Marginal cost of additional gasoline and electric vehicles on air quality

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Abstract

A general assumption made by policy makers is that electric vehicles are cleaner and more sustainable with the environment than gasoline vehicles, but is this true? Electric vehicles (EVs) have emerged as an alternative for gasoline vehicles as they are considered to be greener and more sustainable since they, allegedly, contribute to reduce polluting emissions and, thus, health damage.

In this research I take the Mexican case to compare the air quality marginal costs that one additional electric vehicle has against the air quality marginal cost that one additional gasoline vehicle has, while also accounting for the generation plants' emissions and their local impact due to the increase in electric vehicles. This study's relevance is enhanced given that I study the most health-damaging pollutant ($PM_{2.5}$) and the kind of vehicles that accounts for most emissions in Mexico City (private vehicles).

I calculate that the marginal cost per person for an additional gasoline vehicle in Mexico City is \$0.1322 (MXN), and the marginal cost per person for an additional electric vehicle in Mexico City is \$ 0.018 (MXN). Therefore, in this research I prove that electric vehicles have a lower marginal cost per person than gasoline vehicles, even when accounting for pollution emitted locally due to increased activity of generation plants that respond to an increase in demand due to an additional EV in Mexico City. Hence, the popular hypothesis that EVs are more sustainable with air quality than gasoline vehicles holds for the case of Mexico City.

I also prove that the regional distribution of emissions is important and therefore it should be accounted-for when designing policy. Even when at a national level EVs have less marginal cost per person than gasoline vehicles, the reduction of emissions in Mexico City due to a purchase of an EV instead of a gasoline vehicle increases the marginal damage in all the other regions more than in the Central region, where Mexico City is. This shows that if Mexico City's government should choose to apply an incentive for EVs' consumption the marginal damage would be spread to other regions that were not damaged before.

1 Introduction

A general assumption made by policy makers is that electric vehicles are cleaner and more sustainable with the environment than gasoline vehicles, but is this true?

Electric vehicles (EVs) have emerged as an alternative for gasoline vehicles as they are considered to be greener and more sustainable since they, allegedly, contribute to reduce polluting emissions and, thus, health damage (Carrigan et al., 2018).

When considering tailpipe emissions, it seems obvious that by avoiding internal combustion EVs have less negative impact on air quality than gasoline vehicles (with internal combustion engines). Nevertheless, the previous statement is only accounting for the pollutants emitted in the location where the vehicles are driven. Would this statement hold if the additional pollutants emitted locally by power plants due to additional EVs are taken into account?

To prove if this statement is sustained by evidence, in this study I will take into account the additional emissions generated by power plants due to the increase in demand for electricity that responds to additional EVs in Mexico City, and compare its marginal cost to the marginal cost that gasoline vehicles have due to their effect on Mexico City's air quality. I will exploit that gasoline vehicles can only pollute wherever they are driven since that is where the combustion takes place, and that EVs can pollute wherever the generation of its electricity takes place (if it's not a clean source of energy). By consequence, I separate my research in two main sections: i) Gasoline vehicles' marginal cost; and ii) Electric vehicles' marginal cost.

2 Background

The growth of fossil fuel emissions is an environmental and public health problem that affects all countries, with even more damage in developing countries (Arceo et al., 2016). In this sense, studying the effect of transport choices on air quality for a developing country, such as Mexico, is relevant due to the impact that polluting emissions related to transport have on health damage.

The World Health Organization (WHO) estimates that 25,000 people die in Mexico every year due to sicknesses related to air pollution (World Health Organization (WHO), 2016). INEGI estimates that in 2017 the environmental costs where such that they represented around 2.8% of Mexico's GDP (Instituto Nacional de Estadística y Geografía (INEGI), 2018). Environmental damage is worldwide recognized as a pressing issue, as policy response in 2015 countries around the globe signed the Paris Agreement with the purpose of keeping temperature raise in this century below 2^o C. As a signing country, Mexico committed to reduce from 2013 to 2030 its CO_2 emissions by 22% (Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), 2015).

Air pollution has been an important problem for Mexico City in the past decades, and is strongly related to it's demographic and geographical conditions. Mexico City is the world's 7^{th} most populated city (United Nations, Department of Economic and Social Affairs, and Population Division, 2016). It is located at 2,240 meters above sea level in a valley surrounded by mountain chains to the east, west and south which minimize the wind circulation and, thus, pollutants' dispersion. The city is subject to intense solar radiation that causes thermal inversion and, thus, high temperatures during the day. The lack of pollutants' dispersion together with the effects of thermal inversion and altitude cause that a great proportion of the suspended pollutants are breathed by the inhabitants of the city having a negative effect on health.

