

Article

Car Sales, Fuel Economy and Decarbonization in Mexico

David Bonilla ^{1,*} , David Banister ²  and Adriana Caballero Castrillo ³

¹ Instituto de Investigaciones Económicas, Universidad Nacional Autónoma de México, Circuito Mario de la Cueva, Ciudad de la Investigación en Humanidades, C.U., Ciudad de Mexico 04510, Mexico

² Transport Studies Unit, School of Geography and Environment, University of Oxford, S. Parks Rd., Oxford OX1 3QY, UK; david.banister@ouce.ox.ac.uk

³ Conahcyt, Av. Insurgentes Sur, 1582 Col Crédito Constructor, C.P., Mexico City 03940, Mexico; maribel.caballero@conahcyt.mx

* Correspondence: dbonilla@iiec.unam.mx

Abstract: The car market in Mexico has undergone substantial change over the last twenty years, as sales have increased dramatically and as policy measures have been introduced to improve fuel economy so that decarbonization targets can be achieved. The argument presented in this paper is that overall fuel economy is driven by vehicle sales and the fuel economy standards imposed. In addition, this picture is complicated by the purchasing preferences of buyers, and this might reduce the effectiveness of the policy measures introduced. A case study approach allows analysis of the shifts in transport policy (2003–2020) to be undertaken by linking the fuel consumption of cars (L/100 km) to the purchasing patterns of consumers, and from this estimate the levels of CO₂ emissions. From the empirical analysis, it is found that, although there have been fuel economy gains every year, this is countered by (a) increasing sales of SUVs, and (b) a car market that is increasingly being dominated by larger cars. The current fuel standards are not sufficient to control the continued growth in fuel consumption, and levels of carbon emissions are continuing to increase. In conclusion, tighter emissions standards are needed, together with stronger governance structures and a range of further policy measures to improve car efficiencies and limit growth of the use of larger vehicles.

Keywords: gasoline; emissions; car sales; decarbonization



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1. Introduction

In 2003–2020 the level of fuel economy of new cars (L/100 km) which is determined by consumer decisions, has registered gains which are key to reducing emissions of CO₂ in the transport sector. This paper aims to assess (1) if aggregate fuel economy on the road is given by two factors: (a) vehicles sales and (b) fuel economy standards for the period of 2003–2020; and (2) if changes in car class have led to higher gasoline use and carbon emissions through shifts in the vehicle preferences of buyers. By assessing policy shifts regarding fuel economy and analysing data for various vehicle sizes between the years of 2000–2020 we unpack factors of gasoline use. The chosen period gives sufficient evidence to assess the early impacts of standards and yet is recent enough to determine the effectiveness of standards in controlling fuel use and emissions.

The transport sector has become the largest sources of greenhouse emissions in Mexico [1]. Vehicle use causes fossil fuel dependency, local pollution, traffic congestion, and accidents [2]. Today Mexico is taking steps to electrify its transport system [3].

Over the last 20 years the size of the vehicle fleet has increased to more than 27 million vehicles [4,5]. Rapid population growth, sudden urbanization, and a lack of transportation alternatives have all contributed to an increase in the volume of cars on the road, which has led to an increase in air pollution and an increase in the consumption of gasoline and diesel in Mexico. Although slower economic growth has depressed total gasoline use, the contribution of transport energy to total final energy use continues to grow (see Section 4.2).

According to the Secretary of the Environment and Natural Resources, “the quality of the air in various cities in Mexico has deteriorated significantly in recent decades, due to climate and geography factors, to urbanization processes, to population growth, to economic activities developed by the population in general and the use of poor quality gasoline. These factors have caused an increase in the vehicle fleet and, therefore, an increase in recorded emissions into the atmosphere. The main pollutants generated by automobiles are: carbon monoxide (CO), nitrogen oxides (NO_x) and unburned hydrocarbons (HC)” (standard “NOM-041-SEMARNAT-2015”, [6]).

The Mandatory Vehicle Emissions Control Programs (PVVO in Spanish) (or MOT test in Anglo-Saxon countries) have been essential to improve air quality in the country’s large cities. The program has been successful for two reasons: (1) by providing incentives to adopt emissions control technology and (2) by sending signals for greater fuel economy to the market.

The program aims to improve air quality, mainly through reducing ozone gases, surrounding the Valley of Mexico (ZMVM). In 1989, the driving ban “Hoy No Circula” (HNC) was implemented, which limits the use of automobiles, some industrial activities, and some public services in the ZMVM. Although this program had significant emission reductions in the first years of its implementation, in recent years it has not built on its initial success.

The program’s actions have managed to contain “an accelerated increase in O₃ concentration levels, but not decrease them” [7]. This has happened mainly due to two factors: (1) the vehicle fleet has grown significantly, tripling in less than 20 years, and (2) the proportion of the vehicle fleet that pollutes has increased because (a) a fraction of the fleet is made up of older vehicles and (b) there is a larger vehicle fleet than in earlier years.

As shown in Figure 1, emissions (for the Valley of Mexico, including the industry, electricity, and transport sectors) declined in the first phases of the program but then stabilized, and the decline is less steep, particularly between 2004 and 2019 (highlighted in Chart). At the end of that chart one can see a puzzle: other than CO and SO₂ gases, many gases decline far less than the others do. In fact, NO₂, NO_x, and PM (2.5) gases hardly fall.

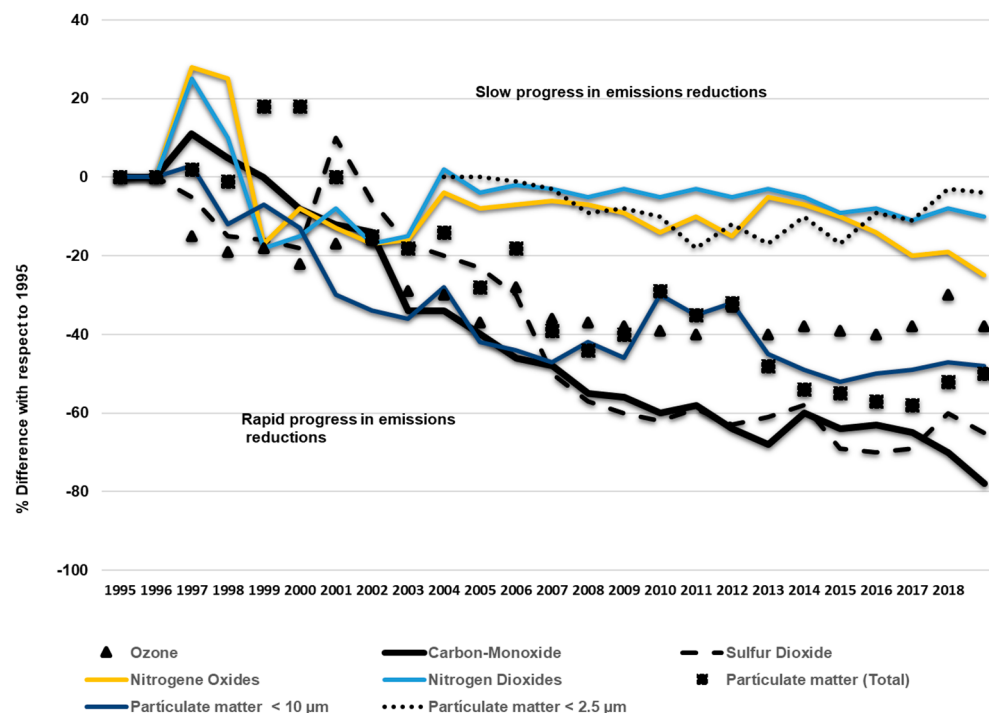


Figure 1. Non-CO₂ emissions. Source: [7].

In 2018, transportation in Mexico was responsible for almost a third (32%) of the GHG emissions emitted in the country and accounted for the largest (50%) share of CO₂ emissions [8]. Out of the key sources of non-CO₂ emissions in the metropolitan region, including mobile, point, natural, and area sources, vehicles (private, coaches, and freight transport modes) emitted 61.6% of total NO_x emissions, 54% of CO, 25% of SO₂, 34% of particulate matter (PM₁₀), and 39% of particulate matter (PM_{2.5}) in 2018 [9].

This paper aims (1) to assess the effectiveness of fuel economy standards for the period of 2000–2020 using vehicle sales as a key metric; (2) to explain how changes in the car market have led to higher gasoline consumption; and (3) to measure the effectiveness of air pollution controls in combination with the fuel economy gains of private vehicles.

2. Background

We describe first the overall trends, which determine the pace of both the gasoline consumption of vehicles and of CO₂ and non-CO₂ of emissions in Mexico for 2003–2022. Secondly, we discuss two factors that also determine the shape of the curve of emissions: the changes in the car market and differences in distance travelled behaviour (VKT, vehicle kilometres travelled). This paper fills a research gap in the literature: there are few studies that examine the interaction of fuel standards, emissions, car size, and consumer behaviours for large emerging economies such as Mexico, which is now the 12th largest economy in the world. The experience of Mexico’s gasoline market offers several useful lessons for other emerging economies.

2.1. Car Markets and Fuel Economy

As shown in Table 1, the growth in the vehicle fleet supersedes the path of both VKT (vehicle kilometres travelled) and of CO₂ emissions. From 2003 to 2020 the fleet has expanded rapidly, despite technological advances (public transport provision) and the gains in vehicle fuel economy from 6.75 (L/100 km) to 5.75 L/100 km. In the 2007–2020 period, one can detect changes in the vehicle stock which did not translate into a large increase in fuel consumption of privately-owned vehicles; two reasons explain decrease in gasoline use (a) the effect of fuel economy standards and (b) a slowing economy.

Table 1. Trends in fuel economy and gasoline demand in México, 2003–2020. Vehicle stock and VKT data include light-duty vehicles, heavy vehicles, and privately-owned vehicles.

	2003	2005	2007	2009	2011	2012	2013	2015	2020
Vehicle stock * (million registrations)	12.7	14.2	17.6	20.4	22.3	23.5	24.7	27.1	33.6
Fuel economy: new cars ** (L/100 Km) Gasoline only: IEA	6.75	6.75	6.8	6.75	6.94	6.66	6.36	5.74	Na.
Gasoline and diesel (L/Ge 100 Km)	Na.	9.1	9.4	9.5	9.4	8.7	8.6	7.5	7.6
Vehicle-km travelled **** (1000 million) highways excluding urban driving, passenger vehicles only	56.6	68.78	n.a.	84.24	95.68	99.63	84.39	85.56	82.8
Vehicle-km travelled (1000 million) freight and passenger transport ****	67.82	71.3	90.6	97.8	108.6	111.5	116.1	125.1	157.3 *
Transport energy consumption (thousand million litres per year)	45	50	57	58	61	61	60	61	43.1
Gasoline consumption (thousand million litres per year)	32	36	41	42	43	43	42	43	32.3

Table 1. Cont.

	2003	2005	2007	2009	2011	2012	2013	2015	2020
Diesel use (thousand million litres per year)	11	13	15	15	16	16	16	17	10.8
*** Transport emissions (million tonnes of CO₂)	117.18	130.06	148.08	152.2	157.7	158.2	155.1	159.9	138.9

Sources: * Estimates based on [10] using monthly sales from the monthly survey of manufacturing industry, “La Encuesta Mensual de la Industria Manufacturera (EMIM)”. Data also are sourced from [11]. Gasoline and diesel data [12], VKT data in [13]. Source: ** Data on fuel economy for 2003 a 2009 from [14]. Data for 2011 to 2017 were elaborated by the authors using [15]. Includes automobiles and vans. We used an average fuel economy of diesel + gasoline fuels. VKT of federal highways in: [16] and various years. Source: *** CO₂ emissions of surface transport private communication [17]. Includes: aviation, rail, maritime modes and road transport. Source: **** for some years the following calculation was used to obtain VKT travelled: VKM = fuelU/FE = fuel use/fuel economy.

