOT analysis made by this study. According to the National Resource Defense Council (NRDC), the new federal electric industry law will modify dispatch to benefit plans owned by the Federal Electric Commission (CFE), eliminate the obligation of CFE to purchase basic supply in auctions, require the revision and potential termination of a certain power purchase agreement and revoke certain self-supply generation permits (NRDC, 2021). The new federal electric industry law is the latest attempt by the president of Mexico, Andres Manuel Lopez Obrador, to boost and prioritize the fossil fuel sector over renewable energy (NRDC, 2021). The change in the clean energy certificates rules disincentivizes the new renewable energy projects and delays the start of commercial operations of solar and wind projects across Mexico (NRDC,2021). The government, among the law, is planning to construct a new oil refinery in Mexico (NRDC,2021).

All these policy plans benefit the fossil fuel sector and produce expensive energy, threatening Mexico City citizens' health and harming the environment (NRDC,2021). The new rules imposed by the Secretary of Energy implement a series of limitations on creating power stations, limiting permits for creating renewable farms, and banning renewable energy projects in certain areas (Serrano et al. 2020). For the government in Mexico, the benefit of the new policy is that it will strengthen the CFE and protect the energy market from being dominated by foreign companies (NRDC,2021).

6.2 WHAT POLICIES CAN HELP MEXICO CITY ADDRESS THESE MULTIPLE CHALLENGES IN THE TRANSPORTATION SECTOR?

The "Don't Drive Today" program and the new electric industry federal law affect the evolution of the transportation sector in Mexico City. Car bans have failed to produce a substantial reduction in pollution. Households buy a second car, often older and higher, polluting with a different digit in the license plate (Guerra and Millard-Ball, 2017). To reduce traffic pollution, Mexico needs to implement new policies or address the weaknesses of the current policies. The new electric industry federal law will reduce green energy investments in Mexico City and prioritize the fossil-fuel industry. By prioritizing the fossil-fuel industry, the citizens of Mexico Citizens can face higher levels of pollution. Mexico City will not prioritize investments in green transportation technologies that are needed in Mexico City to reduce traffic emissions. The "Don't Drive Today" program weaknesses can be address by investing in having control of the number of vehicles in the households in Mexico City and being able to put the ending number of the license plates to all the cars in the home not to make them buy another extra vehicle. The government of Mexico City can also add an extra day of the week to banning fossil-fuel vehicles on the road to make citizens use more public transportation, carpooling apps, or green transportation like bicycles. The creation of incentives policies can make citizens of Mexico City invest in EVs or use another kind of green transportation. According to a report made by the Center For Climate And Energy Solutions, cities that provide the largest economic benefit to EVs owners typically increase the purchase of EVs. Mexico City can implement a policy to offer tax credits, waive some taxes, or rebate for buying or leasing an EV.

Mexico Can implement the policies of some states and local governments from the United States and offer a variety of other fiscal and non-fiscal incentives to promote EVs. The creation of carpooling lanes or HOV systems can also help the transportation sector of Mexico City. HOV lanes decrease commuting time by 21% and decrease energy commuting consumption by 36% (Zhao, 2017). The growth of HOV lanes reduces traffic congestion by encouraging carpooling, saving energy, and protecting the environment (Zhao, 2017). The increment of the fines fees can also be a good way to address the "Don't Drive Today" policy. Mexico City needs to implement policies to reduce the amount of driving and promote renewable energy investments. Mexico City also needs to invest in the electrification of public transportations, invest in R&D to gather data on traffic-pollution correlation, and use carpooling apps.