As stated in Secretaría del Medio Ambiente del Gobierno de la Ciudad de México (2018), most of polluting emissions in Mexico City come from the transport sector, as this sector is responsible for 60% of fossil fuel consumption, which is related to higher emissions of particulate matter smaller than 2.5 μg ($PM_{2.5}$). In this sense, 56% of $PM_{2.5}$ emissions in Mexico City come from the transport sector. It is also important to mention that, within the transport sector, private vehicles are responsible for 83% of overall polluting emissions in Mexico City, thus the relevance of studying this niche.

Studying the effect of transport on particulate matter smaller than 2.5 μg ($PM_{2.5}$) is relevant because this is the smallest pollutant and according to World Health Organization (WHO) (2016) $PM_{2.5}$ accounts for 3.2 million deaths annually worldwide, specially related to cardiovascular and respiratory illnesses, where lung cancer stands out (Secretaría del Medio Ambiente del Gobierno de la Ciudad de México, 2018).

The motivation for the making of this study comes from Holland et al. (2016). In their research for California they calculate the polluting emissions coming from gasoline and electric vehicles while accounting for the electricity generation that is needed to cope with additional electric vehicles purchases. This allows the authors to conclude if the policy of applying subsidies to promote the purchases of electric vehicles is a cost-efficient policy that improves social welfare while accounting for different welfare levels across United States regions. Their conclusion is that geographically differentiated subsidies can reduce deadweight loss but only modestly. The study I carry out is relevant given that a similar study has not been made for the Mexican case. With this I can calculate the marginal cost of an additional EV and gasoline vehicle while also locating where the increase of pollution due to more electricity generation takes place.

Another relevant study for this research is the one made by myself, Gómez Carrera (2019), in which I conclude that even though changes in public transport policy such as the Metrobús implementation (a Bus Rapid Transit system in Mexico City) have an effect to improve air quality in Mexico City, the channel through which this effect takes place is through the change in emissions due to private vehicles. This could either be through the migration of private transport commuting to public transport commuting or through the reduction of traffic congestions. Therefore, research and policy should be aimed to change the private vehicles consumption and behaviour as they account for most of the polluting emissions in Mexico City.

On the other hand, the study of Xing et al. (2019) is interesting because they consider the displacement of technology, this factor has not previously been studied in literature when estimating the impact in air quality of EVs and gasoline vehicles. They define displacement as the amount of gasoline vehicles that are not bought as a result of consumers buying more EVs due to a subsidy in the United States that promotes EVs' consumption. While this approach is interesting, the data for the Mexican case is still insufficient to carry this task out, but it is a possible future scope extension.

In this research I will take the Mexican case to compare the air quality marginal costs that one additional electric vehicle has against the air quality marginal cost that one additional gasoline vehicle has. This study's relevance is enhanced given that I will study the most health-damaging pollutant ($PM_{2.5}$) and the kind of vehicles that accounts for most emissions in Mexico City (private vehicles).

3 Gasoline vehicles' marginal cost

3.1 Data

To estimate the marginal cost of additional gasoline vehicles it is necessary to know the change in gasoline vehicles purchased. There are two useful Instituto Nacional de Estadística y Geografía's (INEGI) databases for fulfilling this propose:

- INEGI's "Venta al público de vehículos ligeros por marca, modelo, segmento y país origen". This national vehicle sales database contains monthly national sales from January 2005 to February 2019. It includes information on brand, model and segment.

- INEGI's "Vehículos de motor registrados en circulación en 2017". With this gasoline vehicles record by state it's possible to calculate the average share of gasoline vehicles for Mexico City (12.03%).

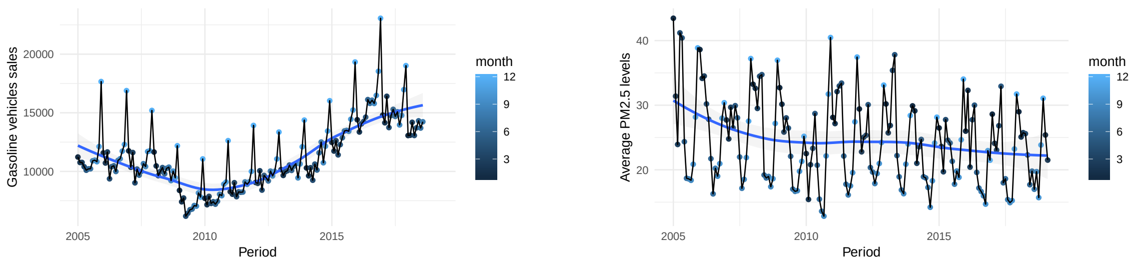
With this databases I construct a monthly database for gasoline vehicles sales in Mexico City from January 2005 to February 2019.[1] It is important to mention that the monthly mean of gasoline vehicle purchases in 2018 and 2019 is 13,671, this figure will be relevant when accounting for the marginal cost.

[1] I do not quantify hybrid or plug-in vehicles as gasoline vehicles, but instead treat them as electric vehicles.