The growth rate of fuel consumption (gasoline and diesel) matches that of CO₂ emissions generated by a larger fleet of private vehicles; thus fuel use grew by 40% in 2003–2015 (prior to the 2020 pandemic). This increase in CO₂ emissions in transport can be explained by three reasons: (1) the growth of the vehicle fleet, which more than doubled from 2003 to 2020 following the growth in urbanization in Mexico, (2) congestion levels in Mexico City; the city tops the list worldwide in congestion levels (Index of Tom Tom traffic since 2016 [18,19] and (3) the increase in VKT: the distance travelled in Mexico increased significantly from 2003 to 2020, which explains partly the increase in the demand for gasoline and diesel in the same period. Except for 2020, the increases in transport CO₂ emissions continue unabated.

The use of gasoline by vehicles is a function of distance travelled, usually measured in VKT. Distances have increased, but this varies from region to region (Tables 1 and 2). It seems that in general the average distance travelled is longer in the centre of the country. For example, in the north of the country, a vehicle will travel shorter distances than a vehicle in the centre of the country. Likewise, a bus will be driven longer distances in the centre south than in the northern region, while the freight transport sector displays less variation in distance travelled patterns among the regions (Table 2). Finally, motorcycles again are driven for longer distances within the centre region. Three factors account for longer distance travelled: (1) greater road transport capacity of the centre region, (2) greater trade activity, and (3) rapidly growing household incomes.

The south east of the country revealed higher VKTs than the other regions. This heterogeneity of VKT will affect the size of the gasoline market on a regional basis.

Table 2. Travel behaviour per region in Mexico (VKT per day). Source [20].

	Privately Owned Vehicles	Buses	Freight Vehicles	Motorcycles
Nation-wide (% shares)	63.6	2.5	30	3.5
North	44.9	145	60.8	50
Centre North	39.9	115	63.3	20
Centre South	42.9	180	65.5	176
Centre	49.2	120	61.5	22
South–Southeast	59.9	150	60.5	30

2.2. Car Sales with Worse Fuel Economy (SUVs and Trucks)

In addition to VKT, car sales feed into the vehicle stock, and after a time lag a number of more efficient vehicles enter the stock on an everyday basis, but the stock cannot be replaced suddenly; new car turnover determines how long a stock will be replaced, and at sales of 1.5 million units per annum it takes about 22 years to renew stocks at current rates of vehicle sales. In 2021, 1.7 million motor vehicles were sold, of which 67.2% were cars

and 32.8% were light trucks (defined as SUV light trucks, trucks, and small and medium pickups) (Figure 2).

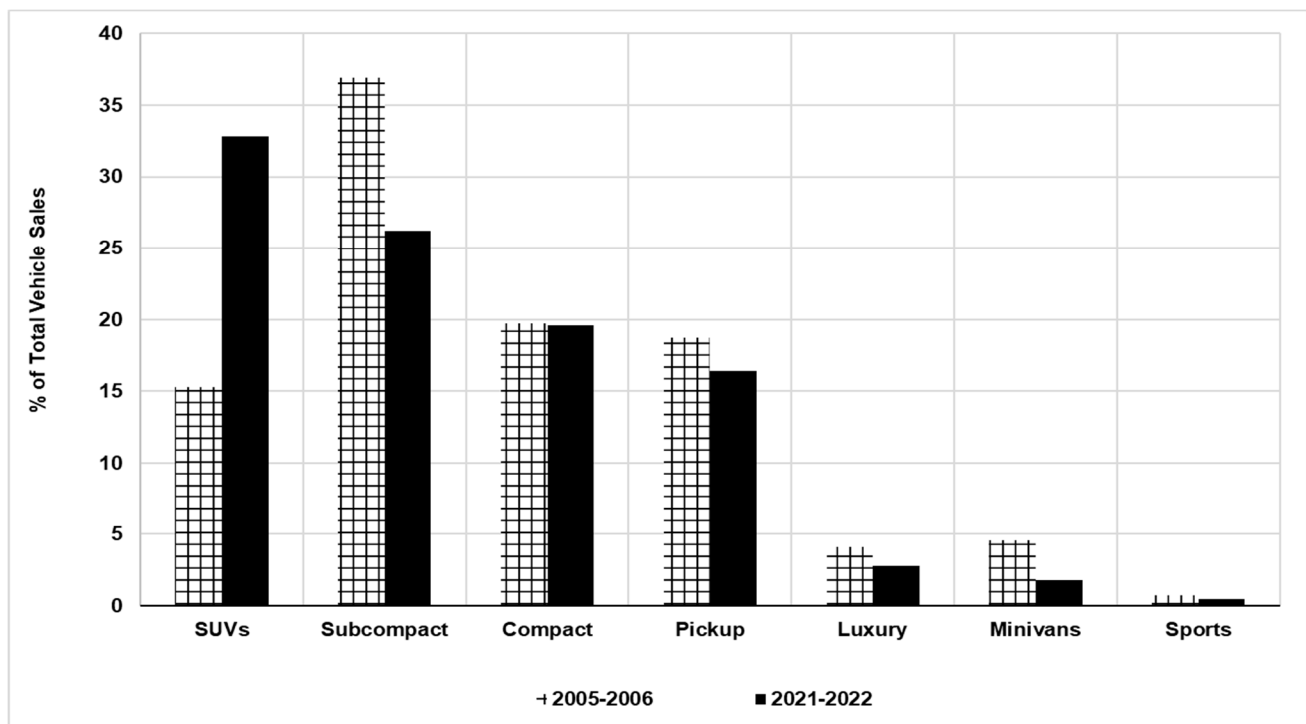


Figure 2. Sales by car class and % changes in sales between 2022 and 2005. Source: [11].

Mexico's market, in general, favours small engine sizes that imply higher fuel economy (fewer L/100 km). However, in recent years, sales of trucks and SUVs have been growing, proportionally more than sales of compact cars. These SUVs and trucks have worse fuel economy (more L/100 km) than ordinary vehicles do. In fact, there has been a shift in consumer tastes, which can be detected in Figure 1, since 2006. One explanation has been higher GDP per capita. The car market in Mexico is dominated by the sales of just 30 models, and these sales can be distributed according to their size from smallest to largest (see Section 4.4). In recent years, there has been a change in consumer tastes for larger and medium-size vehicles rather than the compact and subcompact cars, which have better fuel economy, as shown in Figure 2.

Fuel economy gains are key to reducing the growth of gasoline use, which produces emissions of CO₂ and non-CO₂ gases. The latter vary positively with speed initially and then decrease with higher vehicle speeds [21]. The volume of emissions is therefore a function of speed and the volume of traffic.

2.3. Literature Review

Although most gasoline use studies cover the effectiveness of fuel prices in controlling the use of gasoline by triggering innovation [22] there is also a strand of the literature (discussed below) that focuses on fuel economy standards and the costs and benefits of it. This review is divided into (a) fuel economy studies, (b) gasoline consumption studies, (c) studies on vehicle pollution (i.e., standards and driving bans) for vehicle emissions, and (d) justice theories regarding preferences of larger vehicles. We contribute to advancing the field by examining Mexico's car market and its influence on gasoline use over time as the case study.

There are four key factors affecting aggregate fuel economy: price, fuel standards, household income, and consumer taste ("offensive taste"). On the one hand, fuel economy standards were more effective than price in controlling the growth of fuel use in

1978–1989 [23] while on the other, some more recent research has failed to find significant effects of standards on fuel use [24].

Based on the unconditional quantile approach, which avoids relying on mean estimates of fuel economy changes, some research has found that the effects of the latter on vehicle weight distribution can also lead to fuel savings and to improved safety [25]. Further studies have concluded that there are a variety of fuel savings models available which assess motorcycles to heavy-duty vehicles as well as engine types (thermal, electric, hybrid, etc.) [26–28]. Some of these models assess fuel use instantaneously, while others are based on daily data [29].

Gasoline use can be decomposed by analysis of on-road fuel economy (the metric is based on entire car fleets) and by new car fuel economy [30]. The conclusion of these studies is that higher fuel prices lead at best to gains in fuel economy (fewer L/100 km) or at worst to discernible improvements [31,32]. For example, these improvements can also involve greater energy security. The short-term elasticity of gasoline use is given by the vehicle distance travelled and the efficiency with which each mile is driven [29]. As far as on-road fuel economy, an average elasticity of 0.07 has been found, and an elasticity of 0.30 for VKT, which means that 19% of the price elasticity of gasoline use (-0.37) comes from fuel economy gains for the U.S. case [29]. Some authors find that fuel economy is better explained by recent gasoline prices than past prices [29]. A large number of studies infer gasoline consumption elasticities from VKT [33]. As for Mexico, elasticities range from -0.31 [34] in 2012 to -0.72 [35] in 2017; this reveals that consumers have become price-insensitive, but price elasticity values vary according to the poverty status of consumers [36].

As for the income effect on fuel economy, the literature is divided, with some authors finding that an increase in the former worsens the fuel economy of new cars (more L/100 km) in the USA, Canada, and Japan, while other authors claim the opposite: higher income leads to gains in fuel economy [30]. The consensus is that higher income is associated with gains in fuel economy.

The effect of fuel economy and air pollution standards (that is environmental regulations) is associated with higher production costs for firms, and for this reason the Trump administration opposed standards [37]. In contrast to that argument, the Porter hypothesis [38] maintains that environmental regulation can be effective in improving the competitiveness of the car industry. Fuel economy standards trigger technological innovation, leading to higher competitiveness in the near term. Standards can trigger innovations that partially or fully compensate for compliance costs. Therefore, regulation could bring environmental benefits [39] by adopting a mix of public policy tools: applying a tax for the generation of CO₂ emissions but offering a system of subsidies for investment and technology, not forgetting potential market failures in the application of policy.

Ye et al., [40] argue that public policies on energy efficiency (including the cited standards) can have unexpected (technological risks) effects, which cause technologies adopted in an accelerated manner (by regulation) to be uncompetitive, generating a lack of interest within the industry to invest in new technologies.

This same argument is made in regard to the adoption of new technologies, which ensures that there are low economic incentives to quickly adopt innovation, since rapid technological progress (real or regulatory) decreases the possibilities that a company can recoup their investment by immediately adopting the new technology, so companies wait until the latter is sufficiently mature [41]. Further adoption of direct injection techniques and development of the ICE (internal combustion engine) can improve their efficiency. One example is the improvements in high-pressure direct injection in ICE, which can raise combustion efficiency [42] helping to cut CO₂ emissions indirectly.

Instead of relying on price effects to control both gasoline use and emissions, direct government intervention to cut emissions can have unexpected outcomes: for example, vehicle emissions did not fall after the adoption of vehicle driving bans in Mexico City [43].

Finally, justice theory sheds light on consumer preferences for larger cars thereby increasing fuel use. First, the “offensive taste” argument [44] ensures enforcing control over behaviour on the part of consumers that creates externalities associated with sales of larger vehicles. Second, the “snobbish taste” argument holds that some individuals or social groups may adopt certain tastes owing to their intrinsic enjoyment or utility and as a way to signal their social status. The “conspicuous consumption” argument holds that wealthy individuals often consume highly conspicuous goods and services in order to advertise their wealth and to achieve greater social status [45]. These concepts need to be incorporated into the debate regarding consumer choices of energy-inefficient (SUVs) or energy-efficient cars (small cars).

3. Materials and Methods

The novelty and strength of the current study rely on the data analysis of vehicle choice and fuel economy in disaggregate (by vehicle brand) and aggregate forms. Unlike other fuel economy works, we examine in greater detail changes in the individual brand of vehicles, their fuel economy, and the consumer choice of cars. Methodologically we use both quantitative and qualitative data and draw on insights from gasoline use, fuel economy by new vehicle brands, and other important energy and transport metrics of the country from a wide range of sources. Data were gathered through a combination of surveys and performance metrics analysis, i.e., fuel economy of distance driven (L/100 km). The study was conducted over a period of six months. Key performance indicators were used to assess fuel economy, including vehicle sales, gasoline use, fuel prices, and fuel economy by car brand surveys. We retrieved vehicle sales data from the Mexican Association of the Automotive Industry [46], the energy ministry, and the online sources. Vehicle utilization data were sourced from national surveys. All data sources are tabulated in Appendices A and B, Tables A1–A3.

