

Analysis of the Adoption of EVs and Charging Infrastructure in Mexico

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Abstract

The number of Electric Vehicles (EVs) on the roads worldwide increased from few thousand units in 2010 to more than 10 million in 2020. Developed countries show a rapid adoption of EVs and an intensive deployment of public chargers. In developing countries, the pace of adoption is not as fast as in developed countries. In this paper, we analyze the sales of EVs, the range characteristics of the BEVs and the charging infrastructure in Mexico. We develop time series decomposition and regression models to predict the quarterly and yearly sales of EVs in Mexico. The results show that the sales of EVs in Mexico have trend and seasonal effect. The first and fourth quarters show relatively high sales. However, the increasing trend is not enough to replace soon the sales of new internal combustion vehicles. In addition, considering that over 70% of battery EVs sold in Mexico are low-range vehicles, we show that interurban traveling is hindered for many BEV models due to scarce charging infrastructure outside urban areas and compatibility issues of chargers.

Keywords

Electric vehicles, Chargers, Range, Time series decomposition.

1. Introduction

The adoption of EVs grew exponentially in the last decade worldwide. According to the 2021 Global EV Outlook, the number of Electric Vehicles (EVs) on the roads around the world exceeded 10 million in 2020 (International Energy Agency, 2021a), while in 2010 there were less than 20,000 units. Most of the EVs are in China, Europe, and the United States. Approximately 66% of these vehicles are battery electric vehicles (BEVs) and the remaining are plug-in hybrid electric vehicles (PHEVs). BEVs work only with electricity, and they must be charged from the grid, while PHEVs combine an internal combustion engine (ICE) with an electric motor connected to a battery that also needs to be charged from the grid.

The accelerated adoption of EVs is due to multiple factors. For instance, Münzel et al. (2019) identified several monetary and non-monetary incentives. The former includes tax reduction, waivers, special depreciation, subsidy to install home charger, and rebates; the latter includes access to special circulation lanes and traffic zones, free public charging, and special parking spots.

In addition, several governments have set sustainability targets to incentive and enforce the acquisition of zero-emission vehicles (ZEV). The International Energy Agency (2021a) reported that more than 20 countries set 100% of ZEV sales beginning in 2025 (Norway), 2030 (Denmark, Israel, among others), 2035 (UK, some states in the United States), 2040 (France, Canada, among others) and 2050 (Costa Rica and Germany). While other countries have committed to reach net-zero emission economy by 2050.

On the other hand, an increasing environmental consciousness has also positively influenced the acquisition of EVs (Li et al., 2017; Briseño et al., 2021). Although the tank-to-wheel GHG emissions of a BEV is zero, the emissions in the life cycle of the vehicle and the batteries, and the well-to-tank cycle emissions are still significant (International Energy Agency, 2019). Hence, the transition to electric mobility must also consider the transition to renewable generation of electricity. In 2020, the share of renewables accounted for 20% worldwide (International Energy Agency, 2021b).

Developing countries have also shown interest on EVs. However, the adoption is slower than in developed countries. For instance, 7,675 BEVs and PHEVs were sold in Mexico between 2016 and 2020 (excluding Tesla models) (INEGI, 2021a). This number is relatively low considering that Mexico is the 15th largest economy in the world with an estimated GDP of 1192.48 billion dollars (IMF, 2021) and its total population is 126 million inhabitants (INEGI, 2021b). Moreover, by 2020, the number of registered light passenger vehicles exceeded 35 million (INEGI, 2021c). In addition, the sales of new vehicles have been decreasing from 1.6 million in 2016 to approximately 950,000 in 2020 (AMDA, 2021). Therefore, in average, the sales of BEV and PHEV between 2016 and 2020 represented only 0.123% of all new car sales.

In this paper we present an analysis of the adoption of EVs in Mexico and its charging infrastructure. In particular, we predict the sales of EVs in the short and mid-terms and analyze current charging infrastructure to satisfy the needs of EV models available in Mexico. The following sections are organized as follows. Section 2 discusses the relevant related literature. Section 3 presents the models to forecast the sales of EVs in Mexico. Section 4 analyzes the charging infrastructure to complete interurban trips in Mexico. Finally, Section 5 presents the final remarks.

