CENTRO DE INVESTIGACIÓN Y DOCENCIA ECONÓMICAS, A.C.

Analysis of public policies for the development of the electric car market in Mexico

By
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1 Introduction

To reduce greenhouse gas emissions and prevent climate changes is imperative to decarbonize several sectors of the economy, transport included. In Mexico almost 25.1% of the Greenhouse Gas (GHG) emissions come from this sector. According to INEGI (2017), the Mexican automotive industry is the second most important activity within manufacturing, only behind food industry. It impacts 157 economic activities out of a total of 259 and was the only manufacturing industry with a positive trade balance in 2014. Yet transport sector is almost entirely powered by internal combustion engines (ICEs) burning fossil fuels with only a few using biofuels and even electric engines.

Electric vehicles (EV) are considered as one of the solutions to reduce GHG emissions and local pollution due to its greater energy efficiency with respect to internal combustion engines (ICE) vehicles. This greater efficiency has initiated a transition towards EVs, mainly in developed countries, but Mexico as emerging economy also has targeted it. One of the Mexico´s government stated goals is "the massive electrification of transport, both the transport of people and freight, both public and private (...)." (Diario Oficial de la Federación, 2020). So, there would be a huge substitution from ICEs to EVs. This thesis aims to assess this effect. This work aims to analyze the impacts of such massive electrification in the Mexican economy.

On the other hand, it is well known that Mexico has a large, consolidated ICE vehicle manufacturing sector and it is one of its most important industries. It employs almost one million people across the country and generate near three million light vehicles for exports annually, as shown in figure 1. Hence, it becomes even more relevant to inquire what will be the impact of such massive electrification on the manufacturing sector, the transportation consumers, and the environment.

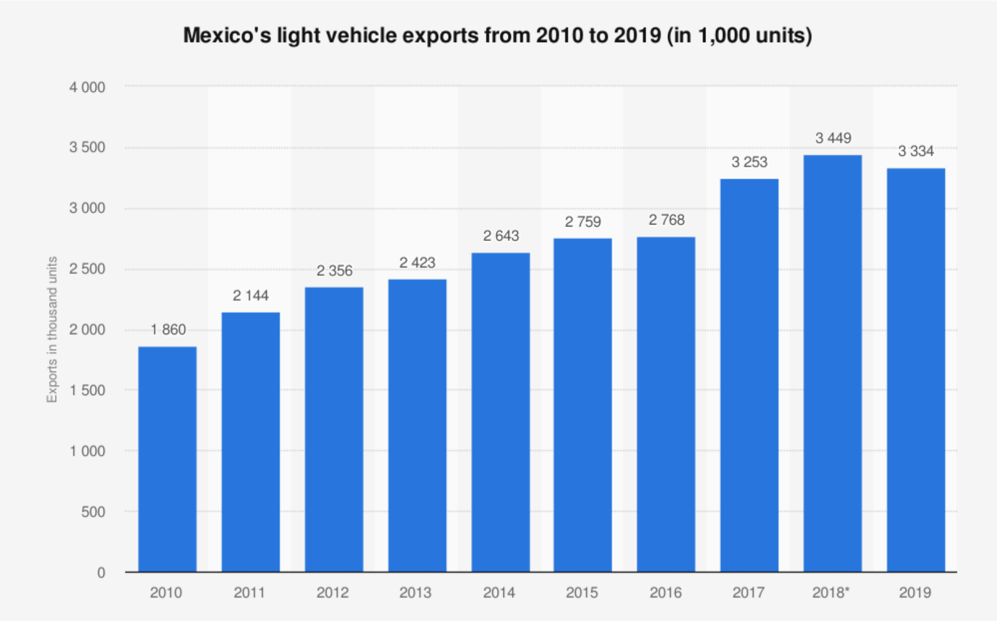

Figure 1: Mexican exports of light vehicles (Statista; INEGI)

Mexico is still developing a National Strategy for Electromobility, (ENME by its acronym in Spanish), which is still to be published. While the ENME itself will not solve much of the questions about the impact of the electrification transition, it may help to reduce the policy uncertainty around the development of a larger EV market. This work also may have an important policy implication by contributing with more information for the developing of his strategy.

Previous studies on the subject in Mexico have focused on the environmental and urban sustainability aspects (e.g.). This thesis aims to fill a gap in the literature on the economic impacts of the massive electrification of light transport (e.g. Su, W., et Al. (2012), Kalghatgi, G. (2018)), by involving several new elements such as focusing on an emerging economy like Mexico, in a context of uncertainty, fossil fuel dependence, a high participation of the automotive industry in the economy, and lack of transparency of some of the projections and data provided by the government.

To achieve these goals, a Computable General Equilibrium (CGE) is used for the analysis. This methodological approach encompasses all the different sectors of the economy and can be applied in general to other emerging economies. This work could serve to guide studies in other countries with similar conditions and will also provide more evidence of the potential impact of the policies taken to develop the electric car market in Mexico.

The rest of the thesis is organized as follows; section 2 provides a brief review of the literature for the electrification of the transport sector. Then, section 3 displays the computable general equilibrium (CGE) model proposed to evaluate the impact of policies and an overview of how it works; this is the economic behavior of each of the economic agents is described, as well as the equilibrium conditions. The next section reports the information used to calibrate the model, including the social accounting matrix (SAM) and the parameters for the initial balance. Section 5 presents the projection of the SAM matrix, the model validation, and the proposed scenarios for the simulation. Section 6 reports the results of the model and discusses them. Section 7 section concludes and discusses some policy implications. The final sections show the conclusions and future work.

2 Electrification of the transport sector

2.1 The Mexican context

While EVs demand is predicted to account for 64-86% of new light-vehicles sold by 2030 in the United States (Becker et al. 2009), demand for EVs has not yet taken off in Mexico due to the lack of infrastructure (for instance, charging infrastructure and electrification of public transport), the poor environmental awareness, and the still high costs of the EVs (according to Gass et al. (2014) the high prices of EVs are one of the biggest barriers for adoption). Mexico needs to move fast in these issues by incentivizing the domestic demand for EV through different channels such as tax credits and a good infrastructure. A weak federal policy to support EV consumption threats the domestic production (Gómez 2016, Briseño et al. 2020, Cirett Galán et al. 2014).

In Mexico, a comprehensive public policy to support the electrification of transport could benefit both the demand for EVs and the manufacturing industry. Among the public policies to encourage the use of EV, those suggested in most studies include purchase incentives (as the high prices are one of the biggest barriers for adoption, Gass et al. (2014)), investment in charging infrastructure and electrify public transport, as well as other fiscal incentives and taxes on fossil fuels, Gómez (2016). It is important to note that economic theory favors the use of taxes to deal with negative externalities and correctly applied should favor the technology with the lowest total cost (private and social cost). Other policy options are increasingly stringent standards on emissions like the ZEV Mandate applied in California by 1990, which required that a certain percentage of all new cars sold in California were "zero emissions" and provide credits to manufacturers selling such vehicles.

From the supply side, it is worth to note that Mexico is one of the ten largest car producers in the world, however, like Brazil, Thailand or India, countries also in this top, it is not a developed economy (PwC 2014). The reasons why a country can develop a strong automotive industry vary from case to case. China, India, and Brazil have large captive markets and relatively cheap labor while Mexico, in addition to having cheap labor, is integrated into a larger market through free trade agreements with the US and Canada. Mexico exports almost 69% of the domestic production of light vehicles to the United States. So, a fall in the US demand could impact severely automotive industry and all its workers in Mexico. Yet Mexico is still on time to develop a cleaner and more sustainable transport industry through EVs. The industry has the know-how already and needs to invest soon to adapt the current and huge manufacturing infrastructure to produce more EVs and less ICEs.

Although the economic and environmental analysis on various mobility choices comprises a vast literature in Mexico, research trends have been oriented towards renewable fuels like green hydrogen and bioethanol (e.g., Ramírez-Salgado and Estrada-Martínez 2004, Nuñez 2018). The analysis for electric vehicles in Mexico has been limited to the environmental issue or economic impact in Mexico City. Only two studies show some of the effects at a national level. Briseño, H et al. (2020) use an econometric analysis to show that GDP per capita, the cost of electricity, the price of gasoline, and sustainable practices have a positive correlation with EVs sales in México. From a prospective point of view, Villarreal (2018) performs an analysis of the demand for alternative vehicles by 2040 using a Robust Decision Analysis model focusing on light electric vehicles. In general studies about the possible evolution of demand or the economic impact in the whole country (e.g., Briseño, H. (2020)) lack clear methods and data, especially those published by the government (e.g., SENER. (2021)).