The methodology is broken down in three steps to examine our case study. First, we examine trends in fuel economy (in the real world) in relation to vehicle size (Section 4.1–4.3). Second, we aim to observe whether changes in fuel economy for new cars reduce the use of gasoline (Section 4.4). Third, we assess the quality of governance (best practice) in Mexico of emissions standards (Sections 4.5 and 4.6). Fourth, we assess the impact of pollution control on privately owned vehicles (Section 4.7).

Using this body of empirical evidence, we show the relevance of changes in car markets and fuel economy to understand the gasoline use of private vehicles of Mexico and uncover the implications for gasoline consumption in the future.

As for the procedure, the methods are based on the analysis of both [30,31], where we first calibrate levels of road fuel economy by (a) using km travelled and (b) motor fuel use, and fuel price effects on car size. Second, we correlate gasoline use to vehicle size and the adoption of fuel economy standards. The only modification is that we use historical and qualitative analysis of transport policy to explain (1) changes in fuel economy, (2) changes in vehicle emissions regulations, and (3) a case study. The evidence at hand allows a detailed analysis of three key variables: gasoline use, fuel economy of new vehicles, and on-road fuel economy. Data analysis is conducted using historical policy shifts in the key variables that help explain changes in gasoline consumption.

During 2003–2014, higher automobile use and the 113% increase in the vehicle fleet led to a 36% increase in gasoline and transport energy consumption. In that period the 55% increase in the price of gasoline led to gains in fuel economy of 17%. These changes led consumers to buy more efficient cars, through “downweighting”. Despite the increase in energy prices, automobile use goes up significantly (Table 1).

4. Results

4.1. The Impact of Standards and Price on “On Road Fuel Economy”

This paper aims to assess (1) if aggregate fuel economy is given by two factors: (a) past and today’s vehicles sales and (b) the impact of standards on gasoline use for the period of

2003–2020; and (2) if changes in car classes have led to higher gasoline use, by examining the vehicle preferences of buyers. In this section we describe the results of our case study.

Figure 3 shows the behaviour of on-road fuel economy (L/100 km) (vertical axis “Y”) and the price of gasoline (index of gasoline price, [47] reflecting real changes in price) on the secondary axis. The on-road fuel economy of the entire vehicle fleet shows that the gap with new car fuel economy is considerable. The fuel economy standard for Mexico was introduced in 2013 [48] and its effect can be seen in the last years (2015–2020): fewer L/ 100 km travelled were registered, as a result of superior fuel economy (Table 1, row on “New Car Fuel Economy”); however, there is a time lag for more efficient vehicles to enter the vehicle stock. The gains in both on-road fuel economy and of new cars, however, in the final part of the 2010 decade result from higher gasoline prices, as Figure 3 reveals. It should be noted that the fuel economy standard applies to new cars, while the rise in fuel price is almost immediate. The combined effect of the standard and price explains the gain in fuel economy of new and older cars. The effect of price on fuel economy (on-road) can be seen in Figure 3. The effect of COVID-19 on gasoline consumption was key in explaining the level of the latter, since the pandemic restricted the distance travelled of vehicles, and as a result gasoline use dropped. In 2020 one can detect an apparent improvement in fuel use per km.

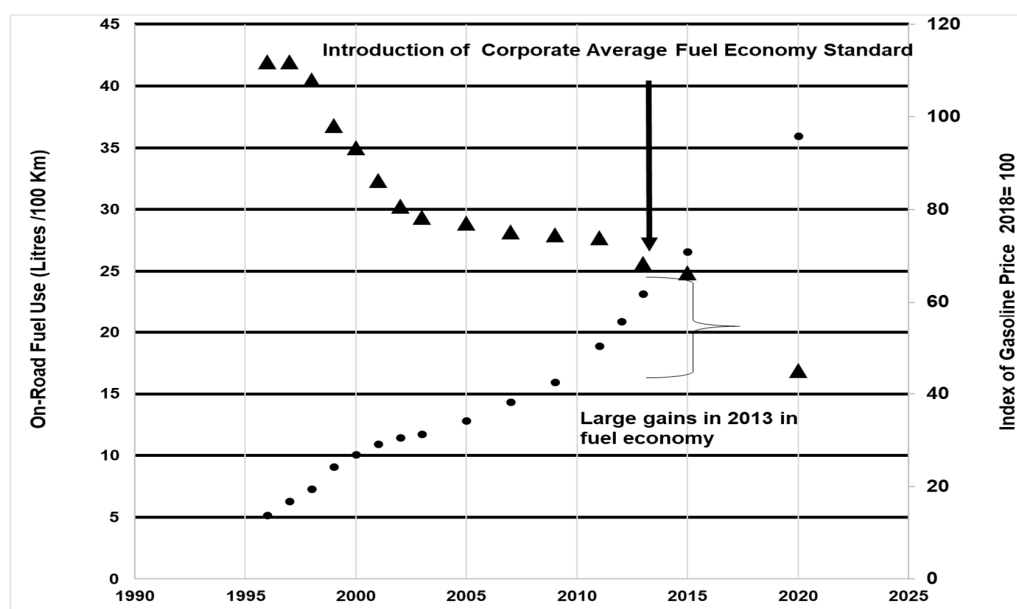


Figure 3. On-road fuel economy and energy prices (gasoline and diesel) (2009–2016). Source: [12,13].

Both gains in fuel economy (for all cars on the road) and the prices of gasoline or diesel (Figure 3) decrease the cost per Km driven. There are many explanations for this effect, such as price elasticity studies of energy use [23,29–31,49]. Looking at the data, the improvement in fuel economy gets larger from 2000 onwards, following the rise in energy prices and fuel economy standards. The gain in fuel economy (Figure 3) can also be explained by (a) a change in the vehicle test cycle, (b) stringent air quality standards, and (c) engine capacity, which influences CO₂ emissions [30]. The absence of fuel economy standards prior to 2013, coupled with the low prices of gasoline and diesel, meant worse air quality in large cities.

In short, fuel economy gains have reduced the consumption of fuel as a result of higher energy prices during the period 2005–2020. Energy prices (using the price index for real prices) show a three-fold increase in gasoline prices from 2000–2020 (all types of gasoline are considered in the index) (Figure 3). Monitoring changes in fuel economy gains can help to understand the trend of future fuel consumption (Figure 4). The increase in gasoline

price is negatively associated with lower gasoline consumption (Figures 3 and 4), but prices are insufficient to control that consumption.

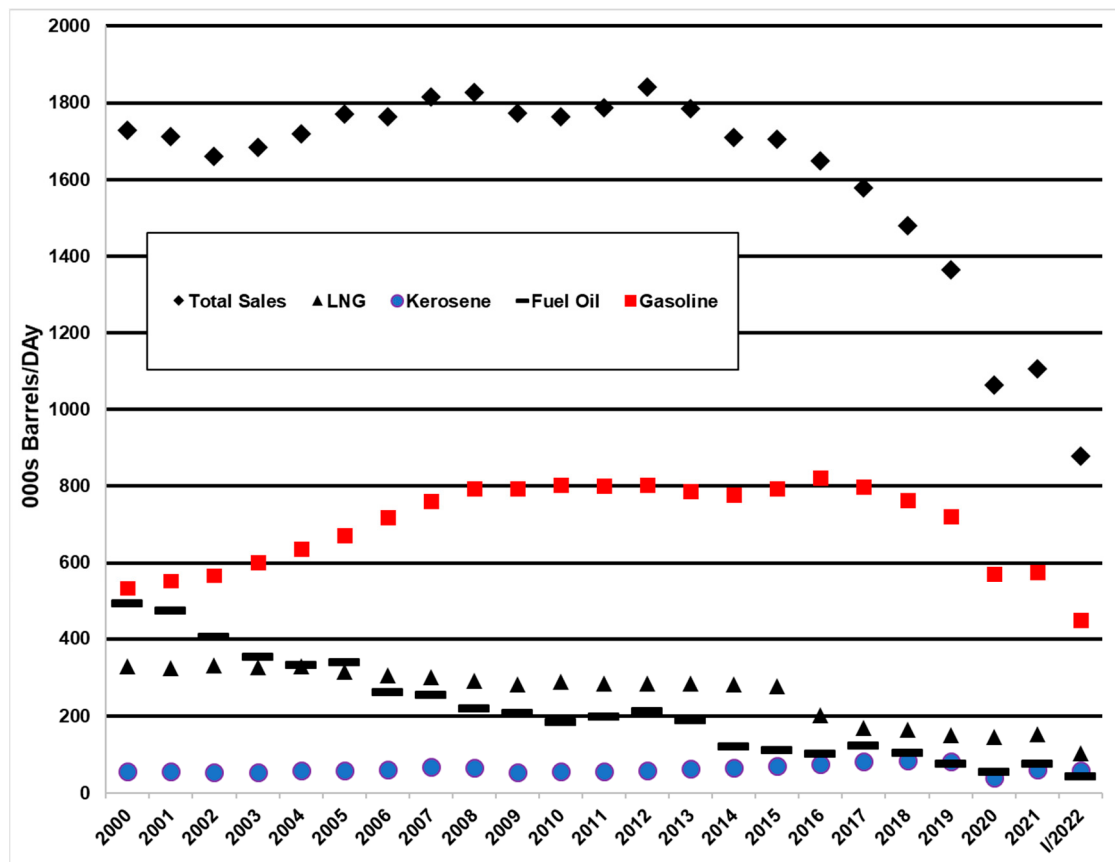


Figure 4. Petroleum product sales volume in '000 barrels per day, 1999–2017. Source: elaborated by the authors using [12].

4.2. Consumption of Petroleum Products

Figure 4 shows the demand for energy by type of petroleum product: the fuel use of transport (private, public, and freight transport modes, gasoline and diesel) represented >47% of total petroleum product consumption in Mexico in 1999–22, above the amount of energy needed by the industrial sector that uses LNG (liquified natural gas) fuel oil, solar energy, petroleum products, bagasse, coal, coke, petroleum coke, coal coke, dry gas, and electric energy (not shown in Figure 4; data from [12]). By 2021, transport energy consumption accounts for 73% of total petroleum products [12] despite efforts to increase the fuel economy of new cars. In terms of final energy consumption, which includes sectors such as residential, commercial, industry, and agriculture, transport energy use now accounts for almost half [12]. In short, transport energy use continues to grow in relation to the sales of vehicles, even though the latter are more efficient. The above, coupled with changes in consumer preferences for acquiring less efficient cars, will be analysed later (Section 4.4). The effect of COVID-19 on transport fuels was key in explaining the level of fuel consumption, since the pandemic restricted the distance travelled of vehicles, and as a result gasoline use dropped. In 2020 one can detect a large drop in gasoline use (Figure 4), although in that year Mexico did not adopt a widespread lockdown as other countries did. If Mexico had adopted a total lockdown it is likely the fall in gasoline use would have been even larger.

Figure 5 shows Mexico's fuel consumption by car type in L per gasoline equivalent of new cars. This metric includes both diesel and gasoline use in L/Km driven. The data for Figure 5 differ from those in Figure 3, as the data reflect the level of fuel economy of

the new car market, excluding that of diesel vehicles. Consumption per km has clearly fallen in all vehicle classes; however, the city car shows the largest gains in fuel economy in comparison to the other car types. The declining trends in fuel economy are less steep for the non-city car classes (SUVs that work as both personal and business use, large cars, and others). Fuel economy levels (new cars) decline from 9.1 to 7.6 (L gasoline equivalent/Km or Lge/100 Km) by 2019 and SUVs from 14 to 10.7 (Lge/100 km). City cars registered gains from 7.6 in 2005 to 6.5 (Lge/100 Km) in 2019. In sum, SUVs are registering gains in fuel economy but have yet to catch up with the fuel economy level of city cars.

