Infrastructure and Development for Electrical Vehicles in Mexico: Bases and Feasibility for a Greener Country.

Jorge Marcelo Montañez-Uribe[1], Javier Morales-Rodríguez[*1], Javier Morales-Castillo[*1], Víctor Manuel Castaño-Meneses[2]

[1] Universidad Autónoma de Nuevo León, Facultad de Ingeniería Mecánica y Eléctrica, Av. Pedro de Alba S/N, Ciudad Universitaria, 66455 San Nicolás de los Garza, Nuevo León, México.

[2] Universidad Nacional Autónoma de México, Centro de Física Aplicada y Tecnología Aplicada, Boulevard Juriquilla 3000, 76100, Queretaro, México.

[*]Corresponding autor e mail. javier.moralescs@uanl.edu.mx

Recibido 01 de Octubre de 2024, Aceptado 17 de Diciembre de 2024

Resumen

El calentamiento global es un tema muy conocido y un problema que nos afecta a todos. Desde 1992, varios países han firmado acuerdos para frenar este fenómeno, como el Protocolo de Kioto y, más recientemente, el Acuerdo de París. Los países europeos han tomado varias medidas para contrarrestar el cambio climático, como prohibir los vehículos diésel en un futuro próximo y aumentar la generación de energía verde. El principal contribuyente al calentamiento global es el dióxido de carbono emitido en cada ciclo de combustión, y una de las medidas que han tomado los países desarrollados es reducir estas emisiones sustituyendo los vehículos de gasolina/diésel por otros eléctricos. México es un país en desarrollo y, en la actualidad, no tiene la capacidad para llevar a cabo este cambio; sin embargo, en este trabajo se presentan las bases para un plan de desarrollo de vehículos eléctricos en este país.

Abstract

Global warming is a very well-known topic and a problem that involves everybody. Since 1992 several countries had signed agreements to slow down this phenomenon, such as the Kyoto Protocol and more recently, the Paris Agreement. Europe countries had taken several actions to counteract the climate change like forbidding Diesel vehicles in a near future and increasing the generation of green energy. The main contributor to Global Warming is the Carbon Dioxide emitted in every combustion cycle, and one of the actions that developed countries has taken is decreasing these emissions by switching gasoline/diesel vehicles to electric ones. Mexico is a developing country, and nowadays hasn't the capability of this change, however in this work are presented the bases for an electrical vehicles' development plan in this country.

Keywords:. Electric Vehicle, Pollution, Mexico, CO_2.

1. Introduction

A study made by The International Council on Clean Transportation (ICCT) declares that the Diesel Vehicles have seven times higher emissions of NO_x than the limit set by the Euro VI [1]. Also, that the car manufacturers have the possibility to reach the emissions limit, but it's needed to implement strong measures against cars that do not comply with the norm. According to global known Ernst & Young consultancy services, Mexico has the 13th place in their 2018 Renewable Energy Country Attractiveness Index, making this country the 3rd most desirable country in Latin America to invest in green energies, mostly in photovoltaic generation [2].

According to the National Grid Circuit renovation plan from 2018 to 2032, Mexico government has as a goal to generate at least 35 % of renewable sources energies and the electrical generation capacity installed is 29 % of renewable sources [3]. The main reason for this goal is the commitment Mexico made with other countries to reduce the CO_2 emissions. According to a study made in March 2018, Mexico City produces about 55,700 Tons of CO_2 yearly, which is traduced to 2.8 Tons per capita, and the cities with the highest CO_2 emissions per capita in Mexico are Toluca and Ciudad Juarez, with 5.2 tons per person [4].

Comparing it with the most polluting city per Hong Kong metropolitan area (34.6 Tons per year), Mexico cities are insignificant against China´s main metropolitan areas, however some of our most important cities have several levels of pollution, which will cause several health issues in the future.

In the country the Federal Electricity Commission (CFE, Comisión Federal de Electricidad) is the government office that manages all the electrical system, in coordination with the Energy Secretariat (SENER, Secretaría de Energía), they present the National Electrical System Development Plan (PRODESEN, Programa de Desarrollo del Sistema Eléctrico Nacional), in which its shared the actual condition of the National Electrical System (SEN, Sistema Eléctrico Nacional), and the plan for a near future. In the most updated version of this document, the SENER says that 78.9 % of the energy generated in 2017 was generated by non-renewable resources (coal & natural gas) [5]. Table 1 shows the emissions generated by kg burned of diverse fuels & a comparison between them.