2.2 Electrification of the transport sector

As pointed out above, this thesis aims to assess the impact of the substitution of conventional cars by EVs, both in the automotive industries and in the consumer side, on other industries, the economy, and the environment. That is why it is important to note the differences that exist between EVs and ICE vehicles. One of the most used strategies to compare GHG emissions between two different types of technologies is to consider the life cycle of the options. In other words, it is needed to compare both options since it is produced until when discarded to establish which has a lower impact. According to Hawkins et al. (2013) a conservative estimate for the decrease in GHG emissions obtained by EVs is of 10% compared to ICE vehicles. However, the reduction could be greater depending on the sources of electricity generation. An increase in the use of renewable energy could improve the environmental impact of EVs. Although increasing the share of clean energy in the energy portfolio will largely depend on the government's stance, EVs can also help reduce local pollution.

The literature oriented to the electrification of transport for other regions is extensive and growing and can serve guidance for new research in emerging economies (e.g., W. Su, et al, (2012), Pereirinha, P. et al (2018)). Literature focused on the technical aspects of EVs, such as battery technology or the impact on the charging network, is rapidly growing (e.g., Hamut, H. S. (2017), J. A. P. Lopes et al. (2011)). This area of research allows updating the impact of the future uptake of EVs in the market. Most studies focus on the environmental and economic impact of the uptake of electric vehicles, and they are concentrated on the analysis for few developed countries such as the United States, Norway, Germany, among others (e.g., Needell, et al. (2016)). The literature about adoption in emerging economies has been led for the cases of China and India (EIA 2020) (e.g., Wu, Y., et al (2012), Wang, S., et al. (2017)).

2.3 Methods for Assessing Future EV Adoption and its impacts.

The literature aimed at evaluating the future uptake of electric vehicles in the market is rich in methods and highly dependent on context. Jochem et al. (2018) carry out an in-depth literature review on the methods for forecasting the market penetration of EV in the passenger car market where it classifies the different studies according to the modeling approach.

Top-down approach: Macro-perspective, uses aggregated methods, based in diffusion.		
Examples	Econometrics with aggregated data	General equilibrium
Data	Aggregated sales	Aggregated economic data
Method	Statistics with aggregated sales	Optimization
Bottom-up approach: Micro perspective, uses disaggregated methods, based in adoption		
Examples	Econometrics with disaggregated data	Agent based modelling
Data	Product and customer data	Costumer data
Method	Statistics with disaggregated data	Simulation

Table 1: Types of methodology according to Jochem et al. (2018)

From the literature review, it can be synthesized that the different approaches shown in table 1 are responses to the available data, objectives, and the economic perspective. Bottom-up approaches may focus on a micro perspective using methods like agent-based simulation and econometric model using disaggregated data and can be useful to determine characteristics that influence adoption. Top-down methods take a macroeconomic stance using methods that allows studying institutional responses like taxes or subsidies. Since this work seeks to provide evidence of the impact of public policies oriented to the production of EVs, a top-down approach is preferred.

Still, the bottom-up approach can offer good results. Cui et al. (2010) use a multi-agent-based simulation for modeling the spatial distribution of EV ownership at the household level and forecast areas based on consumer's attributes, the cost and performance of the vehicle, gasoline, and other energy costs, and the government policies. The authors find that EV ownership may quickly increase in the near future, and residential neighborhoods could need upgrades in the energy distribution infrastructure. Plötz et al. (2014) use consumer-choice modeling focusing on early adopters of EVs in Germany. Their findings show that transport policy promoting EVs should focus on middle-aged men with families from rural and suburban cities as first private EV buyers. In general, these papers (Cui et al. (2010), Plötz et al. (2014), Wang, et al (2017) and Briseño et al. (2020)) are good examples of the bottom-up approach, they use techniques that analyze the diffusion of EVs from a microeconomic point of view and provide individual attributes of early adopters.

As stated above, top-down approaches are a better option to evaluate institutional sanctions or public policies. Gómez-Vilchez et al. (2020) use system dynamics to show that the uptake of EV may depend on the joint effect of policies in other key car markets, meaning that optimal policy design should consider other policies already applied to key markets. In the case of México, this approach may be useful to design its industrial and economic strategies considering the importance of the demand from the US market.

We will be using a computable general equilibrium (CGE) model because of their capability for long-term forecast, their strong theoretical bases, and their wide use for modeling the impacts of public policy changes (Dixon and Parmenter 1996). Applied literature involving econometrics and CGE modeling to forecast the economic impact of EV includes Schmelzer and Miess (2015) that assess the economic costs necessary to reach an EV target in Austria. Here authors use a discrete choice (DC) model of the consumer purchase decision between conventional, hybrid, plug-in hybrid and EV that is then implemented into a CGE model. The authors find that GHG emissions can be substantially reduced by the increase of electromobility with low costs up to 2030. This is achieved because the emissions generated during the life cycle of EVs are lower than those of ICEs, since the energy used by EVs in Austria comes from a portfolio of energies that has a lower impact per mile traveled than that obtained by fuel combustion.

Schäfer and Jacoby (2006) also use a CGE model to assess the impact of GHG emissions constraints on the develop of markets for automobiles, light personal trucks, and three classes of freight trucks in the United States. Authors first develop a model of energy systems and transport technology, linking the two by means of a model of the evolving split of total transport among different transport modes, under GHG emission constraints they found that the EVs are most likely to take a substantial market share. Khanam et al. (2011) use a CGE static model to evaluate the economic and environmental impact of a full transition to EVs in Toyohashi City, Japan. They find that it could result in an increase in Toyohashi City GDP and a rise in labor demand, this is due to the fact that electric cars have fewer parts, but the greater value add. Khaneman et al. (2011) also found that this increase in GDP can be obtained with less GHG emissions than in the status quo scenario. The reduction in GGG emissions is an expected result due to the greater energy efficiency of the electric cars and

2.3.1 Computable General Equilibrium models

The methodology used with CGE models to analyze the economic effects of alternative trade or environmental policies is the conducting of counterfactual experiments or simulations. The model is asked what would have happened in a year if it had been implemented the interest policy and the rest of the domestic and external conditions would have remained unchanged. This methodology works as a "controlled experiment" in which only some of the exogenous variables of the model are modified keeping everything else constant.

According to Dixon and Parmenter (1996) the characteristics of a CGE model are as follow:

- They are general in the sense that describe the economic behavior of different actors in a general way.
- They describe how demand and supply decisions made by different economic actors determine the prices of at least some commodities and factors, and
- They produce numerical results (i.e., they are computable).

The general methodology of the CGE models is depicted in figure 2.

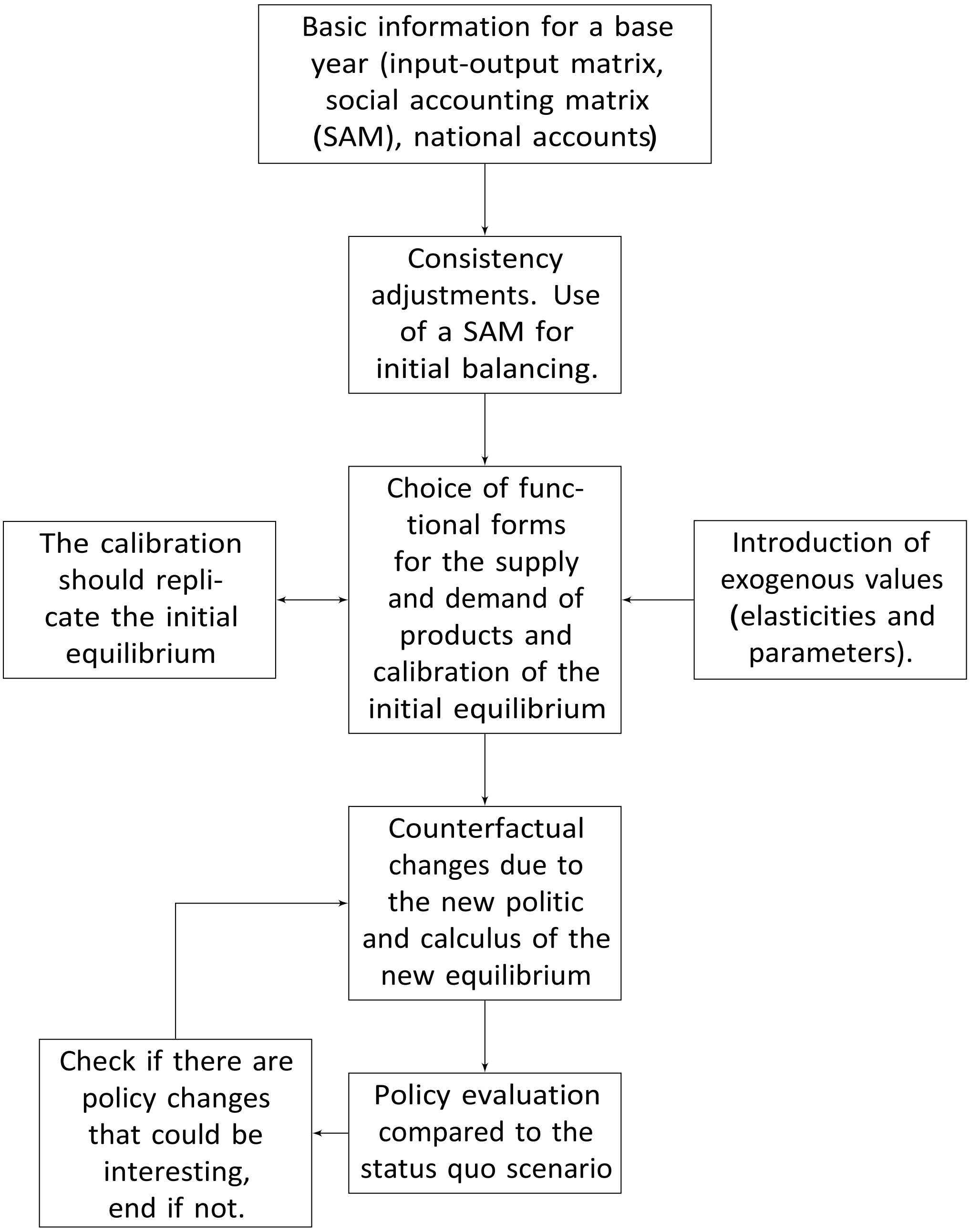

Figure 2: Based on Cicowiez and Di Gresia (2004) general methodology of the CGE model.