For the purpose of the investigation it's important to have data on different pollutants that affect people's health in Mexico City. The more relevant, as stated in Secretaría del Medio Ambiente del Gobierno de la Ciudad de México (2018) and Instituto Nacional de Ecología y Cambio Climático (INECC) (2014), is particulate matter smaller than 2.5 μg ($PM_{2.5}$). It's importance is due to the small size of the pollutant and the high damage that it does to the cardiovascular and respiratory system, where pulmonary cancer stands out as a negative effect from breathing this pollutant.

The data for this pollutant in Mexico City can be obtained from Secretaría de Medio Ambiente's "Red Automática de Monitoreo Atmosférico" (RAMA) database. This contains hourly information by Mexico City's monitoring stations of different pollutants from June 2003 to February 2019.

Figure 1: Vehicles sales -left- and Average monthly $PM_{2.5}$ levels (μg/m^3) -right- in Mexico City



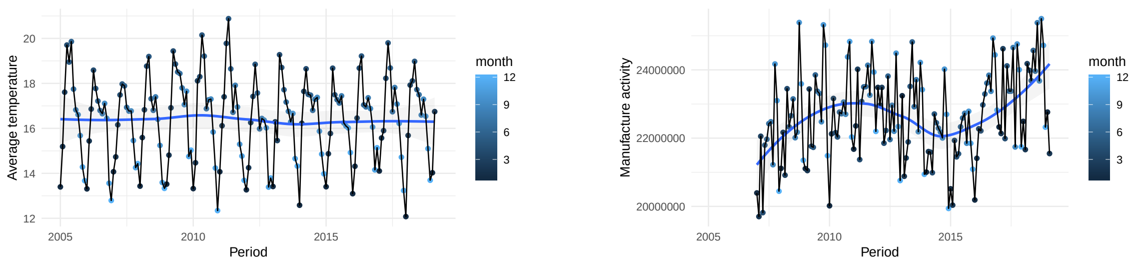
3.2 Data: Controls

As mentioned in the Section 2 and as done by Gómez Carrera (2019), the effect of gasoline vehicles needs to be isolated and this is not possible by only using RAMA's information, as it accounts for all pollution in Mexico City.

To account for weather effects I use Secretaría de Medio Ambiente's "Red de Meteorología y Radiación Solar" (REDMET) database. This contains hourly information by Mexico City's monitoring stations of relative humidity, temperature, wind speed, and wind direction from January 1986 to February 2019. Also from Sistema Metereológico Nacional's database I obtain data for hourly rainfall.

In the same sense, I isolate gasoline vehicles effects by accounting for industrial activity in Mexico City. With this purpose I use INEGI's "Encuesta mensual de la industria manufacturera (EMIM)" for manufacture industry production value in Mexico City from January 2007 to February 2019.

Figure 2: Average temperature levels (^{o}C) -left- and Manufacture value production (MXN million) -right- in Mexico City



3.3 Empirical method

To estimate the marginal change in pollution due to an extra gasoline vehicle (a marginal change in gasoline vehicles), I estimate a dynamic model with controls for weather factors as well as industrial activity.

$$\Delta C_t = \beta_t \Delta Gasoline_t + \phi_t W_t + \theta_t \sum_{s=1}^{12} W_{t-s} + \epsilon_t + \omega \sum_{s=1}^{12} \epsilon_{t-s} \qquad (1)$$

C_t is the endogenous variable for pollutant $PM_{2.5}$ and I want to measure its change due to an increase in a gasoline vehicle in Mexico City; $Gasoline_t$ is the exogenous variable of interest for a marginal change in gasoline vehicles given by sales, W_t is a vector of controls for weather variables (temperature, humidity, wind speed, wind direction, rainfall) and manufacture activity; W_{t-1} is a vector of lagged control variables up to 12 months before the marginal change in gasoline vehicles; ϵ_t is the error term; and ϵ_{t-1} is a vector of the moving-average error term.

3.4 Results

From Table 1[2] I observe that a purchase of a gasoline vehicle increases $PM_{2.5}$ levels by 0.0004 μg/m^3.

Table 1: Marginal change in $PM_{2.5}$ emissions due to a marginal change in Gasoline vehicles