Table 1. Emissions per kg of fuel consumed. Information retrieved from "Factores de emisión para los diferentes tipos de combustibles fósiles y alternativos que se consumen en México 2014" (Instituto Nacional de Ecología y Cambio Climático, 2014).

Fuel	Average kg CO_2/ kg comb.
Gasoline	3.139
Diesel	3.145
Thermal Coal	2.827
Natural Gas	2.69

2. Theoretical Framework

2.1. Emissions on the move

According to the INEGI (National Statistics & Geography Institute), the registered vehicles in circulation until February is about 31,653,162 [6]. For illustrative purposes we will take the most sold car in 2018 in Mexico, which is the Nissan Versa 2018 [7] and with information from the National Climate change & Ecology Institute (Instituto Nacional de Ecología y Cambio Climático, INECC), we will determine how many Tons of CO_2 are produced, supposing that all the cars registered in Mexico are this one. Also, we will compare it versus the best seller Hybrid Vehicle (HV) in Mexico, the Prius & the bestselling Electric Vehicle (EV), the Nissan Leaf.

2.2. Gasoline

Not only does the combustion of fuel cause CO_2 emissions but extracting & refining contributes to this. It's difficult to determine how much CO_2 is emitted per liter of fuel produced, because each refinery has its own configuration to refine crude oil. A study published in ScienceDirect [8] discloses how much CO_2 is emitted in the refining process and transportation of gasoline by different methods in the Well to Tank model.

For both Versa & Prius we will take the data provided by the INECC in city traffic conditions, for the Nissan Leaf we need to calculate the CO_2 path left by the electricity produced. For this we will suppose that the 100 % of the energy stored on the batteries was generated by natural gas, used in the combined cycle electrical generators.

Initial data

$$Natural\ Gas\ Calorific\ Value = 46.74\frac{MJ}{kg}* \quad (1)$$

$$1\frac{KW}{h} = 3.6\ MJ \quad (2)$$

According to CFE, Mexico´s combined cycle plants efficiency is 60% [9], then:

$$46.74\frac{MJ}{kg}*\left(\frac{1kWh}{3.6MJ}\right) = 12.98\frac{kWh}{kg}*0.6 = 7.78\frac{kWh}{kg} \quad (3)$$

Nissan declares the following data for the Leaf in its basic trim in their website:

- *Nissan Leaf® Range = 270 km city/highway range*
- *Nissan Leaf Battery capacity = 40 kW/h*

Then:

$$Nissan\ Leaf\frac{km}{kWh} = \frac{270\ km}{40\ kWh} = 6.75\ km/kWh \quad (4)$$

$$7.78\frac{kWh}{kg\ Comb}*6.75\frac{km}{kWh} = \left(52.569\frac{km}{kg\ Comb}\right)^{-1} = 0.019022\frac{kg\ Comb}{km} \quad (5)$$

$$Natural\ Gas\ kg\ CO_2\ emitted/kg\ combusted = 2.69* \quad (6)$$

$$0.019022\frac{kg\ Comb}{km}*2.69\frac{kg\ CO_2}{kg\ Comb} = 0.05117084\frac{kg\ CO_2}{km} = 51.17\ g\ CO_2/km \quad (7)$$

**Value retrieved from "Factores de emisión para los diferentes tipos de combustibles fósiles y alternativos que se consumen en México" [10].*

For this study we´re using the average of CO_2 emissions of transportation & oil refining of these methods, which is **16.725 g CO_2/MJ Gasoline**. According to Balasubramanian Viswanathan in his book "Energy Sources: Fundamentals of Chemical Conversion Processes and Applications" the Energy Density (ED) of gasoline is 29 MJ/L [11]. Having this data, we can conclude that:

$$Gasoline\ ED = 29\frac{MJ}{l} \quad (8)$$

$$CO_2\ emission\ per\ MJ\ of\ Gasoline\ produced = 16.725\ \frac{g\ CO_2}{MJ} \quad (9)$$

$$16.725\frac{g\ CO_2}{MJ} * \frac{29MJ}{1l} = 485.025\frac{g\ CO_2}{l}\ gasoline\ produce = 0.485\frac{kg\ CO_2}{l} \quad (10)$$