As shown in Figure 2, the first stage for a CGE model is to obtain enough information of the base year to assume the equilibrium in the economy to model. This information usually comes in the form of a social accounting matrix. The balanced matrix provides all the information of an economy in equilibrium. Although there are many possible specifications for the supply and demand functional forms, it is a common strategy to use functional forms that take advantage of the information contained in the SAM, like the Cobb-Douglas or Leontief functions. Having chosen the functional forms of supply and demand, their main parameters are then calibrated using the information from the SAM to replicate the initial equilibrium, this allows us to be confident in the results generated by the model. We investigate the counterfactual changes by changing the parameters of the functions or the information of the matrix to obtain new equilibriums, these changes can be related to public policies, like taxes or subsidies or technological changes. The new equilibria generate data that allow to evaluate the proposed changes when comparing the different scenarios.

3 Model

The CGE model structure proposed in this research follows the one by Hosoe (2004). In a mathematical form, a CGE is a system of simultaneous, nonlinear equations, that can be expressed by a matrix made by blocks. The general structure of the static CGE model used in this thesis is as shown in figure 3.

Figure 3 shows, from the bottom up, how the supply is constructed through a Leontief function, which covers the intermediate inputs from other industries and added value. The added value comes from a Cobb-Douglas function that depends on the factors of production: labor and capital. Each sector then, produces a type of good, which together with imports from the rest of the world generate a composite good related to each industry. These goods are consumed by households, the government, the rest of the world, and other industries.

At the top, households maximize their utility through a Cobb-Douglas function.

In the following subsections, I describe the behaviors of the economic agents included in the model. Households, the government, and external sector that represents the rest of the world (ROW) consume a goods produced by industries that at the same time consume intermediate inputs from other industries, as well as capital and labor.

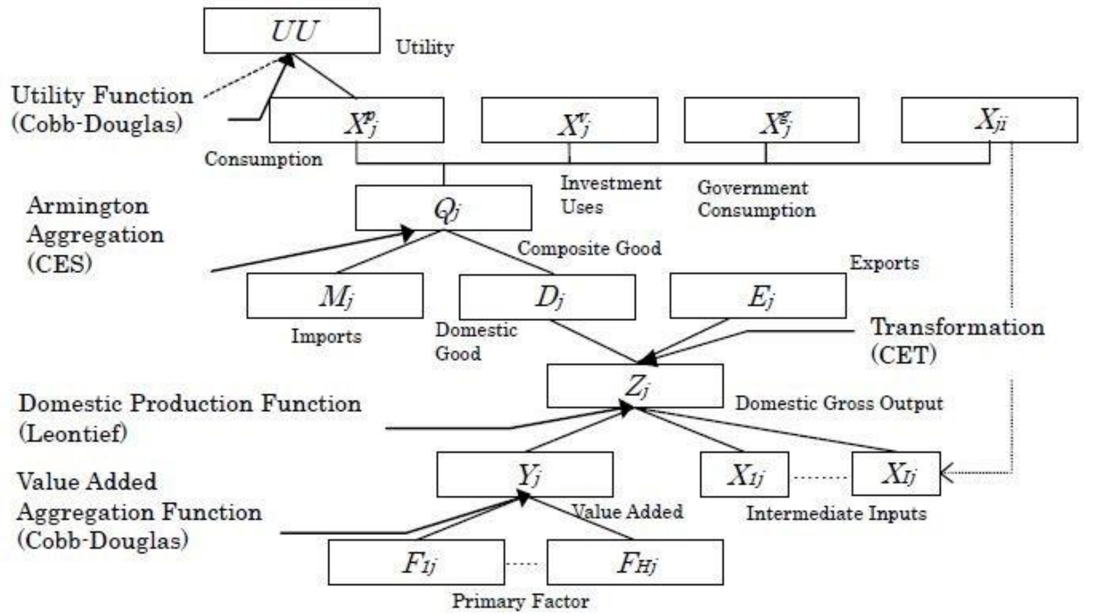

Figure 3: Model structure as proposed by Hosoe (2004)

3.1 Households

Households are assumed to be homogeneous. Therefore, it is possible to consider this sector as a single representative household, but in future works this assumption can be relaxed and delve into the degree of heterogeneity of households, by income level or years of study, for example. This representative household is assumed to choose its consumption bundle that maximizes its utility *U* subject to the income constraint. The income comes from the earnings of its endowments of labor and capital, that are supplied to industries for production. Household utility is assumed to take a Cobb-Douglas functional form. The household utility maximization problem is described by equations (1) and (2).

$$max\ U = \Pi_i X_i^p \quad (1)$$

subject to

$$\sum_i p_i^d + S = \sum_h r_h FF_h \quad (2)$$

Where

i: index for commodities i, with i: 1 to 32.
h: index for factors h, with h: labor and capital.

X_i^p: consumption of the commodity i.

FF_h: amount of endowment of the h-th factor.

p^d_i: demand price of the commodity i.

S: private savings.

r_h: price of the h-th factor.

Solving the maximization problem through a Lagrangian we obtain the demand function for the households in equation (3).

$$X_i^p = \frac{\alpha_i}{p_i^q}\left(\sum_h r_h FF_h - S\right) \qquad \forall i \tag{3}$$

α_i: share parameter in the utility function ($\sum_i a_i = 1$).

3.2 Industries

The industries use intermediate inputs, labor, and capital to produce goods. The industries have Leontief production technology for intermediate inputs and value-added inputs, while value-added inputs come from a Cobb-Douglas technology with inputs of labor and capital. We assume for every firm in an industry to have similar production technology, that is, for each industry we have a representative firm that averages the use of intermediate goods and factors. Industries maximize profits given the demand and price of commodities. In other words, each industry will minimize the sum of costs incurred by intermediate inputs as well as the indirect taxes (tax rate - subsidy rate) and labor costs while maximizing their output. The problem is displayed in equations (4) and (5)

$$max\ \pi = p_j^s Z_j - \left(p_j^y Y_j + \sum_i p_i^q X_{ij}\right) \qquad (\forall j) \tag{4}$$

i

subject to

$$Z_j = min\left[\frac{Yj}{ay_j}, \frac{x_{1j}}{a_{1j}}, \ldots, \frac{x_{nj}}{a_{nj}}\right] \tag{5}$$

where

$$Y_j = b_j \prod_j F_{hj}^{\beta_{hj}} \qquad \forall j$$

π_j: profits in industry j.

Z_j: output of the j-th good.

Y_j : value added of the industry j.

X_{ij} : are the intermediate input of industry i's product in industry j.

F_{hj} : input of h-th factor in industry j.

a_{ij} : coefficient for minimum requirements of the i-th intermediate input for one unit of gross output.

ay_j: coefficient for minimum requirements of value added for one unit of output.

b_j : scaling parameter in production function.

p_j^s is the supply price of j-th good.

$p^q{}_i$ is the price of the i-th intermediate good.

$p^y{}_j$ is the price of the value added of the j-th good.

As equation 5 is not differentiable it is common to replace it with the nonprofit condition. This is justified by the assumption of a competitive market, in which if a firm can make profits, there will be entry of firms to reduce excess profits.

$$pi = p_j^s Z_j - \left(\sum_i p_i^q X_{ij}\right) = 0 \qquad \forall j$$

The values assumed for each parameter is explained in the data section.

3.3 Government

The Mexican government revenue come from taxes to industries and households, and transfers from the external sector (from oil sales, for example). After savings, government expenditure is explained by government consumption X_i^g, transfers to households or industries, and transfers to the external sector. The government behavior is represented in equations (6) and (7).

$$T_j = \tau_j Z_j, \qquad \forall j \tag{6}$$

$$X_i^g = \frac{\mu_i}{p_i^q}\left(\sum_j T_j - S^g - T_h\right) \tag{7}$$

Where:

T_j: is the tax revenue from production of the j-th commodity.