Dependent Variable: D(PM25)
Method: ARMA Maximum Likelihood (OPG - BHHH)
Sample: 2007M09 2018M08
Included observations: 132
Convergence achieved after 55 iterations
Coefficient covariance computed using outer product of gradients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	464.5586	128.9320	3.603128	0.0005
Gasoline vehicles sales	0.000399	$9.54E-05$	4.177219	0.0001
LOG(Relative Humidity)	-9.577213	2.041270	-4.691792	0.0000
LOG(Temperature)	3.572690	3.377670	1.057738	0.2924
LOG(Wind direction)	-2.564558	4.545645	-0.564179	0.5738
LOG(Wind speed)	-41.36307	3.451403	-11.98442	0.0000
Rainfall	-0.911087	0.206404	-4.414097	0.0000
LOG(Manufacture activity)	-11.17940	6.428667	-1.738992	0.0848
LOG(RH(-7))	-7.094460	2.043257	-3.472134	0.0007
LOG(WSP(-1))	38.16339	4.204025	9.077822	0.0000
LOG(WSP(-6))	8.245986	2.422199	3.404339	0.0009
LOG(WSP(-8))	-9.753875	2.820835	-3.457797	0.0008
RF(-1)	1.118720	0.190288	5.879088	0.0000
LOG(MANUFACTURE(-1))	-21.63777	6.979590	-3.100149	0.0024
LOG(MANUFACTURE(-6))	22.40846	5.151490	4.349899	0.0000
LOG(MANUFACTURE(-8))	-13.00206	5.284144	-2.460580	0.0154
MA(1)	-0.468831	0.090102	-5.203345	0.0000
MA(7)	-0.214123	0.091849	-2.331247	0.0215
SIGMASQ	6.233926	0.940562	6.627877	0.0000
R-squared	0.790601	Mean dependent var		-0.001135
Adjusted R-squared	0.757245	S.D. dependent var		5.477021
S.E. of regression	2.698538	Akaike info criterion		4.961084
Sum squared resid	822.8782	Schwarz criterion		5.376033
Log likelihood	-308.4316	Hannan-Quinn criter.		5.129700
F-statistic	23.70215	Durbin-Watson stat		1.780823
Prob(F-statistic)	0.000000			
Inverted MA Roots	.89	.58-.61i	.58+.61i	-.12-.77i
	-.12+.77i	-.67+.34i	-.67-.34i	

INECC stated in Instituto Nacional de Ecología y Cambio Climático (INECC) (2014) that a reduction of 1 μg/m^3 in Mexico City would bring an anual marginal benefit of \$3,000 million (MXN) in the zone. Mexico City has 9,045,719 inhabitants (CONAPO[3]) and

[2]D: difference; RH:Relative humidity; WSP: wind speed; WDR: wind direction; RF: rainfall; MANUFACTURE: manufacture activity; MA: moving-average.

[3]Consejo Nacional de Población (CONAPO) with estimates for 2018.

1,484 km^2 (INEGI), hence a population density of 6,095.5 individuals per km^2. This means that an increase of 1 μg/m^3 of $PM_{2.5}$ translates into a marginal cost of $492,166.35 (MXN) per person per km^2 in Mexico City, or $331.65 (MXN) per person.

Using this information and the results of this research, I conclude that a purchase of a gasoline vehicle in Mexico City increases its $PM_{2.5}$ levels by 0.0004 μg/m^3 which translates into a marginal cost per person per km^2 of $196.2 (MXN). This is also a marginal cost per person of $0.1322 (MXN) for every gasoline vehicle.

Since the monthly mean of gasoline vehicle purchases in 2018 and 2019 is 13,671 units, the marginal cost per person of extra gasoline vehicles in Mexico City is $1,807 (MXN) a month.

4 Electric vehicles' marginal cost

To assess the electric vehicles' marginal cost per person this section will be separated in three subsections. First, I will calculate the marginal increase in electricity demand due to an additional EV in Mexico City. Then, I will calculate the marginal increase in pollution due to a marginal increase in generation. Finally, I will calculate the marginal damage per person according to where the generation of the additional electricity takes place.

4.1 Marginal increase in demand

Since the number of EVs' purchases is still very low in Mexico City (Annex Figure 6), to estimate the marginal increase in demand of additional EVs some assumptions are needed given that an econometric estimation will not deliver any significative results.

The methodology to calculate the marginal increase in demand is based on the electricity needed to charge an additional EV. Given that Nissan Leaf is the most sold EV in Mexico City[4], I will take its battery range and capacity and the results from Martínez (2019) on average distance driven in Mexico City to calculate the marginal demand in-

[4]Obtained with data from INEGI's "Venta de vehículos híbridos y eléctricos por entidad federativa".

crease. The methodology is the following:

$$DemandChange = BatteryCapacityPerKM_{EV} * (KMdriven/day)_{EV} \tag{2}$$

I take into account that i) according to Martínez (2019) the average distance driven by a single driver in Mexico City in a weekday is 27.27 km, ii) the battery range for Nissan Leaf is 200 km and iii) it's capacity is 24 kWh (Nissan, 2017). Then the daily demand change due to an additional EV is 3.2724 kWh. Taking into account that the battery takes in average 6 hours to charge, then the hourly demand change due to an additional EV is 0.5454 kWh, which translates into a marginal demand change of 0.0005454 MWh per additional EV.