6.3 COMPARATIVE ANALYSIS & RESULTS

The ban of cars on the roads program is implemented in Mexico City, and a similar program has been implemented in cities like Beijing. A case study of the city of Beijing is being included in the SWOT analysis to compare both programs' weaknesses, strengths, threats, and opportunities. Mexico City and Beijing are the capital cities of their respective countries. Mexico City adopted the driving restriction policy first, then Beijing. The restriction policy in Beijing does not significantly influence car-driving than its influence on public transit (Wang et al.,2014). In Beijing, 47.8 % of the regulated car owners didn't follow the driving restrictions rules (Wang et al.,2014). A driver restriction scheme was expected to take 20% of cars off the road every weekday (Wang et al., 2014). The efficiency of driving restriction is controversial (Wang et al.,2014). Whereas it was hoped that the driving restrictions programs would cause drivers to substitute to low-emissions transportation modes, there is no evidence of increased ridership in public transportation systems in Mexico City (Davies,2008). In 2007 and 2008, Beijing introduced odd-even license plate restriction policies, and there is evidence of reducing congestion and reducing pollution (Wang et al.,2014). In most developing countries, the public transport system is an imperfect substitute for cars, and they adjust the driving restriction by purchasing additional cars (Wang et al.,2014). In Mexico City, car bans have failed to produce a substantial reduction of pollution, and households are buying a second car, often older and higher, polluting with a different digit in the license plate (Guerra and Millard-Ball, 2017).

Evidence in Mexico City has shown that wealthy people can buy second cars with a different license plate; the total number of cars used in Mexico City has increased (Wang et al.,2014). Beijing people have invented surprising ways to circumvent the driving restrictions policy (Wang et al.,2014). Beijing and Mexico City are already two of the world's most polluted cities in air quality. Both cities contribute heavily hazards use air pollutants such as carbon monoxide, oxides of nitrogen, and volatile organic compounds. The driving restriction policy has not been effective in Mexico City and in the city of Beijing. The driving restriction program identifies the vehicle ban by the last digit of the license plate in both programs. In Mexico City and Beijing, the registered vehicles ban going on the road once per week. In Mexico City, they also have weekend restrictions. In both cities, Mexico City and Beijing, the citizens buy an extra car to avoid being restricted from driving (Wang et al., 2014). Beijing and Mexico City need a more comprehensive policy to reduce pollution and traffic congestion. The increment of parking fees, fuel taxes, and high-speed transit facilities can be policy instruments to reduce air pollution and traffic congestion (Wang et al., 2014).

A SWOT analysis of the policies "Don't Drive Today" and the new electric industrial, federal law. The SWOT analysis will analyze the strengths, weaknesses, opportunities, and threats of each policy law.

Table 6. SWOT Analysis of policy “DON’T DRIVE TODAY” (Franco, 2021

SWOT ANALYSIS OF POLICY "DON'T DRIVE TODAY"

STRENGTHS	**WEAKNESSES**
• Bike-sharing increased on non-driving days • Number of people walking increased on non-driving days • Policy leads the government of Mexico City to invest in bicycle roads and walking pathways	• The policy is not bringing down emissions • The citizens in Mexico City are buying an extra car which is usually older and produce more pollution for the environment • The policy is increasing the number of vehicles on the road

• Increase the usage of public transportation in more impoverished communities	• The fine fee is low for wealthier communities and high for non-wealthier communities
OPPORTUNITIES • The policy has the potential of reducing air emissions and traffic • Promote investments in green transportation like electric vehicles • Increment the usage of public transit and usage of green transportation for wealthier communities • Incentives like fiscal waivers or tax credits can make citizens follow the policy more • Incrementing the days of car banning from one to two days during the high air pollution days can be a good alternative	**THREATS** • The program could have a higher cost for the government of Mexico City • The number of high pollutant vehicles on the road can increase • Traffic congestion can increase

Table 7. SWOT Analysis of the Federal Electric Industry Law (Franco, 2021)

SWOT ANALYSIS OF THE FEDERAL ELECTRIC INDUSTRY LAW

STRENGTHS	**WEAKNESSES**
• CFE and the Oil industry is protected	• Reduce renewable energy investments

• Mexico oil industry has the potential of growing the economy • The fossil-fuel industry will grow	• Reduce foreign investment in renewables • Law is harmful to the environment in Mexico City • Reduce private investments in green transportation
OPPORTUNITIES • The fossil-fuel economy can grow • Oil and energy can reduce its costs for Mexico City citizens	**THREATS** • Pollution can increase • Reduction in renewable energy investments can increase • CFE will control the energy sector • Foreign renewable energy projects investments are going to be reduced and can affect the economy of Mexico City

CHAPTER 7: RESULTS & RECOMMENDATIONS

7.1 HOW CAN MEXICO CITY REDUCE AIR POLLUTION AND EXPAND RENEWABLE ENERGY IN THE TRANSPORTATION SECTOR WHILE ALSO ADDRESSING THE TRANSPORTATION CHALLENGES OF TRAFFIC, SOCIAL EQUITY, SAFETY, AND HEALTH RISKS?