τ_j: is the tax rate on production for the j-th commodity. ($/unit)

X_i^g: is the public consumption of commodity I, share of commodity i is divided by the price of the i-th intermediate good to allow the study of non-composite goods, in our case, the value of the composite good for in each industry is 1.

T_h: are the transfers from the government.

S^g: are the savings of the government.

μ_i: is the share of expenditure for the i-th commodity $(\sum_i \mu_i = 1)$.

3.4 *Investment*

As this CGE is a static model, investment cannot react by periods of time, but capital savings still appear across industries, government, and households. We assume an investment demand function, X_i^v, to model this behavior. This investment demand function uses constant share parameters for the allocation of savings.

$$X_i^v = \frac{\lambda_i}{p_i^q}(S + S^g + S^{ROW}) \qquad \forall i \tag{8}$$

Where:

X_i^v: investment demand for the commodity i.

λ_i: is the share of expenditure for the i-th commodity $(\sum \lambda i = 1)$.

S^{row}: savings of the ROW.

3.5 *Rest of the World (ROW)*

Although Mexico is an important producer of the car market, it makes sense to assume that it cannot influence international prices. Firms within industries compete with each other and international agreements include anti-dumping actions. For the ROW, the balance of payments is shown in equation (9):

$$\sum_i p_i^{ROWe} E_i + S_{row} = \sum_i p^{ROWm} M_i \qquad (9)$$

where

$p^{ROWe}{}_i$: export price of the commodity i (exogenous).

$p^{ROWm}{}_i$: import price of the commodity i.

E_i: amount of exports of the commodity i.

M_i: amount of imports of the commodity i.

3.6 Derivation of Equilibrium

Equilibrium is reached when the supply and demand intersect, this is when market clearing conditions are satisfied. Equilibrium quantities are displayed in equation (10) and (11).

$$Q_i = X_{ip} + X_{ig} + X_{iROW} + \sum_j X_{ij} \qquad (\forall i) \tag{10}$$

$$F_{hj} = FF_{hj} \qquad (\forall h) \tag{11}$$

Where

X_{iROW}: the demand of commodity i of the Rest of the World.

X_{ig}: the demand of commodity i of the government.

Q_i: the total amount of commodity i on the market

Equation (10), equilibrate demands from households, other industries, ROW, and government composite goods with their supply. While equation (11) is the equilibrium of labor and capital factors.

4 Data

4.1 The social account matrix (SAM)

As detailed in the general methodology of the CGE models, it is important to have an instrument that provides us with complete information on the economy that we will be modeling in the base year, for this we use the social accounting matrix (SAM). A SAM is a squared matrix that gives us information on the transfers that the various sectors of the economy make among themselves, about consumer patterns and production structure (Dols 2010).

Social accounting matrices can be traced back to the pioneering papers of Stone (1978) and Pyatt and Round (1979). Subsequently, Pyatt and Round (1985), Pyatt (1988) or Keuning and Ruijter (1988) systemized the structure and the accounting chart of the SAM. The SAMs in Mexico, as in most Latin America countries, are not published regularly, the most recent SAM in Mexico was published by the INEGI in 2013.

The original SAM comes from INEGI and it was modified to disaggregate the branch of electric power generation.[1] For further disaggregation we use the methodology proposed by Núñez Rodríguez (2017) to develop a social accounting matrix with focus

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[1] I thank to Dr. Hancevic from CIDE for providing this manageable version of the SAM (from INEGI) this research.

on the electrical sector and the automotive manufacturing sector, both sectors are expected to be of greatest impact due to this technological change. It is important to note that although we also expect an impact on gasoline consumption, a change in this branch of the social accounting matrix is difficult to achieve, since oil and its derivatives are concentrated in a single cell, so further disaggregation is not possible using the methodology described.

This SAM can also be used for other investigations with scenarios in which the automotive industry and the electrical sector are involved. The industries to be considered are shown in Table 2.

	HOU	FIRM	GOV	ISR	CS	ISP	OIP	SAVE
HOU	0.00	9543.20	586.21	0.00	0.00	0.00	0.00	0.00
FIRM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GOV	0.00	0.00	0.00	1124.13	945.70	653.50	92.45	17.62
ISR	581.71	542.43	0.00	0.00	0.00	0.00	0.00	0.00
CS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISP	645.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OIP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SAVE	2245.23	1562.62	-361.31	0.00	0.00	0.00	0.00	0.00
CAP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AGR	171.41	0.00	0.00	0.00	0.00	0.00	0.00	48.66
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	155.34
GEN	86.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WAT	36.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GAS	4.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BUILD	0.00	0.00	6.19	0.00	0.00	0.00	0.00	1659.72
CARS	309.20	0.00	0.00	0.00	0.00	0.00	0.00	292.58
MANU	2567.11	0.00	2.88	0.00	0.00	0.00	0.00	353.02
COMM	1676.76	0.00	0.00	0.00	0.00	0.00	0.00	357.01
TRANS	1021.52	0.00	0.00	0.00	0.00	0.00	0.00	132.81
SERV	4373.42	0.00	1175.83	0.00	0.00	0.00	0.00	33.42
OTH	4.27	0.00	883.99	0.00	0.00	0.00	0.00	0.00
ROW	610.28	-1.54	539.62	0.00	0.00	0.00	0.00	822.01

Table 2.1. SAM for 2020, values at 2013 prices. Thousands of millions of pesos.

	CAP	LAB	AGR	MIN	GEN	WAT	GAS	BUILD	CARS
HOU	0.00	3858.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FIRM	11646.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GOV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CS	0.00	0.00	0.56	23.04	38.28	2.84	0.00	72.98	25.33
ISP	0.00	0.00	-0.35	-3.86	-3.91	-0.50	0.00	-0.66	-1.09
OIP	0.00	0.00	0.02	0.77	1.21	1.68	0.13	3.72	6.65
SAVE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CAP	0.00	0.00	484.28	795.91	165.34	34.14	2.15	731.61	347.76
LAB	0.00	0.00	99.84	29.95	16.38	14.00	0.00	273.76	64.82
AGR	0.00	0.00	84.53	0.00	0.00	0.00	0.00	0.28	0.00
MIN	0.00	0.00	0.48	1.97	4.66	0.00	0.00	14.70	0.11
GEN	0.00	0.00	8.23	11.23	1.68	18.74	0.02	2.23	14.33
WAT	0.00	0.00	7.96	1.47	0.23	4.60	0.00	3.42	1.25
GAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BUILD	0.00	0.00	0.01	2.96	1.73	1.66	0.07	67.40	0.73
CARS	0.00	0.00	0.71	0.62	0.16	0.17	0.00	4.80	168.79
MANU	0.00	0.00	115.95	45.88	86.08	2.81	0.17	218.10	199.78
COMM	0.00	0.00	52.54	17.20	17.72	1.67	0.15	94.89	215.21
TRANS	0.00	0.00	6.17	5.17	3.93	0.27	0.04	19.41	33.45
SERV	0.00	0.00	8.44	73.05	10.71	3.56	1.25	110.22	86.80
OTH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROW	0.00	0.00	75.43	63.52	67.76	6.16	0.83	154.12	712.23

Table 2.2. SAM for 2020, values at 2013 prices. Thousands of millions of pesos.

	MANU	COMM	TRANS	SERV	OTH	ROW
HOU	0.00	0.00	0.00	0.00	0.00	346.61
FIRM	0.00	0.00	0.00	0.00	0.00	0.00
GOV	0.00	0.00	0.00	0.00	0.00	0.00
ISR	0.00	0.00	0.00	0.00	0.00	0.00
CS	159.15	70.81	40.84	405.88	106.01	0.00
ISP	-9.61	-2.26	-16.74	18.13	28.50	0.00
OIP	28.23	16.45	-1.75	27.37	7.97	0.00
SAVE	0.00	0.00	0.00	0.00	0.00	425.64
CAP	1663.79	2597.92	699.47	4118.07	6.28	0.00
LAB	484.72	402.40	260.28	1701.91	510.78	0.00
AGR	495.27	0.00	0.00	6.18	0.02	138.45
MIN	461.07	0.00	0.00	0.02	0.01	430.52
GEN	146.06	42.36	5.13	56.14	13.11	5.73
WAT	11.44	5.61	1.96	15.89	1.68	0.00
GAS	0.00	0.00	0.00	0.00	0.00	0.00
BUILD	5.16	2.09	2.93	17.26	3.08	0.00
CARS	2.89	3.17	13.24	10.42	0.19	1069.20
MANU	1196.88	100.74	178.62	235.44	28.76	2790.75
COMM	629.97	34.40	41.21	103.89	10.75	545.34
TRANS	121.92	51.63	52.22	50.77	7.47	131.81
SERV	476.66	377.30	145.62	956.14	139.63	49.36
OTH	0.00	0.00	0.00	1.41	0.00	0.00
ROW	2249.37	96.12	215.58	296.49	25.44	197.89

Table 2.3. SAM for 2020, values at 2013 prices. Thousands of millions of pesos.