4.2 Marginal increase in pollution

The marginal increase in pollution will depend on the kind of generation technology needed to produce the additional demanded electricity per EV. To obtain the pollution emitted by each kind of generation technology I use the Comisión Federal de Electricidad (CFE) (2015) study named "Costos y Parámetros de Referencia para la Formulación de Proyectos de Inversión en el Sector Eléctrico (COPAR Generación 2015)". This contains information on $PM_{2.5}$ emissions by each kind of generation technology according to the Electric Energy Inventory of Emissions (Table 2).

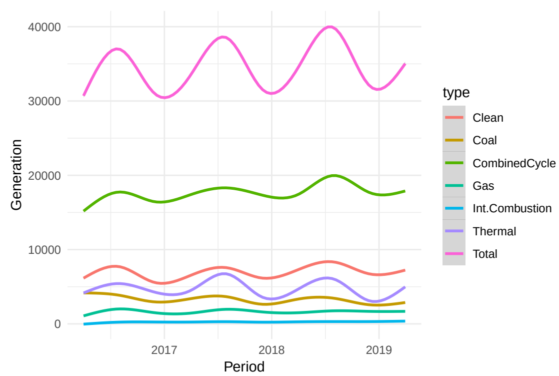
Table 2: Average $PM_{2.5}$ emissions by technology (COPAR 2015)

	$PM_{2.5}$ (μg/MWh)
Biomass	0
Coal	0.41
Combined Cycle	0.03
Internal combustion	0.25
Wind	0
Solar	0
Geothermal	0
Hydroelectric	0
Nuclear	0
Thermal	0.87
Gas	0.06

To measure the marginal change in pollution due to the increase in EVs it is necessary to know the electricity generation, available in Centro Nacional de Control de Energía's (CENACE) "Estadistica de la Energia Generada Liquidada Agregada (MWh) Intermitente y Firme por Tipo de Tecnologia (Proceso de Liquidacion Original)" database which contains hourly generation data by 11 kinds of technologies from April 2016 to March 2019.

For the purpose of this research all technologies that do not produce $PM_{2.5}$ emissions are considered as clean. Thus, it can be appreciated that Combined Cycle and Clean are the main sources of energy in Mexico.

Figure 3: Electricity MWh generation (smoothed)



To measure the increase in pollution I use Higueras Corona (2019) results on hourly change in electricity generation (MWh) by technology given a marginal increase in demand. These results are calculated with a dynamic model by taking wind and solar energy as independent variables as they completely depend on weather conditions. The model used in his study is:

$$\begin{aligned} q_{it} = \beta_{i0} + \beta_{i1} Demand_t + \beta_{i2} Demand_t^2 + \beta_{i1} Wind_t + \beta_{i2} Wind_t^2 \\ + \beta_{i1} Solar_t + \beta_{i2} Solar_t^2 + Z_t \gamma_i + V_t \omega_i + D_t \alpha_i + \epsilon_{it} \end{aligned} \tag{3}$$

Where q_{it} is the observed quantity of electricity produced by generation technology i in each 1-hour time period t, Z_t is a vector with temperature and the square of temperature for every city selected in each 1-hour time period t, V_t are lagged control variables (up to 24 hours before production) and D_t are date and hour dummies. The dynamic results are shown in Table 3.

Table 3: Change in generation (MWh) by technology given a marginal change in demand

Technology	Change in generation (MWh)
Biomass	0.0001
Coal	0.0797
Combined Cycle	0.3023
Int. Combustion	0.0018
Geothermal	-0.0007
Hydro	0.3913
Nuclear	0.0013
Thermal	0.1776
Gas	0.0467

Taking Higueras Corona (2019) results and Comisión Federal de Electricidad (CFE) (2015) pollution coefficients by technology, I multiply these two figures and then multiply them by the marginal change in demand caused by an EV, calculated in the previous subsection.

$$PollutionMgChange_i = PM2.5_i * GenerationMgChange_i * DemandChange \tag{4}$$

Where $PollutionMgChange_i$ is the marginal change in $PM_{2.5}$ by technology i due to an additional EV; $DemandChange$ is equal to 0.0005454 MWh per additional EV, as calculated in the previous subsection; $GenerationMgChange_i$ are the coefficients of change in generation technology i due to a marginal change in demand (Table 3) ; and $PM2.5_i$ is the polluting emissions caused by each technology i (Table 2). As shown in Table 4, Thermal and Coal are the most polluting technologies given a change in marginal demand.