With this data we can determine how much CO_2 will produce each of the cars were comparing. There are several values of fuel consumption, city & highway performance are the most known, but in 2008 the Environmental Protection agency (EPA) made another fuel consumption value which is more attached to reality, considering high speed runs, fast accelerations & the continuous use of AC [12]. For both vehicles were going to use the adjusted performance value:

- *Nissan Versa 2016 1.6 Mt performance = 13.96 km/l**
- *Toyota Prius 2018 1.8 At performance = 19.86 km/l**

For the Versa:

$$\left(13.96\frac{km}{l}\right)^{-1} = 0.07163323\frac{l}{km} * 0.485\frac{kg\ CO_2}{l} = 0.0347421\frac{kg\ CO_2}{km} = 34.7421\ gCO_2/km \quad (11)$$

For the Prius:

$$\left(19.86\frac{km}{l}\right)^{-1} = 0.0503524\frac{l}{km} * 0.485\frac{kg\ CO_2}{l} = 0.0244209\frac{kg\ CO_2}{km} = 24.4209\ g\ CO_2/km \quad (12)$$

**Values retrieved from government data [12].*

2.3. Batteries

A recent study made by the Swedish Environmental Research Institute declares that the EVs will produce more CO_2 emissions than Internal Combustion Vehicles (ICV), by the simple fact that the fabrication of the Li-Ion batteries produces a considerable amount of pollution [13]. The conclusion of this study is that per kWh needed to charge the batteries, 150 – 200 kg CO_2 are emitted. Another study published in ScienceDirect declares that the manufacturing of EVs pollutes 60 % more than the manufacturing of ICVs [14]. Table 2 shows the above-mentioned. For our case we will take the data from this study, because the entire vehicle manufacturing process is retrieved in here.

Table 2. Emissions from vehicle production. Retrieved from "Comparative Study on Life Cycle CO_2 Emissions from the Production of Electric and Conventional Vehicles in China" [14].

Component		CO_2 emissions per vehicle (kg)		
		ICEV	EV-NCM	EV-LFP
Basic Components	Body: including body-in-white, interior, exterior, and glass	2767.9	4393.5	4393.5
	Chassis (without battery)	1684.7	2665.5	2665.5
Special Components	Powertrain system	2092.5	145.6	145.6
	Transmission system	617.4	455.2	455.2
	Traction motor	/	1179.1	1179.1
	Electronic controller	/	1010.2	1010.2
Batteries and attachments	Lead-acid batteries	24.5	15.1	15.1
	Li-ion batteries	/	2788.8	2892.4
	Fluids	230.2	98.3	98.3
	Tires	677.1	677.1	677.1
Assembly	Lead-acid batteries assembly	14.1	8.7	8.7
	Li-ion Batteries assembly	/	141.5	141.5
	Vehicle assembly	1064.1	1064.1	1064.1
Total		9172.5	14642.5	14746.1

There's no data for Hybrid vehicles, however a HV is an ICV with assistance from an electric motor with a battery pack, so we will combine the values in Table 3, in order to calculate the total CO_2 emissions from manufacturing then show in Table 4. For the battery value we will take a 10 % only of its equivalent EV value because Prius´ battery has the capacity of only 1.3 kWh, and for the batteries assembly we will take the same data as the table above. Because of its small battery pack, chassis value is more approaches more to an ICV rather than an EV, which chassis is designed to hold its battery cells.

Table 3. CO_2 Emissions in manufacturing process for ICV, HV & EV and its emissions per Km. Data retrieved from "Comparative Study on Life Cycle CO_2 Emissions from the Production of Electric and Conventional Vehicles in China" (Qiao, Zhao, Liu, Jiang, & Hao, 2016).