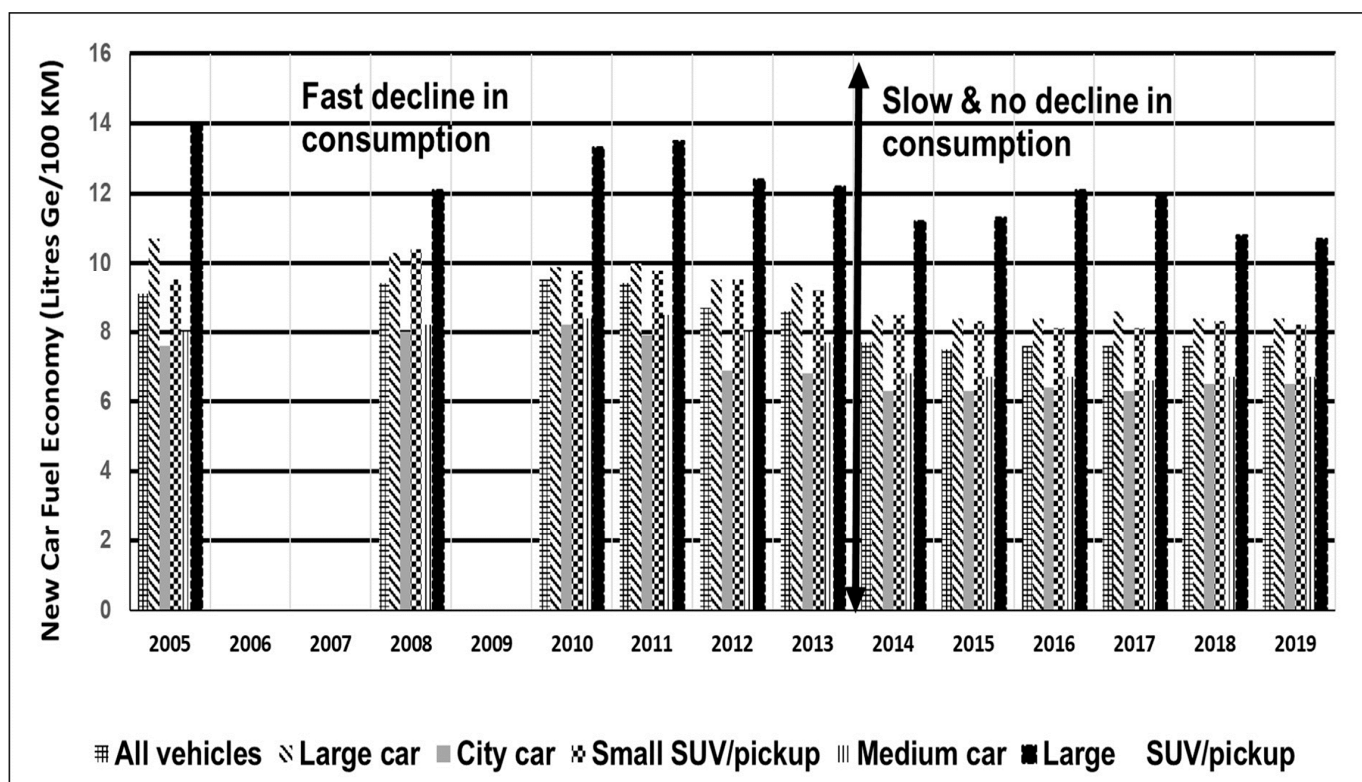


Figure 5. Fuel consumption for new cars (Lge/100 km) by type of car: Mexico. Source: [48].

4.3. Standard: Energy Efficiency of Engines

The objective of the standards (NOM-163, Table 3) is to increase the energy efficiency of motor vehicles, which entered into force in 2013 and were expected to increase the average efficiency “weighted by sales” to 14.9 km/L (6.71/L 100 Km) for 2016. The truth is that, in 2016, the average efficiency of cars that use gasoline reached 17.4 km/L (or 5.74 L/100 Km), superseding the target of the fuel economy standards.

On the one hand, we can observe that the global average fuel economy (on-road fuel economy) is well above the desired fuel economy. On the other hand, the positive results achieved from 2011 to 2020 are undeniable: the fuel economy of new vehicles increased, although this may be the result of a cyclical trend evolving to a permanent one of investment in technology in the automotive industry rather than the effect of the standard (NOM-163, Table 3).

In 2010, before approving the CO₂ standard (NOM-163), the CMM [50] published its proposal for the goal to be achieved in 2016: average values of 5 and 3.84 L/100 km by 2020. The same study argued that, by 2020, Mexico could decrease 30% of their greenhouse gas emissions. The contention of the CMM [50] is that Mexico ought to catch up with the top performers as far as fuel economy.

Table 3. Description of emission standards. Source: elaborated by the authors based on Camara de Diputados [6,51].

Type of Emission Under Control	Description	Producer and Owner Responsibility	Standard (NOM: National Norm or “Standard”)
S & Pb	Petroleum product quality specifications	Producer and fuel trader or broker	NOM-016-CRE-2016
O HC CO Factor λ	Maximum permissible limits for the emission of polluting gases from the exhaust of cars in circulation that use gasoline and that do not exceed 3857kg.	Any owner of an on-road vehicle.	NOM-041-SEMARNAT-2015
CO ₂ HCNM NOx Part HCev	Maximum allowable emission limits for total or non- methane hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter from the exhaust of new motor vehicles whose gross vehicle weight does not exceed 3857 kg that use gasoline, liquefied petroleum gas, natural gas and diesel.	Vehicle makers and importers of cars.	NOM-042-SEMARNAT-2003
HC HCN M CO NOx, PM	Maximum permissible emission limits for total hydrocarbons, non-methane hydrocarbons, carbon monoxide, nitrogen oxides, particles and smoke opacity from the exhaust of new engines that use diesel with a gross weight greater than 3857 Kg.	Car makers, car importers & assemblers of cars	NOM-044-SEMARNAT-2006
O ₃ HC CO CO ₂ NOx, N ₂	It establishes the characteristics of the equipment and the measurement procedure for the emission limits of pollutants from motor vehicles on the road that use gasoline, liquefied petroleum gas, natural gas or others.	MOT centers for vehicle testing (“Verificación vehiculo”) in Spanish)	NOM-047-SEMARNAT-2014
HC CO	Maximum permissible levels of hydro-carbon emissions, carbon monoxide and smoke, from the exhaust of motorcycles in circulation that use gasoline	Motorcycle owner on the road	NOM-048-SEMARNAT-1993
HC CO CO ₂	It establishes the characteristics of the equipment and the measurement procedure, for the verification of the emission levels of polluting gases, from motorcycles in circulation.	MOT center or “Centro de Verificación”	NOM-049-SEMARNAT-1993
HC CO O ₃	Allowable emissions of polluting gases from the exhaust of vehicles on the road that use liquefied gas, natural gas at maximum levels or other fuel.	Car owner who uses fuel other than gasoline or diesel.	NOM-050-SEMARNAT-1993
CO ₂	Carbon dioxide emissions from exhaust and its equivalence in terms of fuel efficiency, applicable to new motor vehicles with a gross vehicle weight of up to 3857 Kg.	Vehicle makers and vehicle dealerships who sell new light duty cars without exceeding a weight of 3857 Kg.	NOM-163-SEMARNAT-2013
HC CO O ₂ opacity NO PM	It establishes the permissible limits of polluting emissions, the test methods for the evaluation and specification of information technologies and holograms.	Vehicle owners, test centers & authorities.	NOM-167-SEMARNAT-2017

CO₂: Carbon dioxide; HC: hydrocarbons, CO: carbon monoxide; NOx: nitrogen oxides; O₃: ozone; PM: fine particles. Pb: lead; N₂: nitrogen. S: sulphur.

4.4. Fuel Economy of New Cars (Gasoline and Diesel)

Figure 6 shows the progress achieved following the adoption of CO₂ standards (equivalent to a downward trend in litres consumed of energy for every 100 km travelled).

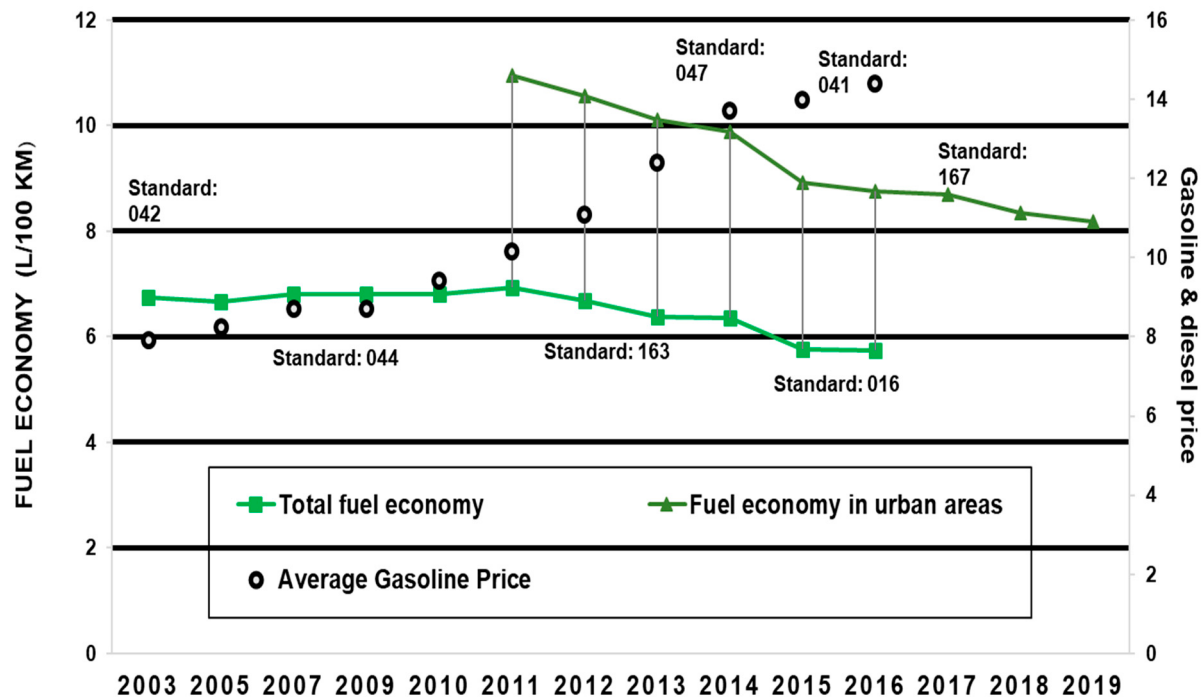


Figure 6. New car fuel economy (passenger only; L/100 Km) and energy prices (gasoline and diesel) (2009–2016). Source: the authors, based on [52–54].

Figure 6 shows the timing of both fuel economy standards and of non-CO₂ standards that aim to improve the air quality derived from the use of motor vehicles. The CO₂ standard (NOM-163, Table 3) follows the changes in energy prices and regulations approved in the last 20 years. The other standards aim to control non-CO₂ emissions. See also Table 3 for a description of each non-CO₂ emission standard.

Figures 7 and 8 show the development of fuel economy gains for new car fleets under city driving and combined modes. Since 2013 there has been an improvement in fuel economy gains (fewer L/100 Km) (Figures 5 and 6); however, the gains in fuel economy also stem from the trend in technology improvements which occur every year.

Figures 9–11 show the box plot of levels of new car fuel economy by car brand: the most common values are shown by the median metric by a line inside the box. These figures show fuel economy levels as a function of vehicle brands. In 2010 the most common fuel economy values range from 6 to 12 (L/100 Km), whilst in 2022 (Figures 9 and 10) the fuel economy levels of new cars supersede the 2010 level (Figures 11 and 12). The most frequent value of fuel economy in 2022 is 5 to 7.4 (L/100 Km, Figure 10), a notable gain from the 2010 level. The shape of the distributions has changed to bimodal: it shows more larger vehicles dominate fuel economy, but these have become more fuel-efficient at the same time (Figures 10 and 12). The data sample of fuel economy is based on more than 2000 vehicle brands for each of the years (2010, 2022; Figures 9–12), and clearly there have been important gains in the fuel economy of both small and large cars that were sold.