Table 4: Marginal change in pollution by technology due to a change in demand

Technology	$PM_{2.5}$ (μg/MWh)	Δ in generation (MWh)	Δ in demand(MWh)	**Mg. damage (μg/MWh)**
Coal	0.410000	0.079700	0.000545	**0.000018**
Combined Cycle	0.030000	0.302300	0.000545	**0.000005**
Int. Combustion	0.250000	0.001800	0.000545	**0.000000**
Thermal	0.870000	0.177600	0.000545	**0.000084**
Gas	0.060000	0.046700	0.000545	**0.000002**

4.3 Marginal cost of EVs per person accounting for geographical allocation

To calculate the marginal damage per person from each kind of technology it is necessary to locate where the generation plants emit pollutants. With this purpose I use Programa de Desarrollo del Sistema Eléctrico Nacional's (PRODESEN) database on operating generation plants' geographical distribution, called Programa Indicativo para la Instalación y Retiro de Centrales Eléctricas (PIIRCE). This contains information of where each kind of operating generation plant is located by regions. The regions are divided as shown in Figure 4.

Figure 4: Electricity generation regions

Then, it is necessary to locate where the generation plants emit pollutants and how many people are affected by the increase in emissions. By using CONAPO's data on population, INEGI's data on state areas and PRODESEN's data on operating generation plants' location, I calculate the population density by region. I assume that the electricity demanded in Mexico City does not come from the Yucatán and Baja California peninsulas due to transmission constraints.

Table 5: Generation plants and population by region

Region	Coal	Combined Cycle	Int. Combustion	Gas	Thermal	Clean	Population	Density by km^2
Central	28	12	36	108	40	188	30,991,227	7,405
Noreste	24	87	39	63	27	102	12,100,248	149
Noroeste		14	10	6	28	48	6,072,310	71
Norte		28	18	22	16	36	5,537,068	30
Occidental		90	180	81	108	729	29,033,961	1,063
Oriental		112	70	49	98	966	31,922,643	917
Total	**52**	**343**	**353**	**329**	**317**	**2,069**	**115,657,457**	**9,635**

To calculate the marginal change per region, I multiply the estimated coefficients for marginal change in pollution per technology (Table 4) by the share of that technology's number of plants in each region (Table Annex 8). Then, I calculate the total marginal change in emissions in every region.

$$MgChangeXRegion_j = \sum_i (PollutionMgChange_i * \frac{\sum Plants_{ij}}{\sum Plants_i)} \tag{5}$$

Where i is kind of technology as before; and j is kind of region. The results are shown in Table 6 along with the population and population density in each region. The three regions with the highest marginal increase in pollution are *Occidental*, *Oriental* and *Central* which is directly related to the fact that these regions have the most Thermal generation plants.

Table 6: Marginal change in $PM_{2.5}$ (μg/m^3) by MWh and population by region

Region	Mg. Change	Population	Pop. Density by km^2
Central	0.00002093	30,991,227	7,405.2
Noreste	0.00001698	12,100,248	149.5
Noroeste	0.00000768	6,072,310	70.5
Norte	0.00000477	5,537,068	29.8
Occidental	0.00003051	29,033,961	1,063.3
Oriental	0.00002794	31,922,643	917.1

Taking into account that an increase of 1 μg/m^3 of $PM_{2.5}$ translates into a health total marginal cost of $3,000,000 (MXN) (Instituto Nacional de Ecología y Cambio Climático (INECC), 2014), I calculate the marginal cost per person for every region and in total. An extra electric vehicle in Mexico City has a marginal cost of $0.018 (MXN) per person.

The monthly mean of EV purchases for Mexico City in 2018 and 2019 is 387. Thus, the marginal health cost per person of extra EVs in Mexico City is $7.12 (MXN) a month.

Table 7: Marginal cost ($) per person of $PM_{2.5}$ increase (μg/m^3) by MWh by region due to an extra EV in Mexico City

Region	Mg. cost per person ($)	Mg. cost per person per km^2
Central	0.002026	8.47
Noreste	0.004209	340.70
Noroeste	0.003794	326.67
Norte	0.002585	480.23
Occidental	0.003152	86.08
Oriental	0.002626	91.40
Total	**0.018394**	**1,333.58**

Figure 5: Marginal cost per person by generation regions

5 Conclusions

5.1 Conclusions

The marginal cost per person for an additional gasoline vehicle in Mexico City is $0.1322 (MXN).The monthly mean of gasoline vehicle purchases for Mexico City in 2018 and 2019 is 13,671. Thus, the marginal cost per person of an additional gasoline vehicle in Mexico City is $1,807 (MXN) a month.

The marginal cost per person for an additional electric vehicle in Mexico City is $ 0.018 (MXN). The monthly mean of EV purchases for Mexico City in 2018 and 2019 is 387. Thus, the marginal cost per person of an additional EV in Mexico City is $7.12 (MXN) a month.

Therefore, in this research I prove that electric vehicles have a lower marginal cost per person than gasoline vehicles, even when accounting for pollution emitted locally due to increased activity of generation plants that respond to an increase in demand due to an additional EV in Mexico City. Hence, the popular hypothesis that EVs are more sustainable with air quality than gasoline vehicles holds for the case of Mexico City even when accounting for additional generation plants' emissions.