4.2 Introducing EVs in the SAM

EVs and ICEs slightly differ in the intermediate inputs required for their manufacture. To simulate any scenario in which the production of EVs take a share of ICE vehicles we need to establish in the best possible way the difference of the input parameters between both types of vehicles. Due to the lack of national data, we use parameters from the literature. Table 3 shows the intermediate consumption needed to produce each vehicle type taken from Leurent and Windisch (2015).

Activity	ICE Cost €	EV Cost €
EV manufacture	0	3350
Agriculture	9	9
Consumer goods	433	433
ICE manufacture	0	3350
Automotive equipment	1341	1341
Ship, aircraft, rail construction	8	8
Machinery	770	770
Electronic equipment	321	10321
Mining	170	170
Textiles	174	174
Wood and paper	42	42
Chemicals, rubber	1084	1084
Metals and metalworking	1742	1742
Other electronic components	271	271
Fuels	84	84
Water, gas, electricity	87	87
Building	18	18
Car dealing and repair	9	9
Trade	99	99
Transport	50	50
Financial, real state, rental activities	1105	1105
Services to companies	823	823
Services to individuals	34	34
Education, health, social care	92	92
Administration	2	2
Added value	1481	1481

Table 3: Intermediate inputs: CV vs EV. Source: (Leurent and Windisch 2015)

The expenditure of the inputs is used to construct new columns and rows in the SAM to divert the projected share of production towards EVs. One of the values that have seen the biggest changes over time is that of electrical and electronic equipment. It mostly represents the battery cost of the EVs. However due to battery research and bigger capabilities of production this activity is projected to follow a path that would help to match the price of ICE vehicles, such as Berckmans (2016) argues. Therefore, it will not be used in the SAM projected for 2050, instead the same cost of the ICE vehicles is used. The manufacture of EVs itself remains higher in our scenario.

4.3 *Parameters and coefficients*

All the numerical parameters and coefficients required to set up the CGE described in section 3 are presented in this subsection , along with a brief explanation.

4.3.1 Industries

The industries in the model are as follow.

Industry classification
Agriculture, animal and forestry exploitation (AGR)
Mining (MIN)
Generation, transmission, and distribution of electrical energy (GEN)
Water collection, treatment, and supply (WAT)
Gas supply through pipelines to the final consumer (GAS)
Manufacturing industries (MANU)
Manufacture of automobiles and trucks (CARS)
Commerce (CARS)
Transport, post, and storage (TRANS)
Services (SERV)
Legislative and governmental activities (GOV)
Building (BUILD)

Table 4: Industries of the model

For the economic behavior of the industries explained above, the following parameters were calibrated, from the SAM2020.

The value-added input requirement coefficient.is defined by dividing the value added produced in industry i by domestic production of the same industry. In this case, "Y" the gross value added implies the inputs of the primary factors of industry i (labor and capital) and "y" can be regarded as an input unit of such production factors.

ay_j value added input requirement coefficient.

AGR	*0.611*	*MIN*	*0.78*	*GEN*	*0.463*
BUILD	*0.565*	*MANU*	*0.254*	*CARS*	*0.214*
SERV	*0.765*	*OTH*	*0.689*	*COMM*	*0.805*
WAT	*0.542*	*GAS*	*0.451*	*TRANS*	*0.58*

Table 5: Value added input requirement.

The coefficient requirements are defined by dividing the production in industry i by the primary factors used by industry i (labor and capital) and can be regarded the minimal input unit of such production factors to produce one unit of industry i.

a_{ij} : coefficient requirements of the i-th intermediate input

	CAPITAL	*LABOUR*
AGRICULTURE	*0.829*	*0.171*
MINING	*0.964*	*0.036*
GENENERATION	*0.91*	*0.09*
WATER	*0.709*	*0.291*
GAS	*1*	*0*
BUILDING	*0.728*	*0.272*
MANUFACTURE	*0.774*	*0.226*
CARS	*0.843*	*0.157*
COMMUNICATIONS	*0.866*	*0.134*
TRANSPORT	*0.729*	*0.271*
SERVICES	*0.707*	*0.293*
OTHERS	*0.012*	*0.988*

Table 6: Value added input requirement.

Intermediate inputs are directly obtained from the SAM and are the expenditures that industry i realize in other industries.

X_{ij} intermediate input of industry i's product in industry j

	AGR	MIN	GEN	WAT	GAS	BUILD
AGR	64,515.30	0.33	-	-	-	305.95
MIN	624.99	4,244.30	6,305.18	-	-	27,101.50
GEN	6,403.95	14,501.57	1,362.70	16,882.35	16.43	2,465.24
WAT	6,742.91	2,064.01	203.33	4,513.03	0.74	4,114.23
BUILD	10.29	6,722.16	2,465.60	2,632.79	95.85	130,969.74
MANU	102,682.38	67,385.61	79,375.78	2,884.98	155.90	274,325.08
CARS	633.38	922.02	150.39	180.32	0.17	6,068.10
COMM	43,197.03	23,456.47	15,170.54	1,593.10	132.20	110,808.70
TRANS	5,802.85	8,064.77	3,850.97	294.67	43.87	25,918.87
SERV	6,740.35	96,737.88	8,905.44	3,286.73	1,051.17	124,984.79
ROW	65,594.36	91,622.38	61,347.73	6,198.83	763.08	190,350.22

Table 7: Expenditure on intermediate inputs by industry.

The scaling parameter in the Cobb-Douglas production function for value added represents the efficiency of the technology of industry i to produce value given production and the elasticities of labor and capital. It is obtained by the next equation.

$$b_j = Y_j / \prod_j F_{hj}^{\beta_{hj}}$$

bj: scaling parameter in the Cobb-Douglas production function.

AGR	1.58	MIN	1.169	GEN	1.354
BUILD	1.796	MANU	1.706	CARS	1.545
SERV	1.83	OTH	1.068	WAT	1.828
COMM	1.483	TRANS	1.794	GAS	1

Table 8: Efficiency of the technology of industry i.

4.3.2 Households

α_i: share parameter in the utility function

AGR	0.014	GEN	0.007	WAT	0.003
GAS	4.14E-04	MANU	0.249	CARS	0.03
COMM	0.151	TRANS	0.105	SERV	0.382
OTH	4.56E-04	ROW	0.058		

Table 9: Share of the expenditure of households.

We use the share of the expenditure in the Cobb-Douglas utility function of households. Shares of expenditure represents preferences.

4.3.3 Government

μi: government consumption shares of good i-th

BUILD	0.004	MANU	0.001	SERV	0.411
OTH	0.378	ROW	0.206		

Table 10: Government consumption adds all government expenses and normalize them.

5 Simulation analysis

5.1 SAM projection

Estimating a SAM for a recent year or even for the future is a difficult and complex problem. Since the SAM requires a large amount of information, these are not usually published on a regular basis. To solve the need for updated SAMs the most accepted approach is to start with a consistent SAM for some an earlier period and "update" it for a later period with information on row and column totals but no information of flows within the SAM (Robinson et al. 2001). The most used method to do so is the RAS method outlined by O'Connor and Henry (1975) and firstly used to update an input-output matrix $A_0 = [a_{ij}]$, that is subject to two intertemporal effects: a substitution effect, measured by the extent to which the output of the i-th sector has been replaced by other sectoral outputs in intermediate production and the fabrication effect measured by the extent to which the ratio of intermediate to total inputs decreased in the j-th sector.

Because of the two effects taking place simultaneously, the new matrix may be written as

$$A_1 = r_1 A_0 s_1 \tag{12}$$

where s and r are diagonal matrices representing the fabrication and substitution effects, respectively. This equation gives the method its name. These matrices are obtained from the base year matrix, and the row and column totals of the new flow matrix. The method amounts to a successive biproportional adjustment of the rows and columns of the base matrix, until convergence is reached, Parikh, A. (1979).

We use a Generalized RAS (GRAS) method to update the original SAM to 2020 as SAM_{2020} with exogenously given row and column totals that is a close as possible to the original matrix SAM_{2013}. To do so, we use Matlab using the code provided by Temurshoev et al. (2013), and data from the annual aggregated change from 2013 to 2020 at constant values of 2013 prices for each of the sectors of the economy as reported by the National Institute of Statistics and Geography (INEGI for its acronym in Spanish). For those entries that could not be updated by this means, we use the change in gross domestic product.

However, to "update" SAMs to future years, we can only use exogenous projections for key variables such as GDP, population growth, or expectations of each sector development. After estimating the SAM_{2020} using the GRAS method, SAM_{2020} was used to model each of the scenarios of interest (presented in the following section). This was done by projecting all sectors towards 2050 using an estimate of average growth of Mexico’s GDP of 3% per year. This way it was obtained SAM_{2050} which serves as reference (base) for the rest of scenarios.