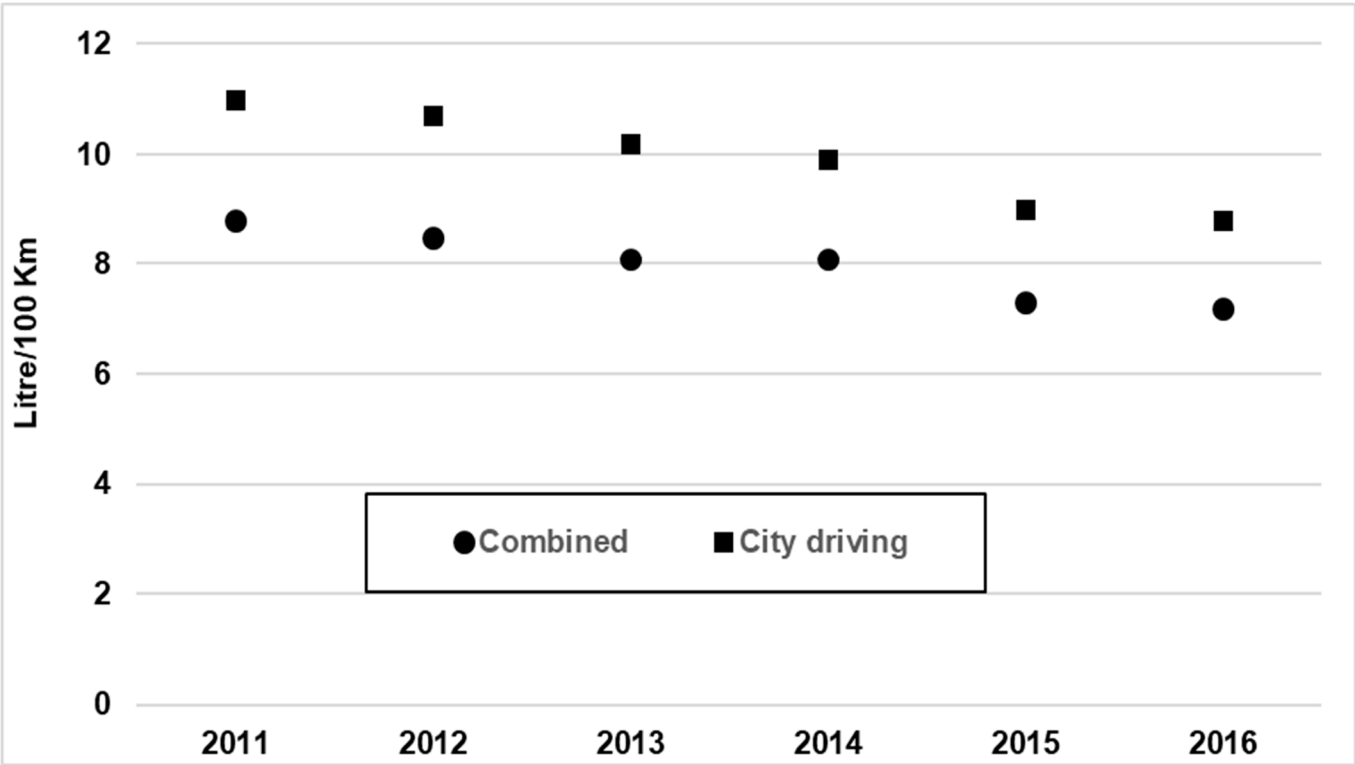


Figure 7. Fuel economy: gasoline fuel. Source: the authors, using data from [53].

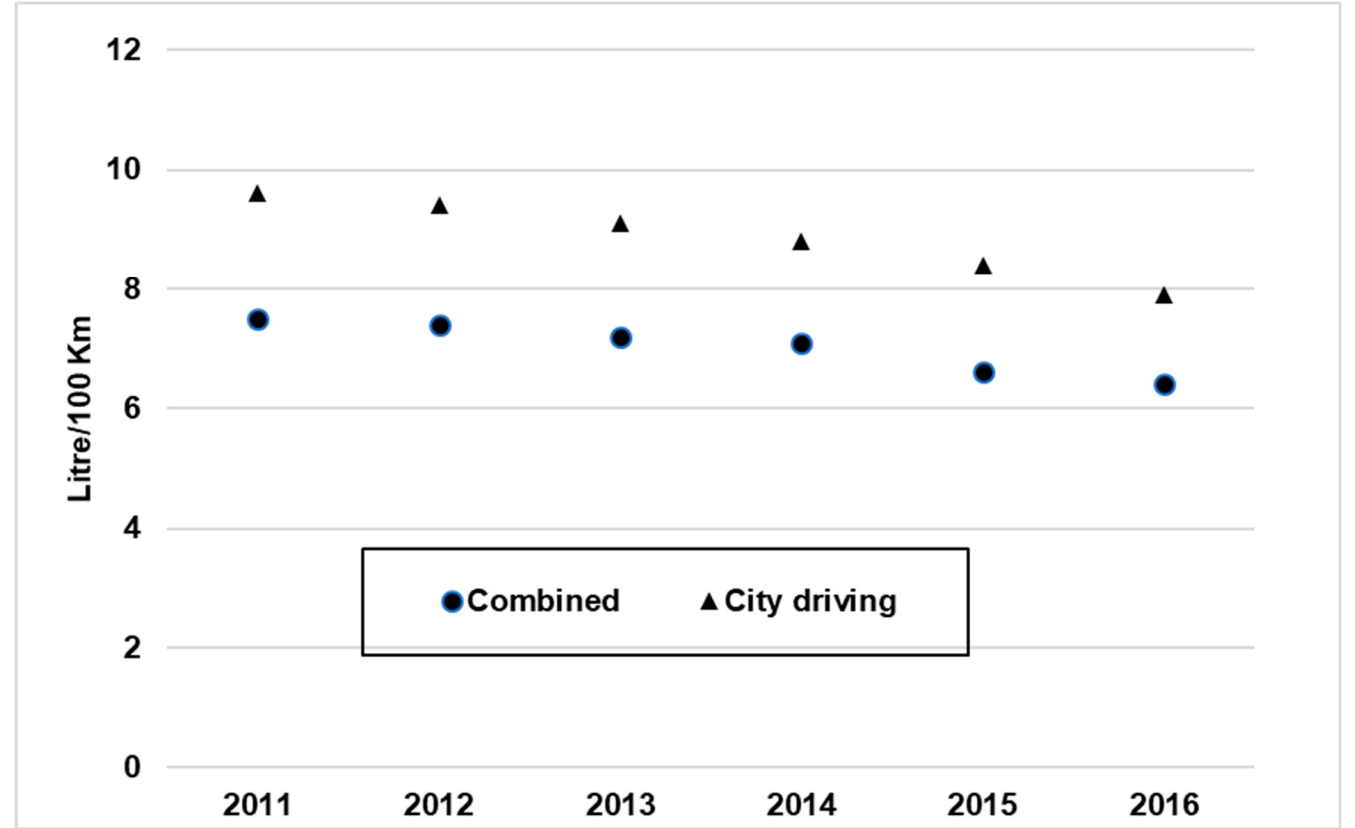


Figure 8. Fuel economy: diesel fuel. Source: elaborated by the authors using data from [53].

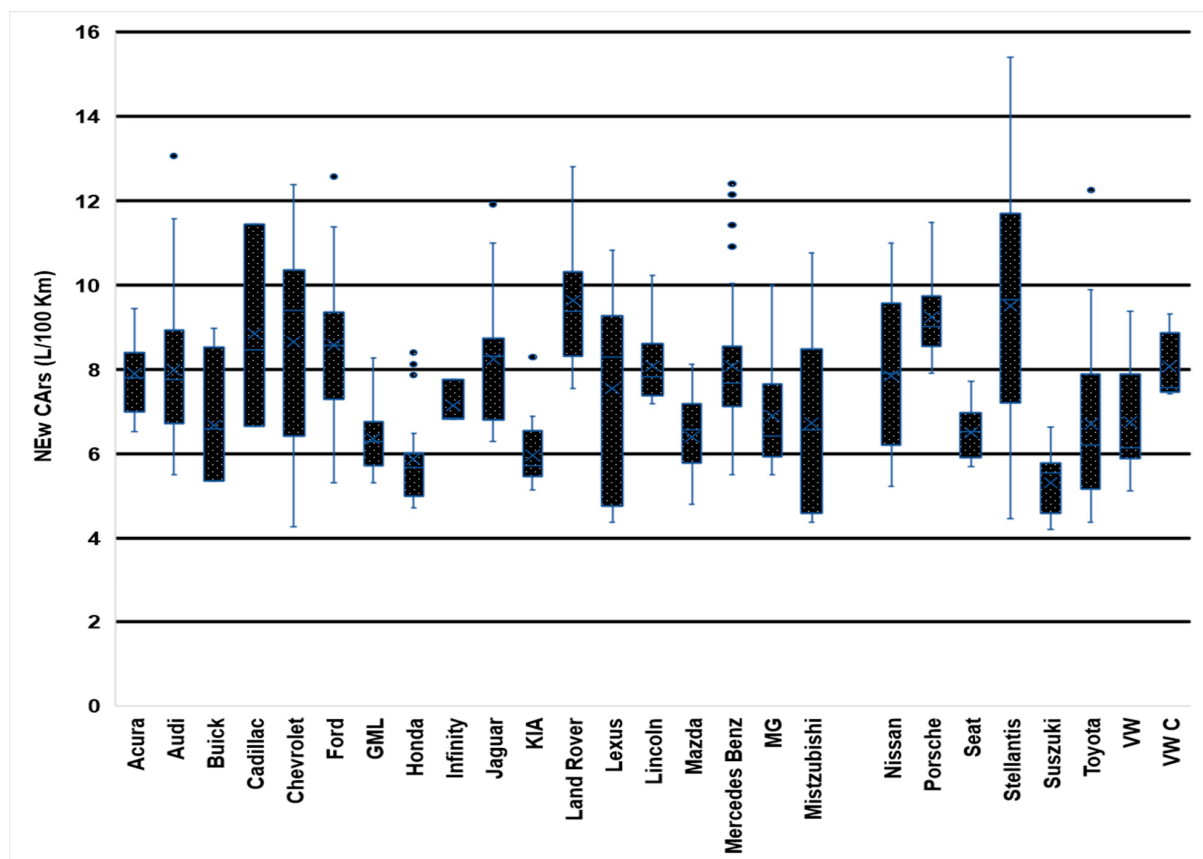


Figure 9. New car fuel economy (L/100 Km) 2022. Data for >700 vehicle types. Source: [54].

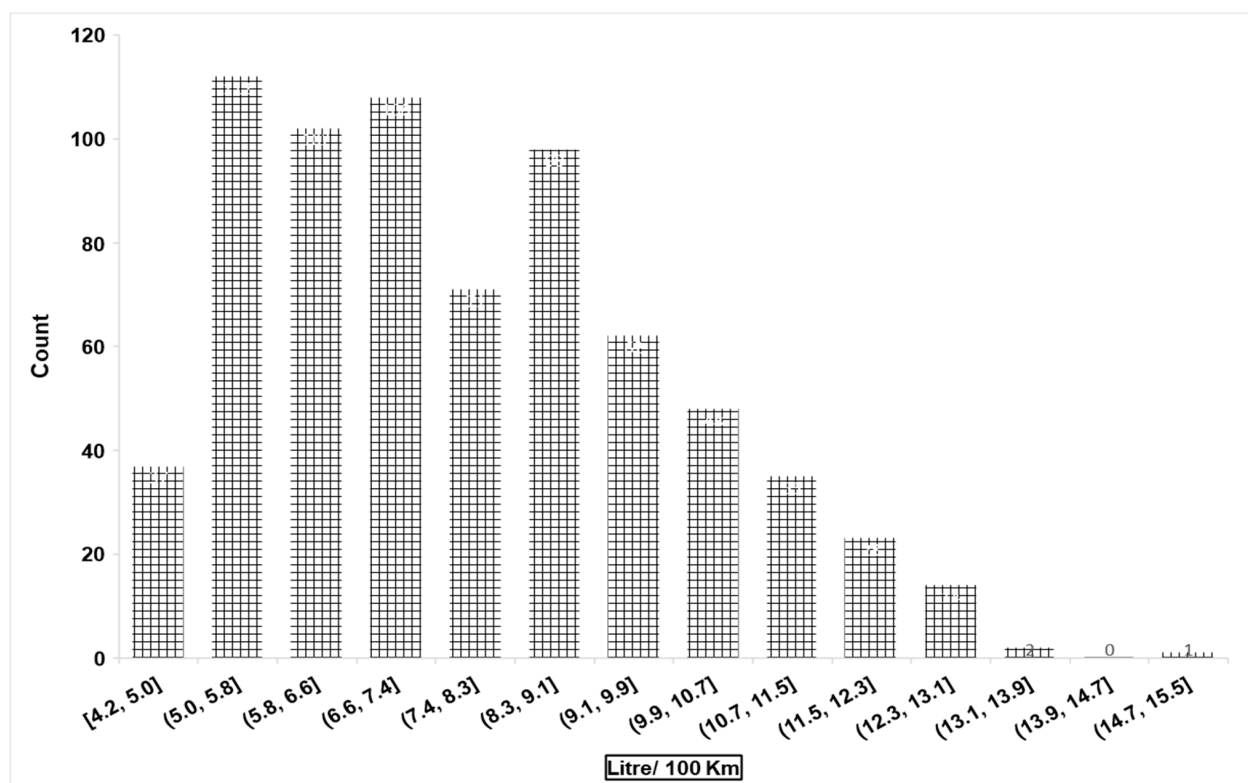


Figure 10. Frequency: fuel economy (L/100 Km) of new cars in 2022. Source: [54].