5.2 Discussion

Given the lack of data and the small figures regarding EVs (which obstruct carrying out an econometric estimation) some assumptions were needed to carry out this assessment. When better and bigger data is available a better assessment can be made. An additional challenge, as shown by Xing et al. (2019), is to calculate the substitution cost or benefit from migrating from a gasoline vehicle to an EV. This scope can be added in the future when more information regarding EVs is available.

It is important to note that the lack of EVs purchases could be related to their higher relative price and the inability of consumers to cope with those prices to substitute their consumption of gasoline vehicles, as mentioned by Hernández Monroy (2019). Given that national marginal cost per person is lower for an additional EV than for an additional gasoline vehicle in Mexico City, the use of subsidies for promoting the production and consumption of EVs (and cheaper EVs' batteries) could lower the relative prices and enhance the purchases of EVs. This would bring higher national health benefits due to the reduction of polluting emissions.

Nevertheless, this study proves that the regional distribution of emissions is important and therefore it should be accounted-for when designing policy. For instance, as shown in Table 7 and Figure 5 the reduction of emissions in Mexico City due to a purchase of an EV instead of a gasoline vehicle increases the marginal damage in all the other regions more than in the Central region, where Mexico City is. This shows that if Mexico City's government should choose to apply an incentive for EVs' consumption the marginal damage would be spread to other regions that were not damaged before, therefore an integral policy is to be considered and negotiation among entities is important.

Another main takeaway from this study comes from crossing information on generation and pollution. The majority of the generation of electricity is produced through Combined Cycle and Clean plants (Figure Annex 7), the latter understood as those that do not emit $PM_{2.5}$. Nonetheless, Thermal and Coal are the biggest polluters (Figure Annex 8). Therefore it seems that in this case more production is not directly related with higher emissions. From this it can be concluded that an additional research that accounts for costs and benefits of generation plants is needed, including the investment for building, operating and maintaining each kind of technology. The aim of the proposed research should be to point out which technology is more fuel efficient, profitable, sustainable, and less dependant on weather factors (like solar or wind). Policy on building generation plants should follow on what the recommended study concludes.

An important assumption made in this study is that there are low transmission constraints for the generation point to the consumption point, in reality this can vary. Having said this, the focus of governments should also be in reducing transmission constraints to gain efficiency and reduce spillovers. Another bigger and more difficult problem to address in the future is the storage of energy, in the present the few technologies that exists to storage electricity are too expensive, thus governments could invest in research looking to reduce future prices and gain comparative advantages.

Moreover, clean generation technologies like Solar and Wind are criticized for depending on weather factors and not being able to produce at high demand peaks, in the case of EVs and Solar technology at night when the vehicles are charging. But this problem can be addressed by using the excess of generation produced during the day, in Solar case, to pump water into a slope (mountain). Then at night, gravity's force due to the slope can be used along Hydric technology to power in a clean way a generation plant, thus the storage problem would be reduced.

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6 Annex

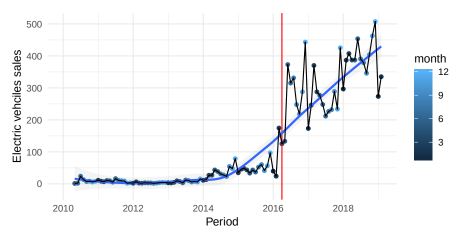
6.1 Marginal increase in electricity demand due to more EVs in Mexico City

There are two useful INEGI databases for measuring EVs sales in Mexico City. From these I conclude that doing an econometric estimation is not useful for measuring the marginal increase in demand as the number of EVs is very little to have an impact; also the frequency of the data, when crossed with generation data, is very low (35 obs.).

- INEGI's "Venta al público de vehículos ligeros por marca, modelo, segmento y país origen". This national vehicle sales database contains monthly EVs national sales from January 2010 to February 2019. It includes information on brand, model and segment.
- INEGI's "Venta de vehículos híbridos y eléctricos por entidad federativa". With this EVs database by state that contains information from January 2016 to January 2019 it's possible to calculate the average share of EVs for Mexico City (41.37%).

The hourly electricity generation databases contain information from April 2016, so when the monthly EVs database is crossed with the generation databases the result is that I obtain only 35 observations. Given the above-mentioned and given that EVs purchases account for a very small portion of the market share in Mexico City (the average mean for EVs sales in 2018 and 2019 is 387 while it is 13,671 for gasoline vehicles), unfortunately this EV database will not be useful to estimate the marginal change of $PM_{2.5}$, therefore to make this calculation some assumptions are needed.

Figure 6: Electric vehicles sales in Mexico City



6.2 Pollution by technology

By joining information from CFE's COPAR Generation 2015 study and CENACE's generation database I obtain the hourly levels of $PM_{2.5}$ due to electricity generation from April 2016 to March 2019. Where Thermal and Coal generation are the main sources of pollutants.