Mexico City needs to improve in the implementation of transportation and energy management strategies. The previous chapters demonstrate that Mexico City traffic is the major air pollution and climate problem in the environment. Traffic is considered the central problem of air pollution in Mexico City. Due to traffic, air pollutants' levels have exceeded the maximum exposure limits established by the World Health Organization (Estrada et al.2016). Low socioeconomic status communities deal with more health risks, safety, and pollution. Most of the

studies on environmental justice show that groups with low socioeconomic status are more likely to face higher levels of air pollution (Lome-Hurtado et al., 2018). People with low socioeconomic status tend to use more public transportation due to the low tariffs. They cannot afford a private vehicle and tend to live or work in the regions of Mexico City in which they are higher health safety and pollution risks. 52% of the total population of Mexico City corresponds to the low-socioeconomic status group (Bolanos, 2020). Chapter 6 demonstrates that the policy program "Don't Drive Today" and the feral electric industry law is not working. The major weakness of the policy "Don't Drive Today" is that the procedure does not bring down emissions as expected. The citizens in Mexico City are buying an extra car that is usually older and produces more pollution for the environment. Car bans have failed to produce a substantial reduction of pollution, and households are buying a second car, often older and higher, polluting with a different digit in the license plate (Guerra and Millard-Ball, 2017).

The major weakness of the federal electric industry law is that the policy is bringing down private and foreign investment in renewable energies. The new rules imposed by the Secretary of Energy implement a series of limitations on creating power stations, limiting permits for creating renewable farms, and banning the construction of renewable energy projects in certain areas (Serrano et al. 2020). Mexico City reduces air pollution and expands renewable energy in the transportation sector while also addressing the transportation challenges of traffic, social equity, safety, and health risks. The study recommends the government of Mexico City invest in intelligent transportation systems (ITS), carpooling schemes and introduce policy incentives to make the private sector invest in EVs. The research also identifies by doing a traffic and spatial analysis of Mexico City the most traffic-congested zones and the vulnerable communities to start applying the transportation system and energy system strategies in those zones. Finally, Mexico City needs to address the "Don't Drive Today" policy carpooling systems, especially the HOV systems, to help address some of the problems of the policy. Also, the public investment in EVs charging stations and the development of strategies like providing incentives will make the private sector invest in EVs, which will help complement the policy's goal, which is reducing emissions from traffic. With the high levels of pollution and energy management strategies, renewable energy is needed in Mexico City. This research recommends eliminating the new electric industrial, federal law, empowering the fossil-fuel industry, and

reducing the investment in green renewable technologies. Mexico City needs to develop an electric industry reform that will align with the Paris Agreement goals and promote green technologies that will optimally bring down the city's emissions.

7.2 FUTURE OF TRANSPORTATION SYSTEMS AND ENERGY MANAGEMENT STRATEGIES IN MEXICO CITY

The Mexican Constitution states the right of all persons to an environment suitable for their development and well-being (Mahady et al., 2020). Under the strategic Mobility Plan 2019, it shows that Mexico City is constructing a cable car system to serve marginalized communities in northern parts of the city. The city is also planning to invest in a zero-emission bus-rapid transit line to help low and middle-income communities in eastern Mexico City. However, the new proposed transportation systems in Mexico City do not explicitly link marginalized communities with variables such as atmospheric pollution (Mahady et al.2020). Mexico City government needs to invest in the electrification of public transportation systems and implement energy management strategies to reduce atmospheric pollution. From a geographical analysis of Mexico City, this study gathered Figure 15 below, highlighting the areas in which Mexico City needs to invest in transportation electrification to address the environmental justice concerns. This study recommends that transportation electrification is convenient in the eastern and northeastern areas of Mexico City. The investment in the electrification of public transportation services in Mexico City will reduce air pollution, innovate, and improve public transportation modes in Mexico City. The electrification of transportation in the eastern and northeastern areas of Mexico City will improve the most vulnerable communities' health, safety, and environmental concerns. The government can optimally reduce investments in the health sector by providing newer, cleaner, and efficient electric transportation systems to the vulnerable communities of Mexico City. Urban congestion and parking cannot be tackled with EVs (Glotz-Ritvcher, and Koch 2016). Mexico City needs comprehensive mobility to reduce traffic congestion.