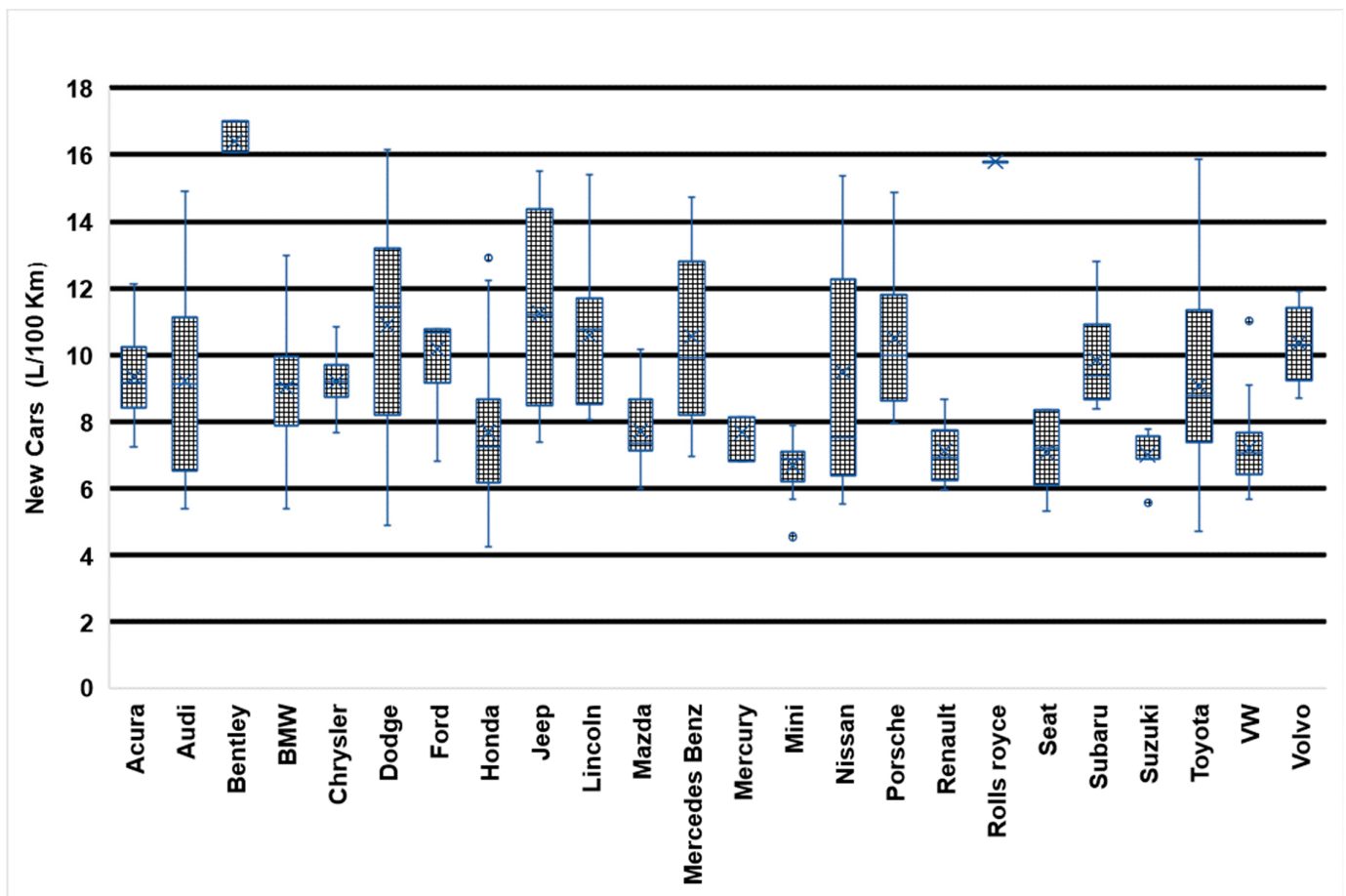


Figure 11. Box plots of new car fuel economy by vehicle brand in 2010. Source [54].

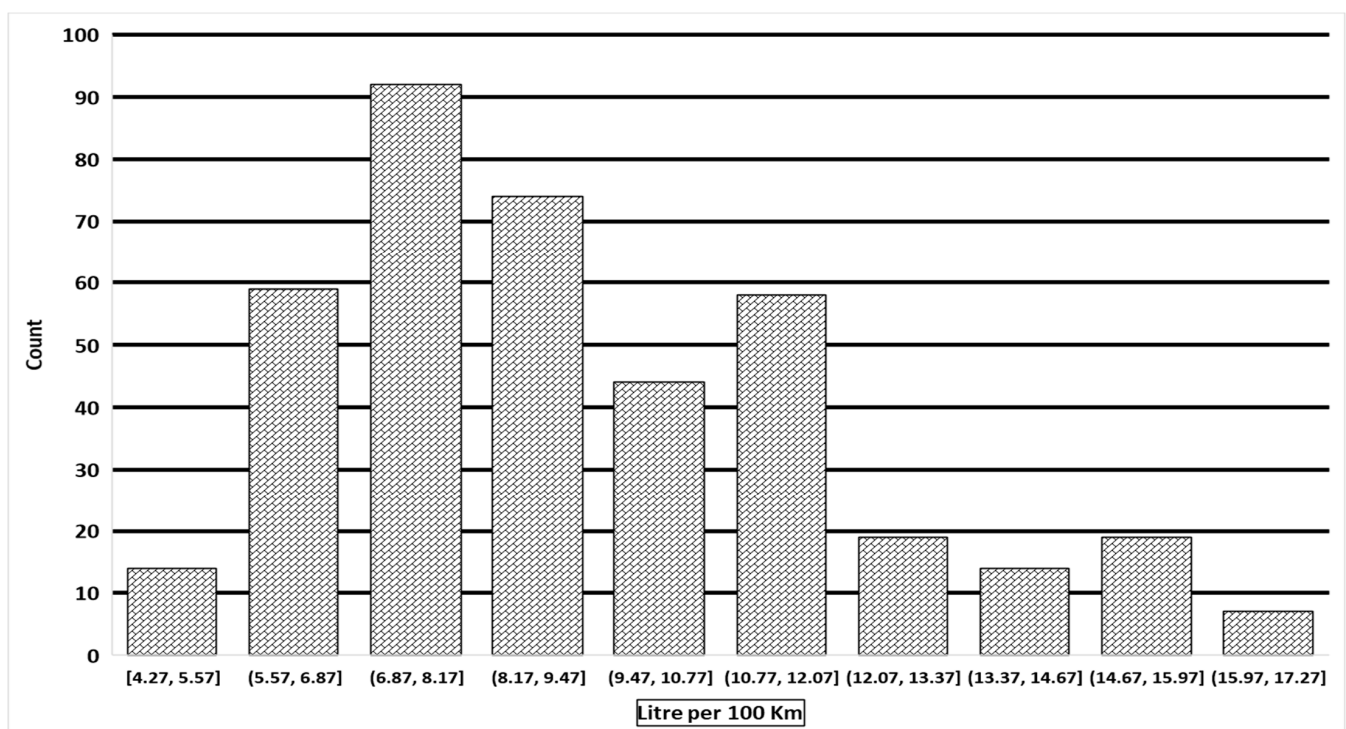


Figure 12. Frequency of new car fuel economy (L/100 Km) in 2010. Source: [54].

Although data by vehicle brand differ somewhat from year to year, the gain in fuel economy is clear (Figures 8 and 10). Fuel economy (Figures 9 and 11) show the frequency of values for fuel economy for 2010 and 2022: clearly, the fuel economy has been improved somewhat since 2010.

The fuel economy of new cars can be converted to g-CO₂/Km (Figure 13): changes in g-CO₂/Km (see also Section 2 for a full discussion on vehicle sales) can be attributed to shifts in consumer preferences, because small cars (subcompact and compact) are designed with smaller engines compared to larger car engines (SUVs and trucks).

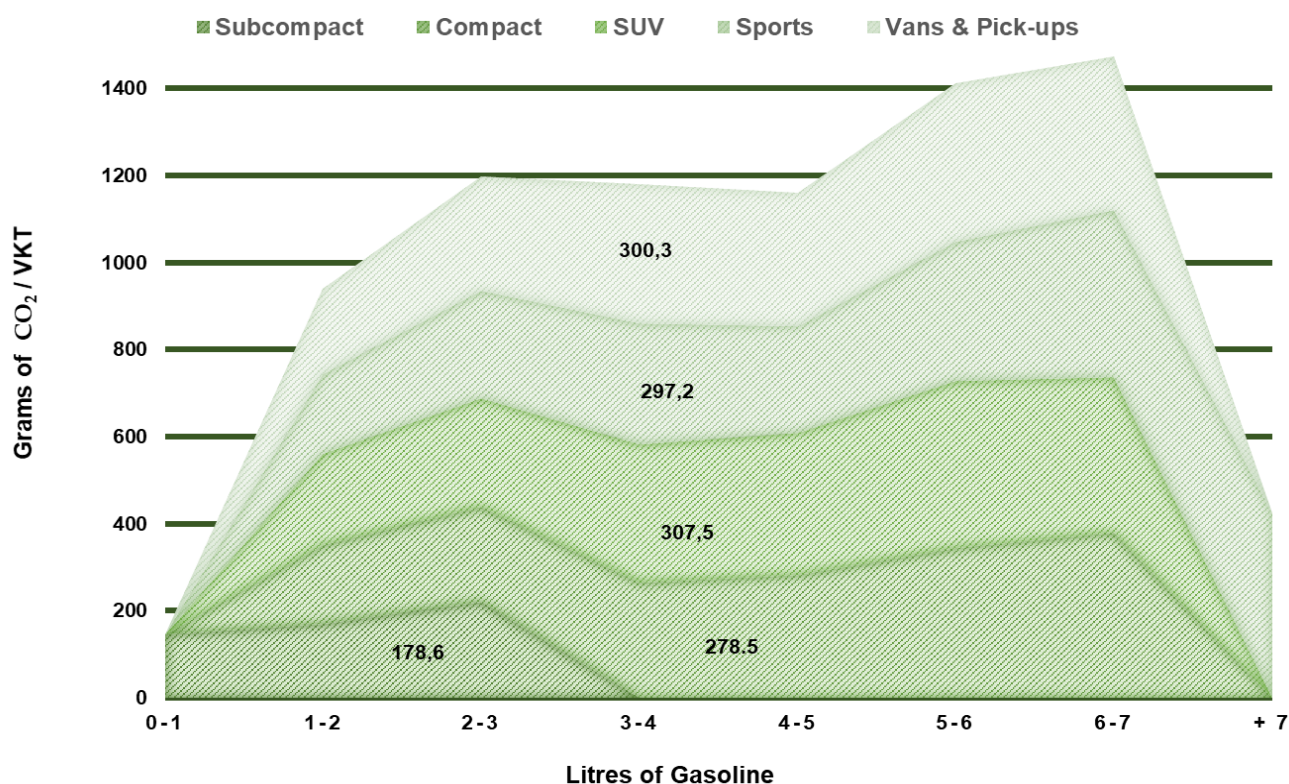


Figure 13. Source: [8].