5.2 Benchmark year

It is important to highlight that the model could replicate the benchmark year 2020 for the economy. The model was able to replicate the 2020 base year for most industries on key variables. However, in some variables, the more disaggregated industries (WATER, GEN and GAS) presented greater deviations due to their smaller scale. The difference between what is observed and what is predicted by the model , as presented in table 1.

	SAM 2020	Model	%
AGRICULTURE	171.41	172.492	0.6%
MINIG	0.00	.	0.0%
GENERATION	86.97	78.978	-9.2%
WATER	36.30	21.025	-42.1%
GAS	4.81	5.772	20.0%
BUILDING	0.01	0.005	-46.3%
MANUFACTURE	2567.11	2744.754	6.9%
CARS	309.20	371.04	20.0%
COMMUNICATIONS	1676.76	1484.039	-11.5%
TRANSPORT	1021.52	707.073	-30.8%
SERVICES	4373.42	1954.781	-55.3%
OTHERS	4.27	3.137	-26.5%

Table 1: Differences in expenditures for households

5.3 The scenarios to be considered are as follow.

For the analysis carried out in this thesis, we present four different scenarios as follows:

1. The current status quo scenario (SQS), although it is unlikely that this scenario will maintain, it is the base scenario in which the SAM matrix obtained for 2020 through the RAS method is projected to 2050. Changes in the demand for ICE vehicles are not considered, neither for Mexico, nor for the Rest of the World. This scenario is unlikely to happen given current trends but allows to assess changes in the other scenarios. For this scenario, we use the $SAM_{2050}\ matrix$.

2. The non-exports scenario (NOEXP): In this scenario, both the national demand and the production of EVs remain practically null, however in this scenario the demand of ICE vehicles in the ROW is reduced by 50% as a result of a higher demand for EVs in the ROW. To simulate this scenario, 50% of the demand from the rest of the world is subtracted from row and column margins of the CARS sector, and the GRAS method is applied again to the matrix obtained for the status quo scenario which is again a square matrix. That is the GRAS method was

used again, however, in the sum of the car manufacturing sector, exports to the ROW were reduced by half.

3. The Low Demand scenario (LODES): In this scenario production increases in a way that satisfies both a projected low domestic demand and the ROW demand, which is still accounts for 50% of the SQS demand. The domestic demand of EVs is assumed to have an average growth of 15% per year. The SAM of the status quo scenario was used as a basis and a sector for the manufacture of electric cars was added. This was done, first by unfolding the CARS row and column in two sectors; the EVs manufacturing sector and the CARS sector and then assigning proportional weights so that the projected demand of households and the rest of the world would be satisfied. This can be done without affecting the balance of the SAM since virtually all the inputs for the manufacture of EVs are equal to ICE vehicles in 2050. At 2020 the main difference is the price of batteries, but it is estimated that for 2030 the price of batteries will fall to make the price of EVs and ICE vehicles similar (Berckmans ,2016). The only exception in the input-output matrix would be within the same sector, which is 10% more demanding within itself, but again this change does not affect the balance of the new SAM.

4. The High Demand scenario (HIDES): In this scenario, the national demand for EVs is high as demand represents almost 80% of the overall light vehicle industry production in 2050, production increases in a way that satisfies both projected demands, domestic and that of the ROW. In this scenario, the SAM of the low demand scenario was used as a basis for the GRAS method and changes in the marginal sums of the ICEs and EVs vehicles were done to satisfy demands for this scenario.

6 Results and analysis

Tables 12-14 show the results for some of the key variables for each of the scenarios described as well as their meaning in this context.

	SQS	Low Exp	LODES	HIDES
AGRICULTURE	1.06E+03	0.97%	0.07%	-0.57%
MINING	1.50E+03	0.44%	0.03%	-0.25%
GENERATION	3.29E+02	1.11%	0.08%	-0.64%
WATER	8.71	0.59%	0.04%	-0.35%
GAS	0.38	0.87%	0.06%	-0.49%
BUILDING	1.82E+03	1.10%	0.08%	-0.65%
MANUFACTURE	3.89E+03	1.32%	0.09%	-0.74%
CARS	7.47E+02	-25.86%	-1.83%	14.99%
COMMUNICATION	5.43E+03	0.45%	0.03%	-0.27%
TRANSPORT	1.74E+03	1.02%	0.069%	-0.6%
SERVICES	1.05E+04	0.50%	0.038%	-0.29%
OTHERS	9.37E+03	0.58%	0.042%	-0.34%
PIB	2.81E+04	-0.001%	0.00%	0.001%

Table 11. Value added by sector and scenario in 2050 in thousands of millions.

Table 11 shows the result on the status quo scenario in the first column, while the following columns show the percentage change concerning the said scenario. Gross domestic product (GDP) is one of the most used economic variables, in this model it is formed as the sum of the value added by each sector. Results show that the low export scenario is the one that harms the most GDP, while the scenario with high demand for EVs is the one that best impacts GDP, although the impacts are minimal. This means that technological change can be sought with practically no cost to the economy, this may imply that any changes in environmental impact may come at no cost.

Labor expenditure is also an important variable as it also allows us to analyze the impact on family income in each of the scenarios. This has an impact on the number of quality jobs that the light car manufacturing sector can offer in Mexico. As shown table 12, it is possible to see a significative loss in the income of households dedicated to this sector in the Low Exports Scenario, while the loss is less steep in the Low Demand Scenario only a High Demand Scenario might be better for the light car manufacturing sector in México.

	SQS	*LOW EXP*	*LODES*	*HIDES*
LABOR CARS	*1.17E+05*	*86755.08*	*48501.62*	*48222.79*
LABOR EVS	*0*	*0*	*66735.61*	*87061.77*
SUM	*1.17E+05*	*-26.11%*	*-1.85%*	*15.22%*

Table 12: Expenditure in labor for manufacture of light vehicles in 2050 by scenario.

The number of units produced is also of importance, taking the value of the production of the ICE vehicle and EVs sectors, we can estimate the number of vehicles produced in each of the scenarios. To do this we divide the value of production by the average price of a vehicle. According to the AMDA (Asociación Mexicana de Distribuidores Automotrices) the ICE vehicles the average price for the 10 most sell cars was of $ 270,000.00. I assume an average price for the EVs in 2050 of $300,000.00. Here we can compare our results with the projections given by the government for 2034 (half the way on our projections), which contemplates three scenarios with an integration of EVs between 2.39 million EVs and 4.81 million. That the government's projections are almost half of ours, in half the time is reasonable.

	ICE VEHICLES	*EV*
SQS	*12.38*	*0*
LOW EXP	*8.85*	*0*
LODES	*4.90*	*6.55*
HIDES	*4.90*	*9.02*

Table 13: Number of vehicles produced in 2050 by scenario (millions of units).

With the production of vehicles, we can also estimate their environmental impact. Considering the life cycle analysis done by Notter et al. (2010), we have that ICE vehicles generate emissions of 62,866 kgCO2E per vehicle from their production to the end-of-life cycle, while EVs generate 31,821 kgCO2E from their production to the end of their life cycle.

	SQS	*Low Exp*	*LODES*	*HIDES*
ICE vehicles	*778*	*556*	*308*	*308*
EVs	*0.00*	*0.00*	*208*	*287*
Sum	*778*	*-28.50%*	*-33.60%*	*-23.47%*

Table 14: Net emissions in millions of tons of CO2e of light vehicles manufacture and use in 2050.

The emissions generated by EVs vary depending on the energy matrix used to generate the electricity, however, it is noticeable that a shift towards electric cars can generate significant reductions in GHG emissions. Actual trends for more renewable energy in Mexico energetic portfolio can generate synergies with EVs, since cleaner and cheaper energy can enhance demand and reduce EVs emissions.

7 Conclusions

The objective of this work was to evaluate the economic and environmental impact of the electrification of light transport. This objective is achieved with the development of a CGE model, which allowed the analysis of four different scenarios of supply and demand of EVs.

The CGE model shows that it is possible to archive a reduction in GHG emissions generated by the light vehicle manufacturing industry with almost no cost or even a small improve in the overall economy. This was observed in the high and low penetration scenario, respectively. At the same time both scenarios can deliver benefits to households linked to the light vehicles manufacturing sector, that in 2019 where almost 1 million. The adoption of EVs can also generate synergies with other ongoing trends such as the rise in generation of clean energy, further reducing the environmental impact and the need of gasoline imports (improving energy security). Both scenarios of EVs adoption highlight the positive relation between economic growth and technological change.

The worst of the scenarios analyzed is in the Low Exports scenario in which no action is taken to adopt this new technology and market share is lost in the export market. The scenario does not reduce GHG emissions in the same way that other scenarios and the fall is due to fewer units being produced and not due to better technology. GDP is affected by the reduction of the value-added in the ICE vehicle manufacture sector and this could be reflected in a loss of revenue for all levels of government. The low exports scenario affects the income, or the employment of households linked to the light vehicles manufacturing sector, which can harm different states disproportionately depending on their exposure on the light vehicle manufacturing industry. Other sectors may see small positive changes due to substitution effects.