The electrification of transport is a major recommendation for Mexico City to reduce dependence on fossil fuels. Mexico City government needs to start with the electrification of more buses and railroad trolleybuses. Mexico City's strategy is to upgrade the trolleybuses systems with battery buses or trolley hybrid systems with diesel bus substitution, which is more

convenient for the environment. Another transportation strategy will be to install solar panels on the exterior of the buses so that the buses can produce energy from the sun and self-sustain during the day. The installation of solar panels in the buses can be cheaper than changing the whole bus for an e-bus. During the night, the buses can be sustained by diesel. Still, after the investment in solar panels, they can invest in better energy storage systems to make the buses capable of storing and producing sun energy during the night shifts. The major challenge Mexico City is going to face with this recommendation is that the electrification of buses is expensive. However, the government can provide incentives and subsidies for private bus companies to invest in transportation electrification. The public buses and trolleys can use bank loans, public equity, or used green bonds. They also will have operational savings of maintenance and fuel. Adding to those savings Mexico City government can also reduce health and safety investments by adopting clean transportation systems. The transportation management strategy for Mexico City will start investing in transportation electrification on a small scale to make it more financially viable in the eastern and northeastern zones. The zones were the most vulnerable communities. The idea is to have the electric buses and trolleybuses on the road in the most susceptible zones and during the traffic peak hours identified during the traffic analysis in this research to reduce pollution. Mexico City needs to implement a goal of increasing the electric buses and trolleybuses on the road each year until they accomplish 100% zero emissions in transportation.

Besides the electrification of transportation, another transportation strategy that Mexico City needs to implement is investing in maintenance and new infrastructure for the subway in Mexico City. On May 3, 2020, the subway of Mexico City collapsed due to shoddy work and poor maintenance for one of the world's busiest subway systems in the world (Sheridan, 2021). The collapse of the subway station killed around 24 people (Sheridan, 2021). According to the National Action Party Marko Cortes, the collapse of the subway station occurs due to bad management, maintenance, and construction of line 12 of the subway station. The line 12 infrastructure suffer damage from a 7.1 magnitude earthquake in 2017 (Sheridan, 2021). The government of Mexico City never addressed the damage provoked by the earthquake. Thanks to the poor maintenance on the infrastructure for line 12, the subway collapse. Following the disaster, the subway workers union talked of the hobs to protest due to poor working conditions

and insufficient maintenance of the subway station (Sheridan, 2021). Mexico City government needs to develop a financial strategy to renew the subway station trains, continue the infrastructure, and electrify the subway station. The subway station is plagued by maintenance problems, crime, and overcrowding (Sheridan,2021). Mexico City's investment in newer subway trains and the subway station's infrastructure will reduce health, safety, and environmental investments. Mexico City's subway is the second most congested subway station globally (Lopez, 2018). The subway of Mexico City is very crowded. The citizens of Mexico City deserve a better subway system in which the health, safety, and environmental concerns will not be a big problem like they currently are. Maintenance and renewing the subway trains is a strategy needed in Mexico City.