Changing consumer preferences have increased the amount of CO₂ emissions generated per VKT travelled: Figure 13 shows the average emissions (Y axis) generated by type of car: a large car emits 300 g-CO₂/km, compared to a small car that emits 178.6 g-CO₂/km. It is noteworthy that SUVs are the vehicles with the highest emissions (307.46 g-CO₂/km), and these vehicles are also the ones with the highest sales growth rates (see Section 2.2). The same graph (X axis) depicts the cumulative distribution of emissions versus the consumption of gasoline.

As we explain below, not all drivers are required to test for emissions. The standard (NOM-041, Table 3) exempts new cars from mandatory tests on exhaust emissions for up to a period of two years “after their acquisition, and in accordance with the provisions issued by the federal authorities and/or competent premises [6]. These authorities will be able to extend the exemption benefit according to the incentive measures of vehicles with new emission control technologies” [51].

The exemption from undergoing a MOT test applies to all new cars, less than two years old, regardless of the type of car, the size of the engine, or the amount of emissions they generate, creating a perverse incentive for the consumer to acquire a new car in order to avoid the MOT. The MOT charge is low by international standards, and it is not financially prohibitive. By applying the exemptions, the rule aims to encourage the renewal of the

vehicle fleet, thus improving the adoption of vehicle technology; however, the new car will still generate emissions.

If the vehicle fleet was sufficiently new, it would be possible to reformulate the exemption to vehicles with high environmental performance or energy efficiency. As suggested by the CMM (the think tank “Centro Mario Molina”) study, the proposal to update the vehicle driving ban law states that “the vehicle will be allowed to go on the road daily and does not require vehicle tests for the first two years and will be exempt from any restriction on the road. The driving ban exemption will be awarded to the cars with the best environmental performance” [55] (p. 3). It is important to emphasize that the best vehicle technology is linked to the renewal of the vehicle fleet; however, the fuel economy of the vehicle should be considered in the first instance [55].

The exemptions (of the MOT) should only apply under the standard (NOM-041) as long as there is a justified emissions saving. On the one hand, the fact that the cars have been bought two years before does not imply that they generate fewer emissions, it only means that they are less dirty due to the fact that they are new. On the other hand, if the cars have a smaller engine, it means that they generate less CO₂ emissions, or contain engine technology designed to save energy (see Figure 8). Drawing on data [56] we can say that, as engine size increases, so does the g-CO₂ per km driven.

By car category, it is observed that fuel economy decreases (Figure 14) as the size (engine size) of the car changes: subcompact cars have a gasoline performance of 5.58 (L/100 Km), while SUV trucks have an average performance of 9.34 (L/100 Km). The size of the motor bears an inverse relationship with fuel economy: the latter is greater in all categories that were made with motors from 1 to 3 L compared to larger motors with capacities from 5 to 7 L. It is noteworthy that trucks and pickups are larger than SUVs; however, the latter have the “worst” average fuel economy 9.34 (more L/100 Km) of the categories considered (Figure 14). One reason for this is that the passenger load factor is lower for the latter than the former.

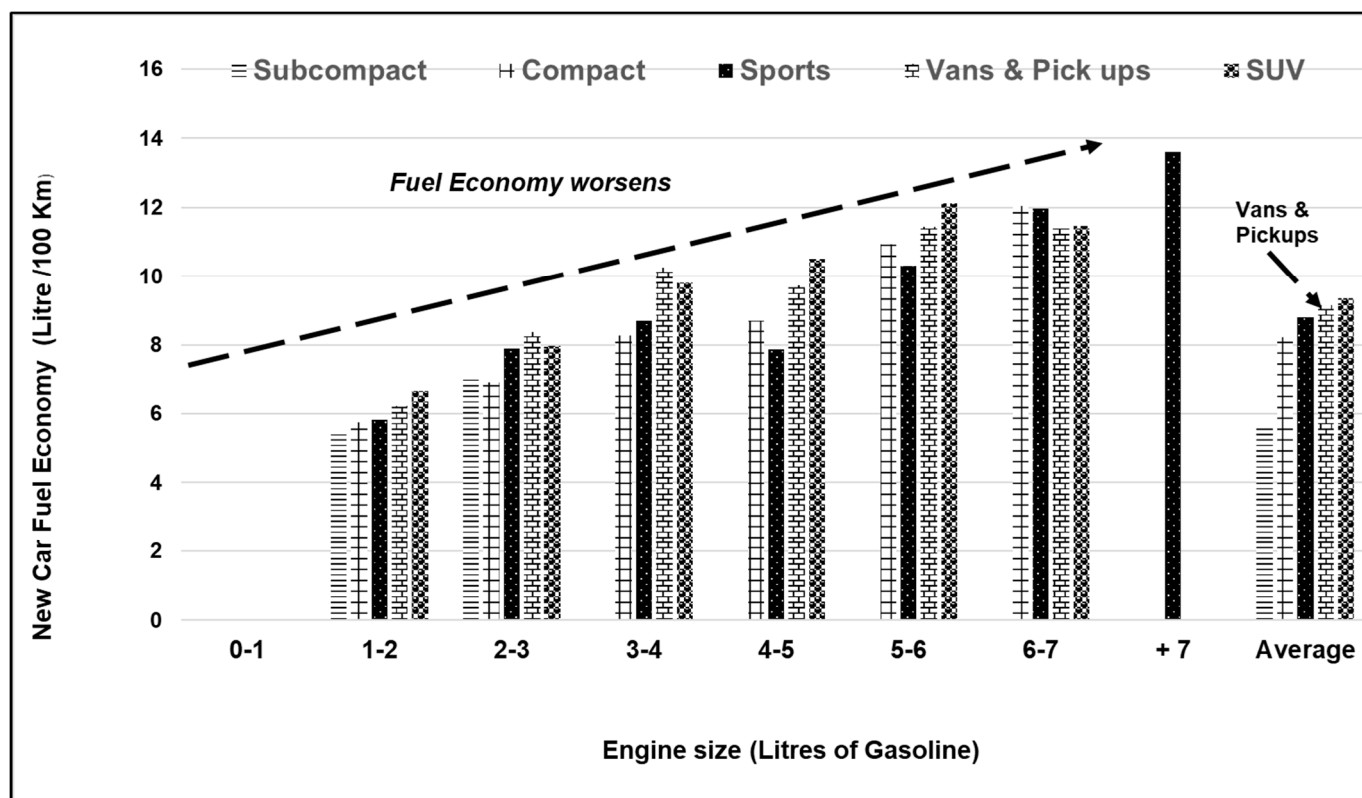


Figure 14. Fuel economy by engine capacity (litres). Source: the authors, based on data from [52].

4.5. Air Quality Standards and Fuel Economy: Recent Changes

Unlike fuel economy, which was first regulated in 2013, emission controls were introduced in 1993. Table 3 tabulates the ten standards for non-CO₂ emission of vehicles. The non-CO₂ emissions generated by motor transport in Mexico began to be controlled under ten standards (labelled “NOMs” in Spanish), affecting emissions in four ways (points A–D). These emission standards are described in the [6].

- A. Emission standards apply to the producers and importers of motor vehicles; under these standards, maximum permissible limits are set for the emission of polluting gases from the exhaust of new cars following the national standards with codes (the standards are labelled in Spanish: NOM-044, NOM-042, and NOM-163). The latter standard refers to fuel economy of new vehicles.
- B. Fuel quality. These standards apply to both the nationally produced and imported fuels that are distributed in the country. The controls aim to improve the quality of the gasoline and diesel formula that is distributed to limit emissions generated by sulphur and lead by motor vehicles (in Spanish: NOM-005 and NOM-016).
- C. Regulatory bodies. The standards that must be met by the testing and regulatory entities, called “verificentros” (in Spanish) or MOT test centres assess the permissible limits of emissions from motor vehicles on the road (NOM-047 and NOM-049, in Spanish).
- D. Owner responsibility. As far as the rules for the vehicle owner, the latter is obliged to keep the car in optimal condition, which implies keeping the emissions of a car under the maximum limits allowed by the standard (standards are labelled in Spanish: NOM-041, NOM-048, and NOM-050).

4.6. Determining the Success of Emission Standards

One way to determine the success of the emissions standards is by examining the governance system of a country regarding its automakers and authorities. The International Council on Clean Transportation [56], carried out a comparative analysis of the practices used in countries for strengthening vehicle markets. The list of criteria in [57] (Table 4) to be evaluated are as follows:

1. Clear establishment of legal authority is needed to make car makers accountable;
2. Avoid conflicts of interest between the car maker and testing agency;
3. Obtain the necessary resources;
4. Review and check responsible behaviour at all levels of use and production;
5. Use fiscal penalties to avoid malpractice;
6. Prioritize data and improve transparency information;
7. Create a roadmap for the program that includes futures regulations and technology changes.

In the case of Mexico, of the seven categories handled by the ICCT, Mexico does not show the necessary criteria (++) to properly enforce the practices in any category. For the first two categories, the “establishment of authority” criterion and the “avoiding conflicts of interest”, the assessment deems those two categories as incomplete. As for the rest of the categories, Mexico lacks the necessary elements for the proper fulfilment of the regulatory practices of its car markets. The country shows the lowest performance as far as the overall assessment (it achieves only 2 points), a level far below from its neighbours (U.S. or California), with a 12-point assessment (last column of Table 5). In sum, the failure to qualify for these categories will affect how far the country is able to meet the emissions standards by the action of its car manufacturers and car buyers. The country needs to strengthen its governance systems.

Table 4. Assessment of best practices to meet and strengthen the vehicle market. Source: [56].

Country	of Legal Authority Clear Establishment	of Interests Avoid Conflict	Acquiring Resources	and Consumption Behaviours: Production Revision of Responsible	Use of Corrective Actions	of Information and Transparency Top Priority for Data	Develop a Program Road Map to	Total
Mexico	+	+	0	0	0	0	0	2
China	++	+	+	++	+	0	+	8
India	+	+	+	+	0	0	+	5
Japan	++	++	+	++	++	0	+	10
South Korea	++	++	++	++	++	+	+	12
EU	0	+	+	0	+	0	+	4
France	+	0	+	+	+	0	+	5
Germany	+	0	+	+	+	0	+	5
UK	+	0	+	+	+	+	+	6
California	++	++	++	++	++	+	+	12
Canada	+	++	+	++	0	0	+	7
U.S.	++	++	++	++	++	+	+	12
Brazil	++	+	+	0	+	0	0	5
Chile	+	+	+	+	0	+	+	6

Notes: 0: the country does not sufficiently meet the criteria for this practice; + the country meets some criteria for this practice; ++ the country meets all criteria for this practice.

In a timely manner, the effectiveness of the air quality controls depends on (1) the standard of fuel quality (NOM-016 fuels), (2) the energy efficiency (fuel economy) standard (NOM-163) on motor vehicles, and (3) whether motor vehicles will be tested on the road following the emissions standard (NOM-041).

4.7. Quality of the Fuels Used by the Vehicle

The same study [56] finds that the reduction of sulphur levels is the key to cutting emissions from motor transport. In addition, the high levels of sulphur in oil products prevent the adoption of clean technologies for the control of emissions such as carbon monoxide (CO), particulates (PM), nitrogen oxides (NOx), and hydrocarbons (HC) [57]. In Mexico in 2016 a standard (NOM-016-CRE, Table 3) was established to regulate the levels of sulphur allowed in national territory and thus to improve the quality of fuels used in automobiles.

The ICCT [56] classifies Mexico as a country that (a) has adopted and (b) has implemented clean regulations with low sulphur standards in gasoline and diesel (10–15 ppm), (c) as well as having adopted world-class emission standards for energy efficiency and CO₂ emissions (95 g CO₂/km for passenger vehicles). However, these improvements in standards are not yet reflected in air quality. In Table 5, a comparison is made of the G20 countries: these countries represent 91% of the total sales of new automobiles in the world. Mexico's standards lag behind those currently in force in G20 countries, and for this reason the ICCT proposes that Mexico adopts world-class vehicle emissions standards compatible with those of the OECD as much as possible [56].