The status quo scenario is the most unlikely scenario due to current trends of technological changes and national and foreign stated goals. The status quo is the scenario with the greatest GHG emissions due to the high production of ICE vehicles, and it does not help to improve actual gasoline import dependency. Although household income or GDP are not greatly affected in comparison with the low demand scenario this scenario risk moving to the Low Export scenario, our worst evaluated scenario, due to the exogenous nature of the demand of the rest of the world.

8 Future work

Future work on the theme is plenty, and as research evolves more possibilities and details can be added.

There is the possibility to evaluate the different public policies that the government is yet to propose, for example a public policy similar to the ZEV policy applied for California, in Mexico City or other big cities could reduce local air pollution and help supply of national manufactured EVs. As INEGI publishes more actual SAMs future work can use them to reduce the impact of the RAS method in the updating of the SAM.

Other possibilities for future work are to add detail to the model. Detail can be added by regionalizing the model using regionals SAMs developed by Chapa Cantú et al. (2019), this would allow state governments to better coordinate actions depending on their exposure to the light vehicle manufacturing industry. This is particularly important for some regions such as the Central-West region where a large light car manufacturing capacity is concentrated and that might find cost-effective to lower state taxes on the EV manufacturing industries. More detail can also be added by differentiating on the types of households by level of income, this would allow to study the impact that focused policies can have in each of them, for example, a determine level of subsidy in the buy of EVs may allow to households with a lower level of incomes to buy EVs, greatly improving access to them.

Converting the model, in a dynamic or intertemporal CGE, can also be done and eliminates the need to manipulate the SAMs outside of the update to the year with more recent data, and allows to obtain an optimal path. This is of special interest for governments (at state level if regionalized) and industries since they can more easily track growth of incomes, demand and supply needed in each of the scenarios.

Other important detail to add in future work may come from the application of a discrete choice experiment around which kind of vehicle does people prefer, this could allow to change the functional form of the demand of light vehicles to better represent the preference of consumers and aside of giving information on relevant characteristics of early adopters it may permit to study of public policies that affect energy prices, like the reform to the Electric Industry Law passed in 2020. If this reform translates in higher energy prices for the consumers, it will make pricier the use of EVs, which can be a factor at time of purchase and then hamper its penetration.