2. Related Literature

Several papers have been published in recent years analyzing different aspects of EVs. In this section, we highlight papers related with the adoption of EVs and the charging infrastructure.

The factors associated with the intention to adopt a BEV were studied by Li et al. (2017) using a bibliometric analysis. The authors identified several demographics, situational, and psychological factors. Among them, the situational factors that include economic incentives, driving range and charging infrastructure stand out. Wang et al. (2019) used multiple linear regression to identify the significant factors that contribute to the adoption of EVs in several countries. The authors found that the charging infrastructure and fuel price are positively correlated with the adoption of EVs. Sobh et al. (2017) studied the factors that affect the adoption of EVs in the United States using cross-sectional/time series methods. The authors showed that electricity price had a strong negative correlation with the market share of EVs, while government incentives had a positive effect. Another study in the United States was presented by Jenn et al. (2018) who analyzed the effectiveness of different types of incentives, finding that rebates and access to restricted lanes were significant incentives for the adoption of EVs. Ingeborgrud and Ryghaug (2019) presented a comprehensive analysis of the BEV market in Norway, which has the largest market share of BEVs worldwide. The authors argued that the rapid penetration of BEVs in Norway is due to the combination of incentives (economic and symbolic), as well as environmental concerns. Briseño et al. (2021) used multivariate analysis to identify the significant factors associated with the increasing adoption of EVs and hybrid vehicles in Mexico. The authors found that the sales of EVs and non-plug-in hybrids in Mexico were positively correlated with the economic development (measured with the GDP), the education level, the price of gasoline, and a green indicator that takes into account the adoption of sustainable practices in the population. In addition, they found that the electricity cost was negatively correlated with the sales of low emission vehicles.

On the other hand, the analysis of charging infrastructure has focused on the development of optimization models for the location of new stations (Capar and Kuby, 2012; Capar et al., 2013; Xi et al., 2013; He et al., 2019, Chen et al., 2020). These models consider set up costs, coverage, and served flow in their objective functions. The models require assumptions regarding the paths that EVs follow and their range. A recent model proposed by Anjos et al. (2020) consists of an optimization model for the deployment of charging stations considering the effect on the adoption of EVs and its repercussion on future demand of chargers.

Most of the studies found in the literature focus the analysis on developed markets for EVs. In this paper, we focus on of the adoption of EVs in Mexico. The records of EV's sales in Mexico began in 2016. Since then, less than 8,000 units have been sold. However, the data suggest an increasing trend of the adoption of EVs. Complementing the analysis presented by Briseño et al. (2021), in this paper we use time series decomposition to analyze the sales of EVs (discarding non-plug-in hybrids) and forecast the new sales in the short and mid-terms. In addition, we analyze the characteristics of the BEVs' models available in Mexico and discuss the feasibility to complete interurban traveling under current charging infrastructure.

3. Forecasting Sales of EVs in Mexico

The sales of EVs in Mexico has been increasing since 2016 as shown in Figure 1. This figure depicts the total quarterly sales of EVs comprised by BEVs and PHEVs. The total sales of EVs between 2016 and 2020 were 7,675 units. BEVs represented 19% of all EVs sales (1,446 units), while PHEVs represented 81% (6,229 units). The figure shows that the economic stress caused by COVID-19 pandemic seem to have had small effect on the sales of EVs. While the total sales of light vehicles in Mexico decreased by 28% in 2020 respect to 2019, the sales of EVs increased by 38% in the same period (AMDA, 2021; INEGI, 2021).