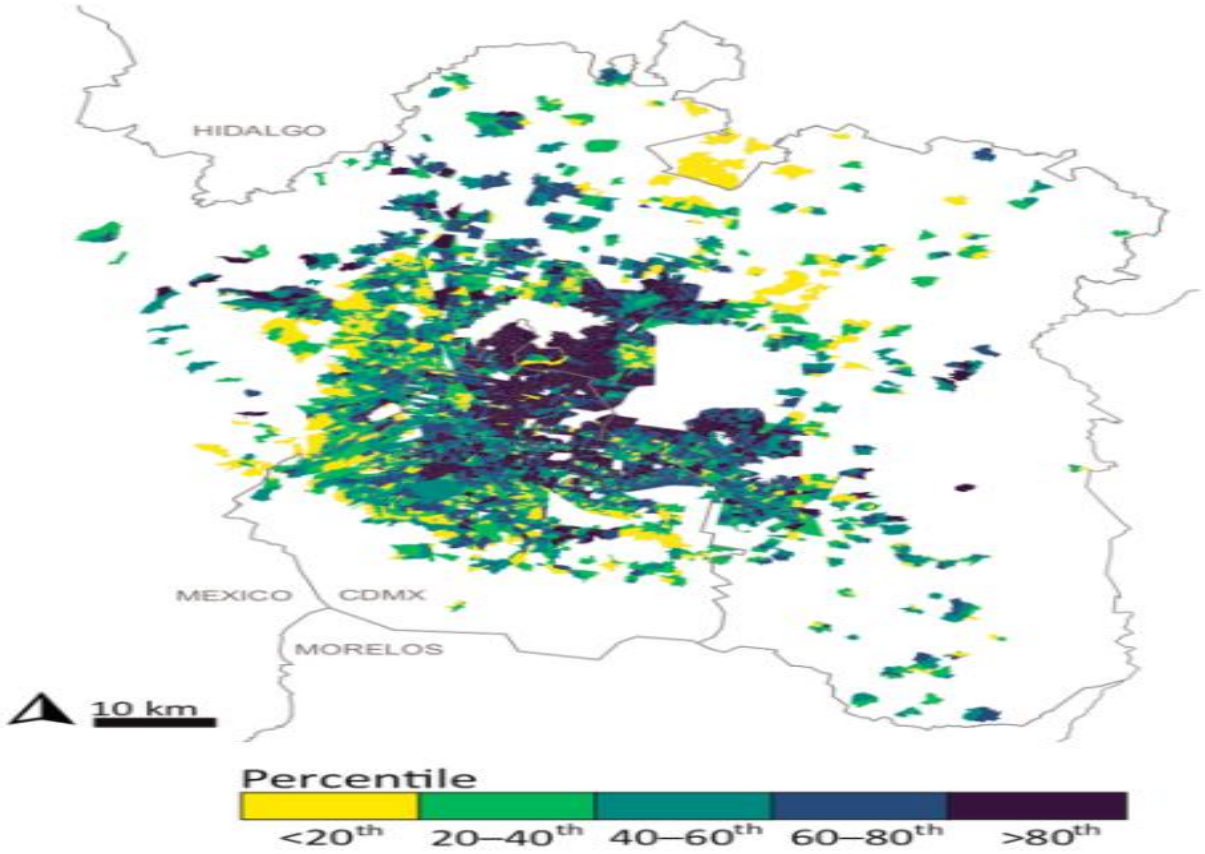

Figure 15. Identification of the zones for the electrification of transportation in Mexico City, where lighter yellow shows low burden and dark purple colored regions denote higher burden (Source: Mahady et al.2020)

Energy management strategies are needed in Mexico City to reduce pollution and develop renewable energy projects to help achieve the Paris Agreement goals. The new rules imposed by the Secretary of Energy implement a series of limitations on creating power stations, limiting permits for creating renewable farms, and banning the construction of renewable energy projects in certain areas (Serrano et al. 2020). Mexico City's new federal law inducted in the year 2021 will reduce renewable energy private investments, foreign investments in renewable energy projects and bring back the overuse of fossil fuels. In 2020 Mexico City implement a solar city at the Sedeco zone in Mexico City. According to the government of Mexico City, the two solar arrays implemented will generate around 140,000 kWh of clean power, which will avoid approximately 75 tons of carbon dioxide emissions and help the Sedeco zone save up to 600,000 MXN pesos in electricity bills. The renewable projects, mainly solar renewable projects, were helping Mexico City to reduce emissions. With the new federal law and the new policy of energy trade certificates inducted in Mexico City, it will be more challenging to see investments in renewable energy projects like the one implemented in the Sedeco region of Mexico City.

The recommendation for the government is to change the new electric federal reform. The government should continue to have energy efficiency as a priority in its energy policy and ensure that the energy efficiency targets promote economic growth and improve energy efficiency monitoring in Mexico City. The government should put higher green energy standards to make the industrial sector investment in renewable energies. The government should also offer federal tax incentives, preferential pricing, and subsidies to the industries that voluntarily agree to invest in renewable energies to support the electric grid. Finally, the government should also offer tax incentives and subsidies to the private sector to invest in solar panels for private homes. The trading of carbon credits produced by investing in renewable energy projects can also be another good incentive that the government of Mexico City can give the citizens who choose to invest in renewable energy projects. Mexico City has a lot of potential for adopting renewable energy projects. The modification of the new electric law and the creation of new clean energy policies is needed.