Figure 7: Average electricity generation by hour (MWh)

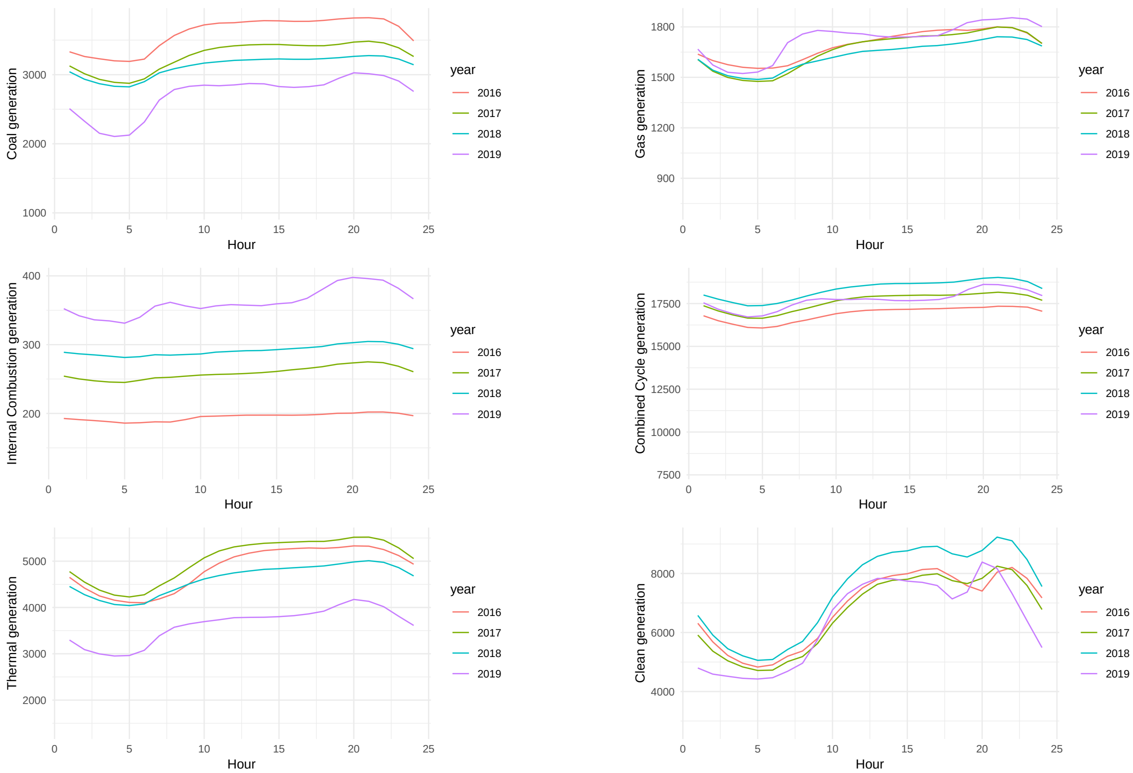


Figure 8: Pollution ($PM_{2.5}\ \mu g/m^3$) due to electricity generation (smoothed)

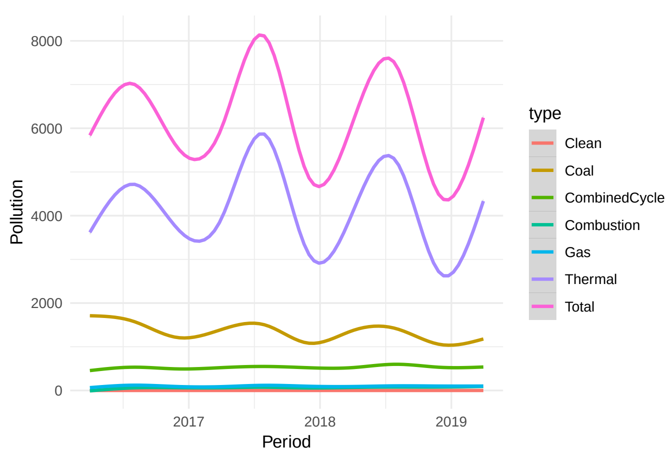


Table 8: EVs increase mg. effect on $PM_{2.5}$ emissions (μg/m^3) by MWh by technology and region

Region	Coal	Combined Cycle	Gas	Int. Combustion	Thermal
Central	0.00000960	0.00000017	0.00000050	0.00000003	0.00001063
Noreste	0.00000823	0.00000125	0.00000029	0.00000003	0.00000718
Noroeste		0.00000020	0.00000003	0.00000001	0.00000744
Norte		0.00000040	0.00000010	0.00000001	0.00000425
Occidental		0.00000130	0.00000038	0.00000013	0.00002871
Oriental		0.00000162	0.00000023	0.00000005	0.00002605