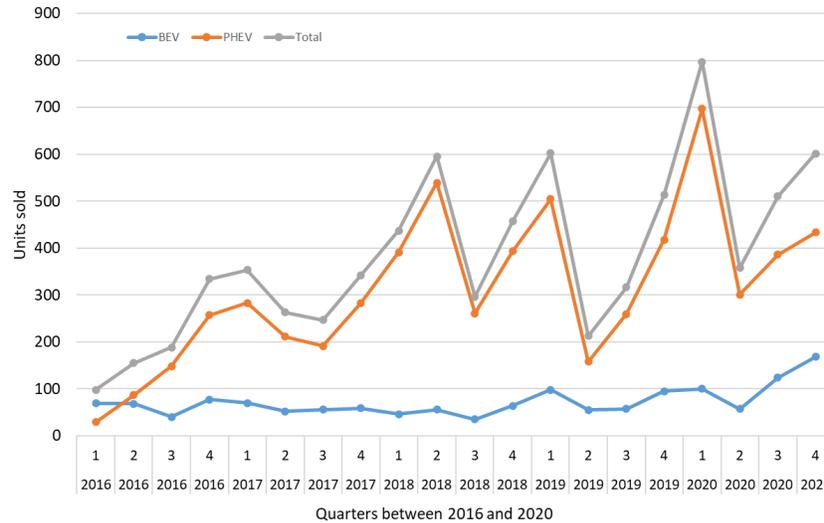


Figure 1. Quarterly sales of EVs in Mexico between 2016 and 2020. Source: INEGI (2021a).

The figure also suggests seasonality in 2019 and 2020. The first quarter has the highest sales, followed by a decline in the second and third quarters and a recovery in the last quarter. Similar patterns are observed in 2017 and 2018, except that the second quarter of 2018 shows the highest sales that year. However, this might be due to a delay in the records of sales, which would confirm that the seasonality observed in the last two years is consistent.

The adoption of EVs varies per state. According to INEGI (2021a), the state with the highest sales of BEV and PHEV is Mexico City with 3,810 sold units between 2016 and 2020. On the other hand, no EV was sold in Guerrero in the same period. Figure 2 shows the normalized sales using the number of sold EVs per 100K inhabitants per state in Mexico. This figure suggests that the states with the highest adoption rate are Mexico City, Queretaro, Nuevo Leon, Morelos and Jalisco. These results are similar to the results presented by Briseño et al. (2021), who consider not only BEV and PHEV, but also non-plug-in hybrid vehicles.

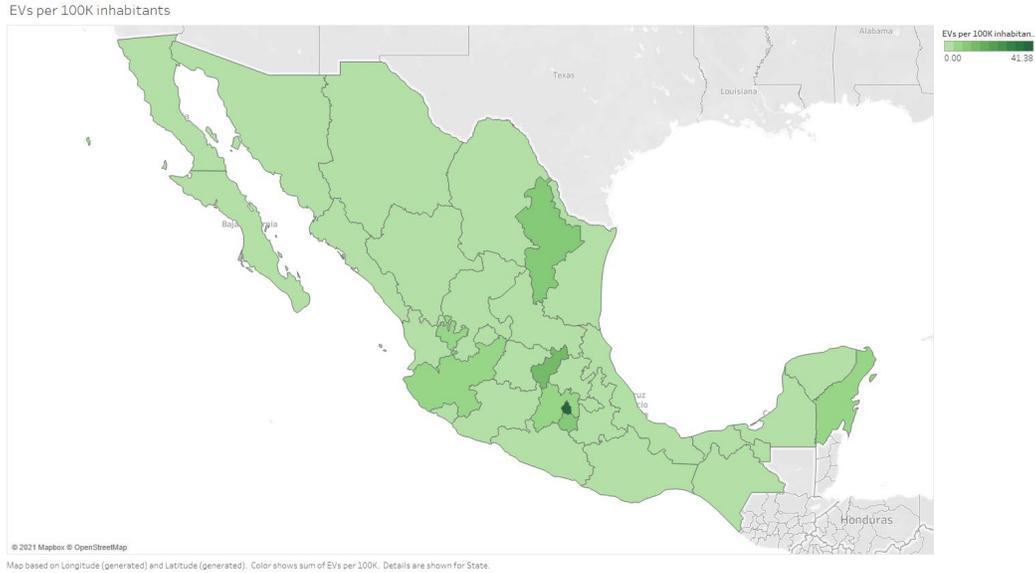


Figure 2. EVs sold per 100K inhabitants. Source: INEGI (2021a)

Given the trend and seasonality of EVs sales, we fitted a time series multiplicative decomposition model of the total EVs sales. The analysis was performed using Minitab 20.2. The model that fits the quarterly EV sales is:

$$\hat{y}_t = (176.5 + 20.43t)I_q$$

where t is the index of the forecasted period (quarter) and I_q is the seasonality index. That is, $t = 1$ for the first quarter of 2016 and $t = 20$ for the fourth quarter of 2020. In addition, the seasonality indices for the four quarters are shown in Table 1.