7.3 INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

The introduction of ITS can mainly eliminate the adverse effects of accidents, traffic congestion, and pollution in the environment brought by the vehicles on the road (Makino et al.2018).In the Asia-Pacific areas, the introduction of ITS is alleviating congestion and easing air pollution by collecting and providing traffic information (Makino et al., 2018). Traffic congestion, traffic accidents, and deterioration of the environment because of a growing population, increasing urbanization, and increasing car ownership have become severe problems (Makino et al.2018). Mexico City is growing in population, increasing in urbanization, and increasing car ownership. , The adoption of ITS is needed in Mexico City to reduce and manage traffic air pollution. ITS referred to autonomous transportation systems, traffic analysis models, and intelligent transportation systems. In the Asia-Pacific regions like Mexico City, the cities have faced population growth and traffic congestion. Several countries in the Asia-Pacific areas endeavor to solve such traffic issues by deploying ITS and achieving positive results (Makino et al., 2018).

It is essential to select suitable technologies and create master plans ideal for each country (Makino et al., 2018). The ITS can achieve zero traffic accidents and develop smart cities such as MaaS (Makino et al.,2018). MaaS can create sustainable travel behavior with the increased use of public transport and gather information to reduce traffic congestion in smart cities (Joshi, 2019). The recommendation of adopting ITS in Mexico City can reduce traffic congestion, traffic accidents, and air pollution. ITS can reduce intersections, promote speed control, autonomously reduce travel time, and improve capacity management. ITS can reduce the citizens' travel time by 25% in a city and reduce greenhouse emissions (Knupter et al., 2018). One report predicts that accidents would drop by 80 percent by 2040 if autonomous transportation systems are adopted (Sperling, 2018). The strategy of adopting ITS can solve traffic, safety, and environmental problems in Mexico City.

7.4 CARPOOLING SYSTEMS

Another strategy that Mexico City can implement to reduce traffic congestion and environmental pollution is implementing carpooling systems. The carpooling systems include car-sharing apps, HOV systems, and autonomous carpooling systems. Carpooling shared apps provides innovative mobility, low travel costs, mitigates congestion, and reduces greenhouse

emissions (Sperling,2018). The shared mobility can include scooters, shared bikes, and cars. Mexico City needs to focus more on placing more people in a single-vehicle to reduce traffic congestion. However, with the COVID-19 pandemic that occurred in the year 2020, it will be more difficult for passengers to get on with strangers on the carpooling apps. The creation of carpooling lanes or HOV systems can also help the transportation sector of Mexico City. HOV lanes decrease commuting time by 21% and lower energy commuting consumption by 36% (Zhao, 2017). The growth of HOV lanes reduces traffic congestion by encouraging carpooling, saving energy, and protecting the environment (Zhao, 2017). The government should create HOV lanes just for carpooling system users. Finally, Mexico City should start investing in autonomous carpooling technologies. Transportation without a driver can make carpooling cheaper (Sperling, 2018). The investment in shared mobility apps, HOV lanes, and autonomous carpooling transportation systems are other recommendations that Mexico City needs to adopt to overcome traffic congestion problems and reduce greenhouse emissions.

7.5 ELECTRIC VEHICLES

The EVs are needed to cut pollution and reduce global warming (Speling,2018). Right now, EVs are more expensive to produce than gasoline cars (Sperling, 2018). By 2024, it is predicted that EVs' battery has a parity price with a fossil-fuel vehicle. The transition to EVs needs to begin in Mexico City. According to the government of Mexico, they are over 500 EVs in Mexico City, which is around 0.7% of the entire automotive market. The number of EVs on the road is still low for a big city like Mexico City. The main reason is that EVs are currently more expensive than fossil-fuel cars. But they are other two reasons, they are not enough EVs charging stations on the road, and Mexico City needs to adopt EVs policy incentives. Some of the recommendations for the government of Mexico City and policymakers are to introduce subsidies and tax credits for EVs owners. Provide discounts on vehicle registration or reduce annual taxes for EVs owners. The government should also increase the number of EVs charging stations on the roads by providing private charging station infrastructure investments. The government of Mexico City should focus on increasing the number of EVs charging stations in the Northwest zone of Mexico City, the zone identified by the traffic analysis as the most traffic-congested zone. Finally, another strategy will be providing free parking sports for EVs users in public areas and providing them access to HOV lanes to avoid traffic congestion. These policies,

strategies, and incentives can be attractive for Mexico City citizens to increase EVs on the road in Mexico City. EVs can help reduce pollution in Mexico City.