	ICV Nissan Versa ® 1.6 L 2016	HV Toyota Prius® 1.8 L 2018	EV Nissan Leaf® 2018
Manufacturing CO_2 emissions by car type (Kg CO_2) (11)	9172.5	11782.1	14642.5
CO2 emissions (g/km) electricity, fuel production & combustion	201.74	141.42	51.17

Table 4. CO_2 Emissions in manufacturing process for Hybrid Vehicles. Data retrieved from "Comparative Study on Life Cycle CO_2 Emissions from the Production of Electric and Conventional Vehicles in China" (Qiao, Zhao, Liu, Jiang, & Hao, 2016).

Component	CO_2 emissions in HV (Kg)
Body	2767.9
Chassis	1684.7
Powertrain	2092.5
Transmission	617.4
Traction motor	1179.1
Electronic controller	1010.2
Lead Acid batteries	24.5
Li-Ion batteries	2788.8*0.1 = 278.8
Fluids	230.2
Tires	677.1
Lead acid batteries assembly	14.1
Li-Ion batteries assembly	141.5
Vehicle assembly	1064.1
Total	11782.1

2.4. Energy needed for a gradual incorporation of EVs

According to CENACE data, in 2017 the peak of electric load was 43,319 MWh, specifically in the month of June, and they expect by 2032 this peak to be 69,249 MWh [15]. This prediction was made in basis of several data, not including EVs, because nowadays the electrical load needed to charge these vehicles is negligible in comparison with other factors. There's no EVs sales forecast in Mexico because it still a low volume market, and its only few data from past years. Multinational investment bank JPMorgan Chase forecast the growth of the EVs worldwide until 2030, taking this information and supposing Mexico will follow the global growth trends, we can forecast how many load EVs will need from the SEN. In this case we will suppose all EVs are plugged at the same time. According to JPMorgan [16], the EVs growth rate will be the following will be as follows as shown in Fig. 1.

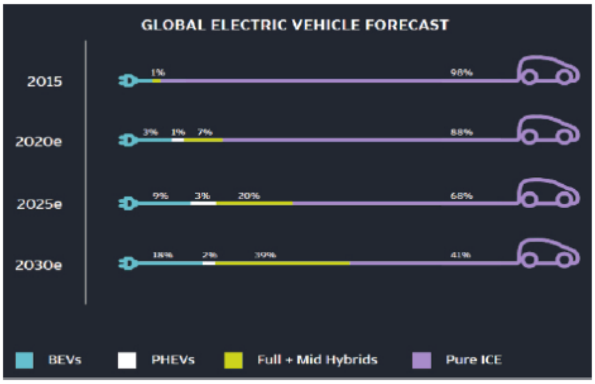

Fig. 1. Global electric vehicle forecast. Info retrieved from JPMorgan Chase Webpage (BEVs: Battery electric vehicles, PHEVs: Pluggable Hybrid Electric Vehicles, ICE: Internal combustion engine) [16].

3. Results

3.1. Carbon Dioxide emissions per Kilometer

In the table 5 the emissions per km are calculated to see how the behavior of the emissions will be over the years, including a second and a third battery change after 100,000 km of use (Nissan gives a 100,00 km warranty to 24 kW/h Nissan Leaf battery) to add the CO_2 emission from its manufacturing process must be added as shown in Figure 2.

Table 5. CO_2 Emissions per km travelled

	50,000 Km	80,000 Km	100,000 Km	150,000 Km	210,000 Km
Nissan Versa	19,259.5	25,311.7	29,346.5	39,433.5	51,537.9
Toyota Prius	18,853.1	23,095.7	25,924.1	33,288.13	42,066.36
Nissan Leaf	17,201	18,736.1	19,759.5	25,248.3	31,248.8

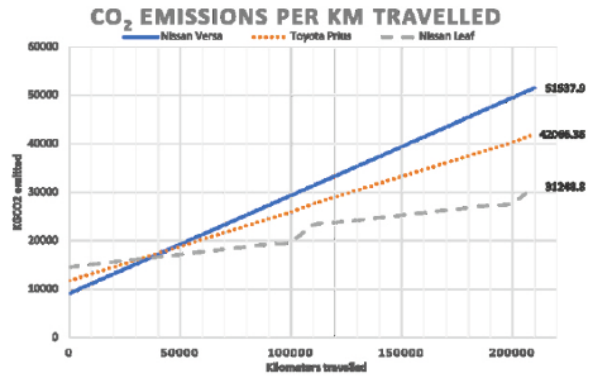

Fig 2. CO_2 emissions per km from production to 210,000 km travelled.