Table 1. Seasonal indices by quarters for the EV sales in Mexico

| Quarter | Index |
|---------|-------|
| 1 | 1.39 |
| 2 | 0.77 |
| 3 | 0.77 |
| 4 | 1.07 |

This table confirms our observations regarding the seasonal pattern. According to the seasonal indices, in the first quarter of the year the sales are 39% above the average, while in the second and third quarters they are 23% below the average. In the last quarter of the year, the EV sales increase up to 7% above the average.

The fitted model suggests that every quarter, the sales of EVs increases 20.43 units in average, after removing the seasonality effect. Even though this trend is positive, it is not enough to replace a significant proportion of ICE vehicles on the roads of Mexico.

Figure 3 shows the actual time series, the fitted model, the trend and the sales forecast for 2021. According to this figure, the mean absolute percentage error (MAPE) is 22.17%. This error could be smaller, but the unusual observation in the second quarter of 2018 ($t = 10$) affects the accuracy of the model. The forecast for the first quarter of 2021 is 840 units. The actual sales in that period were 501 units. That is, the model overestimated the sales by 339 units. However, the actual sales in that period also suggest that external factors might have reduced the sales by a significant proportion. These factors might be related with the COVID-19 pandemic or the uncertain situation in the energy market in Mexico.

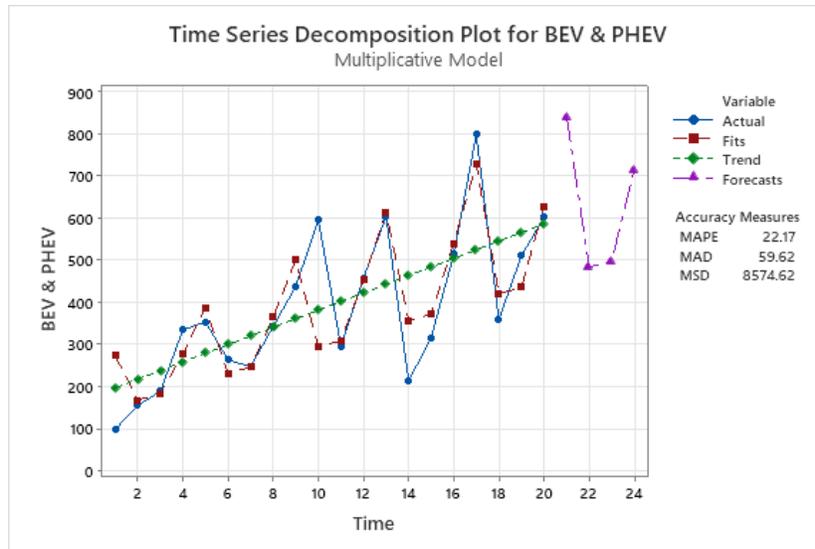


Figure 3. Actual time series, fitted model, trend and 2021 EVs sales forecast in Mexico.

In addition, a linear regression model was fitted to predict the EV sales per year. The fitted model, the actual series and the forecast for the next five years are shown in Figure 4. According to this figure, every year, the number of EVs sales increases by 342 units in average. The MAPE for this model is 8.2% and the coefficient of determination (R^2) is 90.36%. This model has higher accuracy as expected because of the principle of forecasting that suggests that models with high aggregation of the response variable have better accuracy than models with less aggregation. According to this model, 16,227 EVs are expected to be sold in the next five years. This represents an expected increase of 111.4% respect to the first five years.

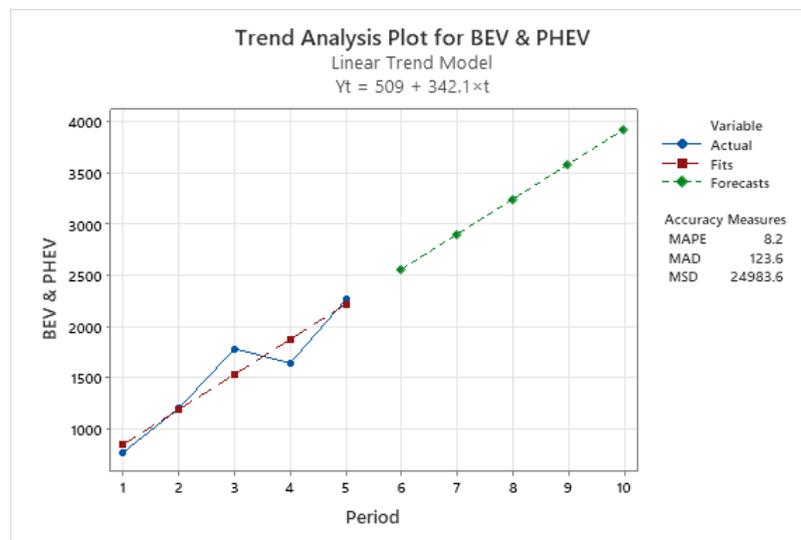


Figure 4. Linear regression model of the EV sales per year in Mexico.