Table 5. Emission standards (tail pipe emissions) of vehicles and standards of sulphur (SO_x) emissions of fuels, G20. Source [56].

Region	Emission Standards		Sulphur Standards of Fuels	
	Softer Standard	Stringent Standard	Gasoline	Diesel
Mexico	Tier/Euro 4	US 2004/Euro IV	80 (30)	500 (15)
China	China 4	China IV	10 [2017]	10 [2017]
EU	Euro 6	Euro VI	10	10
US	Tier 3 [2017]	US [2010]	10	15
Japan	PNLTES	PNLTES [2016]	10	10
Brazil	L-6	P-7	50	500 (10)
Germany	Euro 6	Euro VI	10	10
India	Bharat III	Bharat III	150 (50)	350 (50)
U.K.	Euro 6	Euro VI	10	10
Russia	Euro 5 [2016]	Euro V [2016]	10	10
France	Euro 6	Euro VI	10	10
Canada	Tier 2	US 2010	30	15
South Korea	Euro 6	Euro VI	10	10
Italy	Euro 6	Euro VI	10	10
Indonesia	Euro 2	Euro II	500	3500 (avg) (500)
Australia	Euro 6 [2018]	Euro V/US07/JE05	50	10
Saudi Arabia	Euro 2	Euro II		500
Turkey	Euro 5	Euro VI	10	10
South Africa	Euro 2	Euro II	500 (50)	500 (50)
Argentina	Euro 5	Euro V	150	30 (10)

Notes: euro equivalency for standards. The values outside the brackets are the maximum values. Values inside the brackets are the minimum emission limits. Without standards ; Euro 2/II ; Euro 3/III ; Euro 4/IV ; Euro 5/V ; Euro 6/VI ; Post Euro 6/VI .

5. Discussion

In this section we discuss the practical implications, including policy choices, of the research findings discussed above (Sections 2–4). We can pinpoint seven areas that need additional policy measures to control emissions and gasoline use.

Our findings are the following:

- Modest gains of new car fuel economy (passenger cars only) have been registered, but the overall gains largely depend on the type of car sold. On-road fuel economy gains (fuel savings per km driven) have been achieved because of vehicle stock renewals of recent years. New vehicles are more efficient than older vehicles.
- On-road fuel economy is determined by today's vehicle sales, vehicle type, and past sales, as well as by the vehicle fleet, while new car fuel economy is determined by today's vehicle sales. This difference is critical and needs to be made transparent.
- SUV sales are capturing a larger market share, which will affect the path of fuel economy over time and push up gasoline use. To understand the future path of gasoline use and CO₂ emissions, benchmarking the fuel economy of new cars will be key. Consumers are switching from smaller, more efficient vehicles to larger, less efficient, and heavier vehicles.
- Non-CO₂ standards are effective in some periods and less so in other periods in controlling emissions. This is because of the incentive to own two cars following the driving ban.
- There is a need to improve governance of standards for fuel economy and best practice of these adopted by the car industry; Mexico seems to lag behind progress that has been made in other G20 countries.

- Broad changes in new car fuel economy and car size reveal some gains, but also increases in fuel economy by car brand in recent years; manufacturers have responded to the wider requirements of the market and policymakers.
- The CO₂ emissions profile and vehicle class show that changes in consumer preferences have influenced the profile of CO₂ emissions: increasing incomes have resulted in a greater preference for larger vehicles, and this has implications for the environmental gains and, over the longer period, for the second-hand vehicle market.

The following eight policies can be adopted to reduce gasoline use and vehicle emissions of CO₂ and of non-CO₂. These measures also tackle the problems identified in Sections 2–4.

1. Apply economic instruments to restrict VKT (i.e., car tax ownership, fuel taxes, congestion charge in heavily used roads, parking charges). The revenues collected from these policy measures could be recycled to expand public transport, walking, and cycling facilities. Distance-based charging would influence the type of vehicle that is used, while the instruments can (a) control the unchecked growth of vehicle stock and (b) shift the car profile from CO₂-intensive vehicle sales in favour of smaller cars with low CO₂ and zero CO₂ emissions.
2. Encourage fuel switching of transport energy towards low-CO₂ energy sources i.e., electric vehicles, hydrogen, CNG, solar, and other energy sources. Mexico currently has a plan for electrification of privately owned vehicles, but the plan holds overambitious targets for vehicle sales [3].
3. Tighten the MOT test and widen the test to include all vehicles, including freight transport, buses, and coaches. This measure is costly for the economy.
4. Tax vehicle sales by vehicle size and adopt a CO₂ escalator programme; but the tax design should consider social equity issues to avoid harming vulnerable groups.
5. Improve consumer awareness regarding the fuel and CO₂ savings of smaller vehicles.
6. Accelerate investment in mass public transport that is safe and reliable.
7. Restrict the rate of urbanisation around the city.
8. Shorten commuting distance, i.e., travel to work or to school, and work-from-home practices.

The last five policy measures in the list relate more to the planning features of any strategy.

6. Conclusions

The transport sector needs to be decarbonized now and in the next decades to support efforts to achieve the energy transition, and the potential for gains of fuel economy of new cars are key to success; the on-road fuel economy metric has recorded smaller gains than the fuel economy of new cars, which has improved strongly in the last 15 years. This paper has examined the effectiveness of fuel economy standards on gasoline consumption from the perspective of the car market in Mexico through the analysis of trends of (1) more than 2000 vehicle brands over a number of years, and (2) fuel economy of various vehicle sizes. The chosen period gives sufficient evidence to assess the early impacts of standards and yet is recent enough to determine the effectiveness of standards in controlling fuel consumption and emissions.

From the empirical analysis, it is found that, although there have been fuel economy gains every year, this is countered by (a) increasing sales of SUVs, and (b) a car market that is increasingly being dominated by larger cars. The current fuel standards are not sufficient to control the future growth in total gasoline consumption, and levels of carbon emissions will continue to increase. The use of transport fuels now exceeds that of the industrial sector, even though economic expansion has slowed down the growth of total gasoline consumption in recent years. In conclusion, tighter emissions standards are needed, together with stronger governance structures and a range of further policy measures to improve car efficiencies and limit growth of the use of larger vehicles.

The hypothesis has been confirmed by our analysis: fuel economy standards have restrained the growth in gasoline use despite substantial changes in the car market and other factors. The standards were first introduced in 2013, and while these have been an effective tool, three risk factors that may weaken the effect of the standards on cutting gasoline use have been identified. First, the stock of vehicles continues to increase at a rate that supersedes the annual growth of per capita incomes; second, the distance travelled per vehicle also continues to grow; and third, vehicle size and weight continue to grow requiring more fuel per VKT. The combined effect of a larger vehicle stock, longer distances travelled, and larger vehicles will push up the gasoline consumption and CO₂ emissions of Mexico's private transport sectors. New car fuel economy has improved, but the gains can be explained by a combination of two factors: the adoption of the fuel economy standard in 2013 and the rise in gasoline prices under the period of analysis.

By car category we have observed that fuel economy worsens (more litres/100 km) as the size of the vehicle grows; thus, we find that the size of the engine has an inverse relationship with fuel economy.

A key influence on gasoline use is growing VKT, which can be curbed by various measures listed in Section 5. Reducing VKT (private vehicles) can cut CO₂ and non-CO₂ emissions in Mexico, particularly in its cities.

Gasoline use also contributes to the volume of non-CO₂ emissions; these can be controlled by the testing technology which can be continuously upgraded, and the testing programme can be tightened to reduce NO_x and PM emissions. The non-CO₂ emissions standards also need to be extended to cover all vehicle types and all sources of fuels.

Gasoline use is also controlled indirectly by the air quality program (based on standards) and by the driving ban (HNC), which have not been enough to reduce non-CO₂ emissions. However, the latter ban has managed to significantly contain the growth of these emissions in some years, but not in all. The increase in the vehicle fleet, the purchase of inefficient and larger cars, and exemptions of MOT or emissions control tests of new cars and motorcycles are some of the reasons identified. The failure of Mexico's regulatory system to fulfil the criteria of governance will affect how far the country is able to meet the emissions standards by the actions of both its car manufacturers and of car buyers. The governance of emissions standards needs to be strengthened in order to successfully cut actual emissions of new cars. One limitation of our study is the lack of more detailed data on non-CO₂ emissions by car type and on distance-travelled profiles for individual cities of Mexico and Latin America. Future studies should study emissions using information on distances travelled as a function of vehicle age, type, weight, and car price. Our work can set out a plan to build econometric analysis of vehicles sales, fuel economy, and consumer preferences to build projections for the next decades, but this requires longer-term datasets than are currently available. Mexico offers valuable lessons for other emerging economies which register high growth rates of car sales.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Data sources:

Table A1. Emissions and car sales.

Variable	Unit	Database	Source
Ozone Emission	% difference	[7]	SEMARNAT, SMAGEM, SEMARNAT and CaMe (2021) [7]
Nitrogen oxides	% difference	As above	As above
Carbon-Monoxide	% difference	As above	As above
Nitrogen dioxides	% difference	As above	As above
Sulphur-dioxide	% difference	As above	As above
Particulate matter (<10)	% difference	As above	As above
Particulate matter (<2.5)	% difference	As above	As above
Particulate matter (total)	% difference	As above	As above
Air pollution standards	Codes	Emission standards	Cámara de Diputados (2022) [51] and the Diario Oficial (2015) [6]
Emission standards (tail pipe emissions) of vehicles: G20 economies	Codes	Emission standards	ICCT (2017) [56]
SUVs	% of total vehicle sales	Source: Amia [11]	Source: Amia (2022) [11]
Subcompact	% of total vehicle sales	As above	As above
Pickup	% of total vehicle sales	As above	As above
Luxury	% of total vehicle sales	As above	As above
Minivans	% of total vehicle sales	As above	As above
Sports	% of total vehicle sales	As above	As above
Gasoline price	Index of gasoline price 2018 = 100	SENER (2022) [12]	SENER (2022) [12]

Appendix B

Table A2. Petroleum products.

Variable	Unit	Database
On-road fuel economy	Litres per 100 km	SCCT (2019) [13] and SENER (2022) [12]
Vehicle kilometres	VKT	(INECC) [17]
Gasoline sales	barrels per day	Petroleum products
Diesel sales	barrels per day	As above
Kerosene sales	barrels per day	As above
Fuel oil sales	barrels per day	As above
Total sales	barrels per day	As above

Table A2. Cont.

Variable	Unit	Database
Large car consumption	Fuel use (Lge/100 km)	IEA (2022) [48]. https://www.iea.org/articles/fuel-economy-in-mexico (accessed on 14 January 2023)
City car consumption	Fuel use (Lge/100 km)	As above
Small SUV/pickup consumption	Fuel use (Lge/100 km)	As above
Medium car consumption	Fuel use (Lge/100 km)	As above
Large car use	Fuel use (Lge/100 km)	As above
SUV/pickup use	Fuel use (Lge/100 km)	As above
Total fuel economy	Litre/100 km	The authors, based on: INECC [17]
Fuel economy in urban areas	Litre/100 km	The authors, based on: [52], INECC [17]

Table A3. Data sources: fuel economy for new cars and on road cars.

Variable	Unit	Database
Combined Fuel economy	Litre/100 km	The authors, using data from Plataforma Nacional de Transparencia, 2022 [53]
City driving: fuel economy	Litre/100 km	As above
City driving fuel economy	Litre/100 km	As above
Combined fuel economy	Litre/100 km	As above
New car fuel economy	Litre/100 km of new car in 2022	Conuee (2022) [54]
Frequency of fuel economy levels	Litre/100 km of new car in 2022	As above
Box plots of new car fuel economy	Count per vehicle brand in 2010	As above
Frequency of new car fuel economy	(L/100 km) in 2010	As above
Grams of CO ₂ per Vkm	Litres of gasoline by type of car	INECC (2022) [8]
Fuel economy engine capacity	Litre/100 km by type of car	The authors, based on data from Plataforma Nacional de Transparencia (2022) [53]

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