As we can see in the chart above, one single internal combustion car expels more than 3 times the CO_2 that an EV. The hybrid one does reduce the CO_2 emissions but still pollutes more than 2 times than an electric one. At the beginning the EVs does pollute more because the production process of its batteries, but as the distance travelled increase, we see that the CO_2 emissions are reduced significantly. Even after two battery replacements, the EV expels 40 % less CO_2 emissions than the ICV & 25 % less than an HV. In mileage & practicality, the hybrid & Internal combustion cars are nowadays the preferred ones, and a hybrid car could be a good option nowadays. This panorama is showed as if nowadays all electricity was generated by combined cycle plants, but in the future, these plants are more likely to be replaced by greener energies.

3.2. Power demand Forecast

There's no data of how much EVs are now in circulation in Mexico, but the quantity of EVs on the road currently low, minus than 1 % for sure. For practical purposes we will take JPMorgan´s EVs forecast and project it into the future to observe how the incorporation of EVs will affect the electrical power supply that the PRODESEN 2018 have predicted.

According to the Mexican Automotive Industry Association (AMIA, Asociación Mexicana de la Industria Automotriz) 2018 car sales were in total 1, 421,458 units of which only 102 were EVs, representing approximately the 0.01 % of the sales. This will be our initial percent for the forecast:

- Total automobiles registered in Mexico (February 2019) (Instituto Nacional de Estadística y Geografia, 2019) : 31,653,162.

$$31{,}653{,}162\ Vehicles * 0.01\ \% = 2271.508703 \approx 2272\ EVs\ on\ the\ road\ (aprox) \quad (13)$$

EVs battery consumption doesn´t have a standard size, it goes from 16 kWh in the smallest vehicles (Mitsubishi iMiEV®, Chevrolet Volt®) to 90 kWh for the bigger ones (Tesla S) [17], as time passes & new technologies are applied to EVs, the battery capacity will be bigger, so we will take a base value of 50KWh per car, and supposing all these vehicles are plugged:

Actual MWh demand for EVs

$$2{,}272\ EVs * 50\ kWh * \left(\frac{1\ MWh}{1000\ kWh}\right) = 113.6\ MWh \quad (13)$$

EVs demand percent from 2017 peak load

$$\frac{113.6MWh}{43{,}319MWh} = 0.26\ \% \quad (14)$$

Mexico´s average 2010 – 2018 registered vehicles annual growth rate: **5.32 %***

**Data retrieved from INEGI (Instituto Nacional de Estadística y Geografia, 2019).*

Table 6. EVs MWh consumption growth forecast.

Mexico´s EVs growth forecast

	Percent of EVs	Vehicles registered (estimated)	Total EVs	Electrical consumption from EVs (MWh)
2018	0.01%	31653162.00	2,215.721	110.786067
2020	3%	34897611	1,046,928	52,346.41666
2025	9%	44539178	4,008,526	200,426.2993
2030	18%	56844531	10,232,016	511,600.7809

4. Conclusion

With the initial transition from ICVs to EVs & HVs, CO_2 emissions will remain high in the beginning, however as the time passes & the conversion rate increases, the CO_2 emissions coming from vehicles could reduce almost 40 % with the actual manufacturing processes. Due an Increase of the demand of batteries, better & cleaner battery manufacturing processes will be created, reducing even more the percentage of CO_2 emissions coming from vehicles. Mexico's electrical system is not prepared for a fast change as the one presented by JPMorgan, it will take an excessive effort for the government and for the Mexicans to continue with this change if we´re only dependable from nonrenewable energy sources.

ORCID IDs

Jorge Marcelo Montañez-Uribe[1] https://orcid.org/.

Javier Morales-Rodríguez[1] https://orcid.org/0009-0009-6084-3206.

Javier Morales-Castillo*[1] https://orcid.org/0000-0002-9985-3008.

Víctor Manuel Castaño-Meneses[2] https://orcid.org/0000-0002-2983-5293.

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