CHAPTER 8: CONCLUSIONS

The traffic analysis results show how Mexico City is the city with the most traffic congestion in North America. The northwest region of Mexico City is identified as the most traffic-congested zone. The traffic congestion level of Mexico City during the years 2017,2018 and 2019 was 52%. In 2020 the traffic congestion level declined by 16% due to the COVID-19 pandemic that occurs during that year. According to the traffic analysis, the most congested hour are on Thursdays from 7-8 pm. City drivers spend around 227 extra hours on the road in Mexico each year (Castellanos, 2018). The research recommends the electrification of public transportation, especially in the northwest zone, the most traffic-congested area, shared carpooling mobility and investing in HOV lanes to reduce traffic congestion and pollution. Traffic is the primary source of pollution in Mexico City. Traffic is a significant problem in Mexico City because the population is high and is increasing around 0.63% each year since 2015.

The air pollution produced mainly by traffic in Mexico City brings social equity, health, and safety risks to Mexico City citizens. Low-socioeconomic status sectors tend to face high health risks, levels of pollution, and safety risks in Mexico City (Lome-Hurtado et al., 2020). The low-socioeconomic status sectors tend to use more public transportation. According to the environmental and social impact analysis results across Mexico City transportation in public transit, more exposure to health and safety risks. The equity analysis identified that 52% of the total population of Mexico City corresponds to the low-socioeconomic status communities. The equity analysis identifies the center-west of Mexico City as the region where the high-socioeconomic sectors communities are located. According to the equity analysis, the low-socioeconomic sectors households are in the north, center-east, and south of Mexico City. The electrification of transportation in the eastern and northeastern areas of Mexico City is the main recommendation to address the problems with environmental justice in Mexico City. The recommendation will improve the health, safety, and environmental concerns of the most vulnerable communities. The government can optimally reduce investments in the health sector

by providing newer, cleaner, and efficient electric transportation systems to the vulnerable communities of Mexico City.

Finally, a SWOT analysis of the policies “Don’t Drive Today” and the federal electric industry law is shown in this research. The main weaknesses of the “Don’t Drive Today” approach are that the policy is not bringing down greenhouse emissions. The policy is increasing the number of vehicles on the roads. The citizens in Mexico City are buying an extra car that is usually older and produces more pollution for the environment. The strengths of the policy are that bike-sharing and the number of people walking increased on non-driving days. To overcome the weaknesses, the research recommends developing tax credits or fiscal incentives to make citizens invest in EVs or make the citizens use other types of green transportation systems. Adopting the three revolutions of transportation, EVs, carpooling schemes, and ITS, can help the policy reduce traffic in Mexico City by around more than 25%. The weaknesses of the federal electric industry law are that the law is reducing the local and foreign investment in renewable energy projects in Mexico City. The new electric industrial law is harmful to the environment. With the implementation of the new electric industrial law, the fossil-fuel industry will grow in Mexico City. To overcome the law's weaknesses, the government should continue to have energy efficiency as a priority in its energy policy standards and goals. Make sure that the energy efficiency targets promote economic growth and improve energy efficiency monitoring in Mexico City. The government should put higher green energy standards to make the industrial sector investment in renewable energies. The government should also offer federal tax incentives, preferential pricing, and subsidies to the industries and private sectors that voluntarily agree to invest in renewable energies to support the electric grid. The government of Mexico City by improving public transportation infrastructure, providing incentives to invest in EVs, implementing traffic and energy strategies, especially in the northwest zone. Mexico City can reduce air pollution, and expand renewable energy in the transportations sector, while also addressing the transportation challenges of traffic, social equity, safety, and health risks.

CHAPTER 9: REFERENCES

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