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Appendix A. Code

```
$title CGE model for the evaluation of EV on Mexico
$setglobal ruta 'C:\Users\Lenovo\Desktop\CIDE\Tesis'
$offsymxref offsymlist


*** SETS  ***
Set
   u   'SAM entry' / HOU, FIRM, GOV, ISR, CS, ISP, OIP, SAVE, CAP, LAB, AGR, MIN, GEN, WAT, GAS, BUILD,
MANU,
CARS, EV, COMM, TRANS, SERV, OTH, ROW /
   i(u) 'goods'     /AGR, MIN, GEN, WAT, BUILD, MANU, GAS, CARS , COMM, TRANS, SERV, OTH/
   h(u) 'factor'    /CAP, LAB/;
Alias (u,v), (i,j), (h,k);


*Loading data
*Table SAM(u,v) 'social accounting matrix 2050'
*$ondelim
*$include %ruta%\sam 2050 PROY.csv
*$offdelim
*;

Table SAM(u,v) 'social accounting matrix 2020'
$ondelim
$include %ruta%\SAM.csv
$offdelim
;
*Loading of initial values
Parameter
Xp0(i) household consumption of the i-th good
F0(h,j) the h-th factor input by the j-th firm
Y0(j)   value added
X0(i,j) intermediate input
Z0(j)   output of the j-th good
FF(h)   factor endowment of the h-th factor

Xg0(i) government consumption
Xv0(i) investment demand
E0(i)  exports
M0(i)  imports
D0(i)  domestic good
Td0    direct tax
Q0(i)  Armington's composite good
S0     private saving
Sg0    government saving
Sf     foreign saving in US dollars
tau(i)  indirect tax rate
T0(j)   tax per industry

pWe(i) export price in pesos
pWm(i) import price in pesos
```

```
;

Xp0(i)  =SAM(i,"HOU");
F0(h,j) = SAM(h,j);
Y0(j)   = sum(h, F0(h,j));
X0(i,j) =SAM(i,j);
Z0(j)   =Y0(j) +sum(i,X0(i,j));
FF(h)   =SAM("HOU",h);

Xg0(i)  =SAM(i,"GOV");
Xv0(i)  =SAM(i,"SAVE");
E0(i)   =SAM(i,"ROW")+0.00000000001;
M0(i)   =SAM("ROW",i);

Td0     =SAM("ISP","HOU")+SAM("ISR","HOU")-SAM("HOU","GOV");
Q0(i)   =Xp0(i)+Xg0(i)+Xv0(i)+sum(j,X0(i,j));
S0      =SAM("SAVE","HOU");
Sg0     =SAM("SAVE","GOV");
Sf      =SAM("SAVE","ROW");
T0(j)   = SAM("ISR",j)+SAM("ISP",j)+SAM("OIP",j)+SAM("CS",j);
tau(i) =T0(i)/Z0(i);
D0(i)   =(1+tau(i))*Z0(i)-E0(i);

pWe (i) =1;
PWm (i) =1;

display Xp0,F0,Y0,Z0,X0,FF,Xg0,Xv0,E0,M0,D0,Td0,Q0,S0,Sg0,Sf, tau;

*Calibration
Parameter
eta(i)       substitution elasticity parameter
phi(i)       transformation elasticity parameter;

eta(i)=0.3;
eta("AGR")=1.5;

eta("TRANS")=1.7;
eta("WAT")=1.1;
eta("CARS")=1.01;
eta("MANU")=1.2;
eta("COMM")=1.1;
eta("GEN")=1.38;
eta("SERV")=1.1;

phi(i)=0.2;
*phi("AGR")=0.1;
*phi("TRANS")=0.1;
*phi("WAT")=0.2;
*phi("MANU")=0.8;
*phi("COMM")=0.4;
*phi("CARS")=2;
```

```
Parameter
alpha(i)       share parameter in utility function
beta(h,j)       share parameter in production function
b(j)       scale parameter in production function
ax(i,j)       intermediate input requirement coefficient
ay(j)       value added input requirement coefficient
mu(i)       government consumption share
lambda(i)       investment demand share
deltam(i)       share  parameter  in Armington function
deltad(i)       share parameter in Armington function
gamma(i)       scale parameter in Armington function
xid(i)       share parameter in transformation function
xie(i)       share parameter in transformation function
theta(i)       scale parameter in transformation function
ss       average propensity for private saving
ssg       average propensity for government saving
taud      direct tax rate
;


alpha(i)=Xp0(i)/sum(j, Xp0(j));
beta(h,j)=F0(h,j)/(sum(k, F0(k,j))+0.0000000000001);
b(j) =Y0(j)/prod(h, F0(h,j)**beta(h,j));

ax(i,j) =X0(i,j)/Z0(j);
ay(j) =Y0(j)/Z0(j);
mu(i) =Xg0(i)/sum(j,Xg0(j));
lambda(i)=Xv0(i)/(S0+Sg0+Sf);

deltam(i)=M0(i)**(1-eta(i))/(M0(i)**(1-eta(i))+D0(i)**(1-eta(i)));
deltad(i)=D0(i)**(1-eta(i))/(M0(i)**(1-eta(i))+D0(i)**(1-eta(i)));
gamma(i) =Q0(i)/(deltam(i)*M0(i)**eta(i)+deltad(i)*D0(i)**eta(i))**(1/eta(i));

xie(i)=E0(i)**(1-phi(i))/(E0(i)**(1-phi(i))+D0(i)**(1-phi(i)));
xid(i)=D0(i)**(1-phi(i))/(E0(i)**(1-phi(i))+D0(i)**(1-phi(i)));
theta(i)=Z0(i)/(xie(i)*E0(i)**phi(i)+xid(i)*D0(i)**phi(i))**(1/phi(i));

ss =S0/sum(h,FF(h));
ssg =Sg0/Td0;
taud =Td0/sum(h,FF(h));
display alpha,beta,b,ax,ay,mu,lambda,deltam,deltad,gamma,xie,xid,theta,ss,ssg,tau, T0;


* defining model system
Variable
Xp(i)       household consumption of the i-th good
F(h,j) the h-th factor input by the j-th firm
X(i,j) intermediate input
Y(j)       value added
Z(j)       output of the j-th good

Xg(i)       government consumption
Xv(i)       investment demand
```

```
E(i)       exports
M(i)        imports
Q(i)       Armington's composite good
D(i)       domestic good

pd(i)       the i-th domestic good price
ps(i)       supply price of the i-th good
pq(i)       Armington's composite good price
py(j)       value added price
pm(i)       import price in local currency
pe(i)       export price in local currency

r(h)       the h-th factor price
epsilon      exchange rate

Td       direct tax
S       private saving
Sg       government saving

T(i)      indirect tax
UU       utility [fictitious]
;

Equation
eqXp(i)  household demand function
eqpy(j)  value added aggregation function
eqX(i,j) intermediate demand function
eqY(j)   value added demand function
eqF(h,j) factor demand function
eqps(j)  unit cost function
eqTd     direct tax revenue function
eqT(j)   indirect tax revenue function
eqXg(i)  government demand function
eqXv(i)  investment demand function
eqpe(i)  world export price equation
eqpm(i)  world import price equation
eqepsilon balance of payments
eqpqs(i)  Armington function
eqM(i)    import demand function
eqD(i)    domestic good demand function
eqpqd(i)  market clearing condition of composite good
eqpz(i)   transformation function
eqr(h)    factor market clearing condition
eqDs(i)   domestic good supply function
eqE(i)    export supply function
eqS       private saving function
eqSg      government saving function
obj       utility function [fictitious]
;

*[household consumption] --
eqXP(i)..     Xp(i)=e= alpha(i)*(sum(h,r(h)*FF(h)) -S -Td)/pq(i);
*[domestic production] ----
```

```
eqpy(j)..     Y(j) =e= b(j)*prod(h, F(h,j)**beta(h,j));
eqX(i,j)..   X(i,j) =e= ax(i,j)*Z(j);
eqY(j)..       Y(j)=e= ay(j)*Z(j);
eqF(h,j)..       F(h,j) =e= beta(h,j)*py(j)*Y(j)/r(h);
eqps(j)..       ps(j)       =e= ay(j)*py(j) +sum(i, ax(i,j)*pq(i));
*government behavior] ----
eqTd..       Td   =e= taud*sum(h, r(h)*FF(h));
eqT(i)..     T(i) =e= tau(i)*ps(i)*Z(i);
eqXg(i)..    Xg(i) =e= mu(i)*(Td+sum(j,T(j)) -Sg)/pq(i);
*investment behavior] ----
eqXv(i)..       Xv(i)       =e= lambda(i)*(S +Sg +epsilon*Sf)/pq(i);
*[international trade] ----
eqpe(i)..       pe(i)       =e= epsilon*pWe(i);
eqpm(i)..       pm(i)       =l= epsilon*pWm(i);


eqepsilon.. sum(i, pWe(i)*E(i)) +Sf =e= sum(i, pWm(i)*M(i));

*[Armington   function] -----
eqpqs(i)..  Q(i) =e= gamma(i)*(deltam(i)*M(i)**eta(i)+deltad(i)*D(i)**eta(i))**(1/eta(i));
eqM(i)..  M(i) =e= (gamma(i)**eta(i)*deltam(i)*pq(i)/pm(i))**(1/(1-eta(i)))*Q(i);
eqD(i)..  D(i) =g= (gamma(i)**eta(i)*deltad(i)*pq(i)/pd(i))**(1/(1-eta(i)))*Q(i);

*[transformation function] -----
eqpz(i).. Z(i) =e= theta(i)*(xie(i)*E(i)**phi(i)+xid(i)*D(i)**phi(i))**(1/phi(i));
eqE(i).. E(i) =e= (theta(i)**phi(i)*xie(i)*(1+tau(i))*ps(i)/pe(i))**(1/(1-phi(i)))*Z(i);
eqDs(i).. D(i) =e= (theta(i)**phi(i)*xid(i)*(1+tau(i))*ps(i)/pd(i))**(1/(1-phi(i)))*Z(i);

*[market clearing condition]
eqpqd(i).. Q(i) =e= Xp(i) +Xg(i) +Xv(i) +sum(j, X(i,j));
eqr(h).. FF(h) =l= sum(j, F(h,j));

*[savings]
eqS.. S =e= ss*sum(h, r(h)*FF(h));
eqSg.. Sg =e= ssg*(Td+sum(j,T(j)));


*fictitious objective function]
obj..  UU =e= prod(i, Xp(i)**alpha(i));


* initializing variables
Xp.l(i) =Xp0(i);
F.l(h,j)=F0(h,j);
X.l(i,j)=X0(i,j);
Y.l(j) =Y0(j);
Z.l(j) =Z0(j);
Xg.l(i) =Xg0(i);
Xv.l(i) =Xv0(i);
E.l(i) =E0(i);
M.l(i) =M0(i);
Q.l(i) =Q0(i);
D.l(i) =D0(i);
```

```
pd.fx(i) =1;
ps.fx(i) =1;
pq.fx(i) =1;
py.fx(j) =1;
pm.fx(i) =1;
pe.fx(i) =1;
r.l(h) =1;
epsilon.l=1;
Td.l =Td0;
S.l =S0;
Sg.l =Sg0;

* setting lower and upper bounds to avoid division by zero or inf ----------------------
Xp.up(i)=Xp0(i)*1.2;
Xp.lo(i)=Xp0(i)*0.4;
F.lo(h,j)=0.0000000001;
F.up(h,j)=10000;
X.lo(i,j)=0.0000000001;
X.up(i,j)=10000;
Y.lo(j) =0.0000000001;
Y.up(j)=10000;
Z.lo(j) =0.0000000001;
Z.up(i)=10000;
Xg.lo(i)=0.0000000001;
Xg.up(i)=10000;
UU.lo= 0.000000001;
Xv.lo(i)=0.0000000001;
Xv.up(i)=10000;
E.lo(i) =0.0000000001;
E.up(i)=10000;
M.lo(i) =0.0000000001;
M.up(i)=10000;
Q.lo(i) =0.0000000001;
Q.up(i)=10000;
D.lo(i) =0.0000000001;
D.up(i)=10000;
pd.lo(i)=0.0000000001;
pd.up(i)=1;
ps.lo(i)=0.0000000001;
ps.up(i)=1;
pq.lo(i)=0.0000000001;
pq.up(i)=1;
py.lo(j)=0.0000000001;
py.up(i)=1;
pm.lo(i)=0.0000000001;
pm.up(i)=1;
pe.l(i)=1;
pe.up(i)=1;
r.lo(h) =0.0000000001;
epsilon.lo=0.0000000001;

Td.lo=0.0000000001;
```

```
S.lo=0.0000000001;

*numeraire ---
r.fx("LAB")=1;



*Defining and solving the model
model CGE_ev /all/;
solve CGE_ev maximizing UU using NLP;

*end of model


* Display of changes
Parameter
dXp(i),dF(h,j),dX(i,j),dY(j),dZ(j),dXg(i),dXv(i),
dE(i),dM(i),dQ(i),dD(i),dpd(i),dps(i),dpq(i),dpy(j),
dpm(i),dpe(i),dr(h),depsilon,dTd,dT(i),dTm(i),dS,dSg;

dXp(i)$(Xp0(i)=0)=0;
dXp(i)$(Xp0(i)>0) =(Xp.l(i) /Xp0(i) -1);

dF(h,j)$(F0(h,j)=0)=0;
dF(h,j)$(F0(h,j)>0)=(F.l(h,j)/F0(h,j)-1);

dX(i,j)$(X0(i,j)=0)=0;
dX(i,j)$(X0(i,j)>0)=(X.l(i,j)/X0(i,j)-1);

dY(j)$(Y0(j)=0)=0;
dY(j)$(Y0(j)>0) =(Y.l(j) /Y0(j) -1);

dZ(j)$(Z0(j)=0)=0;
dZ(j)$(Y0(j)>0) =(Z.l(j) /Z0(j) -1);

dXg(i)$(Xg0(i)=0)=0;
dXg(i)$(Xg0(i)>0) =(Xg.l(i) /Xg0(i) -1);

dXv(i)$(Xv0(i)=0)=0;
dXv(i)$(Xv0(i)>0) =(Xv.l(i) /Xv0(i) -1);


dE(i)$(E0(i)>0) =(E.l(i) /E0(i) -1);


dM(i)$(M0(i)>0) =(M.l(i) /M0(i) -1);
dQ(i)$(Q0(i)>0) =(Q.l(i) /Q0(i) -1);
dD(i)$(D0(i)>0) =(D.l(i) /D0(i) -1);

dpd(i) =(pd.l(i) /1 -1);
dps(i) =(ps.l(i) /1 -1);
dpq(i) =(pq.l(i) /1 -1);
dpy(j) =(py.l(j) /1 -1);
```

```
dpm(i) =(pm.l(i) /1 -1);
dpe(i) =(pe.l(i) /1 -1);
dr(h) =(r.l(h) /1 -1);
depsilon=(epsilon.l/1 -1);
dTd =(Td.l /Td0-1);

display dXp,dF,dX,dY,dZ,dXg,dXv,dE,dM,dQ,dD,dpd,dps, dpq,dpy,dpm,dpe,dr,depsilon,dTd.
```