4. Charging Infrastructure in Mexico

According to PlugShare (2021), there are approximately 1002 public charging stations in Mexico, including 67 fast charge stations. Fast chargers can charge up to 80% of the battery in less than one hour, depending on the power of the charger and the size of the battery. Figure 5 shows the location of charging stations in Mexico. We can observe high correlation between the number of stations in a state (Figure 5) and the sales of EVs (Figure 2). Moreover, the correlation coefficient between these variables is 0.95.



Figure 5. Charging stations in Mexico. Source: PlugShare (2021).

Based on this analysis, we obtain that the ratio Charging stations:EVs is 1:7.6. Considering that most of the charging stations comprise two or more chargers, the actual ratio chargers:EVs is larger than 1:10, which is the ratio suggested by the European Parliament and of the Council (2014). Nevertheless, the map in Figure 5 suggests that most of the stations are located in urban areas, which would hinder interurban traveling for BEVs with low range.

There are approximately 17 light passenger BEV models available in Mexico. Table 2 shows the BEV models that can be found in the Mexican market, their average range across different versions (obtained from the maker's websites) and the estimated market share based on the reported sales between 2016 and 2020 available at INEGI website (INEGI 2021a). The INEGI database does not report the sales of Tesla and Zacia models. However, experts in the EV market estimate that the number of Tesla models sold in Mexico are between 1000 and 2000 units. On the other hand, Porsche and Mercedes Benz recently introduced their BEV models in the country and the database does not show any sale in the period under study.

The table shows that most sold cars are models with low range. This might be due to the high upfront cost of EVs, which is mainly driven by the cost of the batteries. Therefore, considering the low availability of chargers outside urban areas and the low range of many EVs on the roads of Mexico, the possibility to complete interurban trips is restricted to only few models. In order to enable interurban traveling for most EV models, fast charging infrastructure must be deployed to guarantee access to chargers without significantly deviating from the highways.

As an example, Jalisco is the state with the third largest sales of EVs in Mexico and its capital city, Guadalajara Metropolitan Area, is the third largest metro area in the country. The distance to travel between the limits of Guadalajara and the limit of Mexico City is approximately 535 Km. In the path to travel between these cities there are three locations for fast chargers: Morelia Airport, Km 118 and Toluca. The path, location of stations, and distances between stations are shown in Figure 6. According to this figure, the distance between Guadalajara and the next station at Morelia Airport is 280 Km. The distance between the station at Morelia Airport and the next station Km 118 is 120 Km. The distance between the station at Km 118 and Toluca is 110 Km. Finally, the distance between Toluca and Mexico City limit is 25 Km.

Table 2. BEV models available in Mexico. *These vehicles cannot use fast chargers.

| Maker | Model | Range (km) | Share (%) |
|---------------|---------|------------|-----------|
| Nissan | Leaf | 240 | 31.7 |
| BMW | i3 | 260 | 29.7 |
| Renault | Twizy* | 100 | 11.8 |
| GM | Bolt | 416 | 7.8 |
| Audi | e-Tron | 446 | 6.6 |
| Renault | Kangoo* | 200 | 3.3 |
| JAC | E Sei 1 | 360 | 3.0 |
| JAC | E Sei 4 | 450 | 2.4 |
| Jaguar | I-Pace | 415 | 1.9 |
| JAC | E Sei 2 | 350 | 1.8 |
| Tesla | Model S | 647 | - |
| Tesla | Model X | 580 | - |
| Tesla | Model Y | 525 | - |
| Tesla | Model 3 | 423 | - |
| Porsche | Taycan | 400 | - |
| Mercedes Benz | EQC | 417 | - |
| Zacua | MX3* | 160 | - |

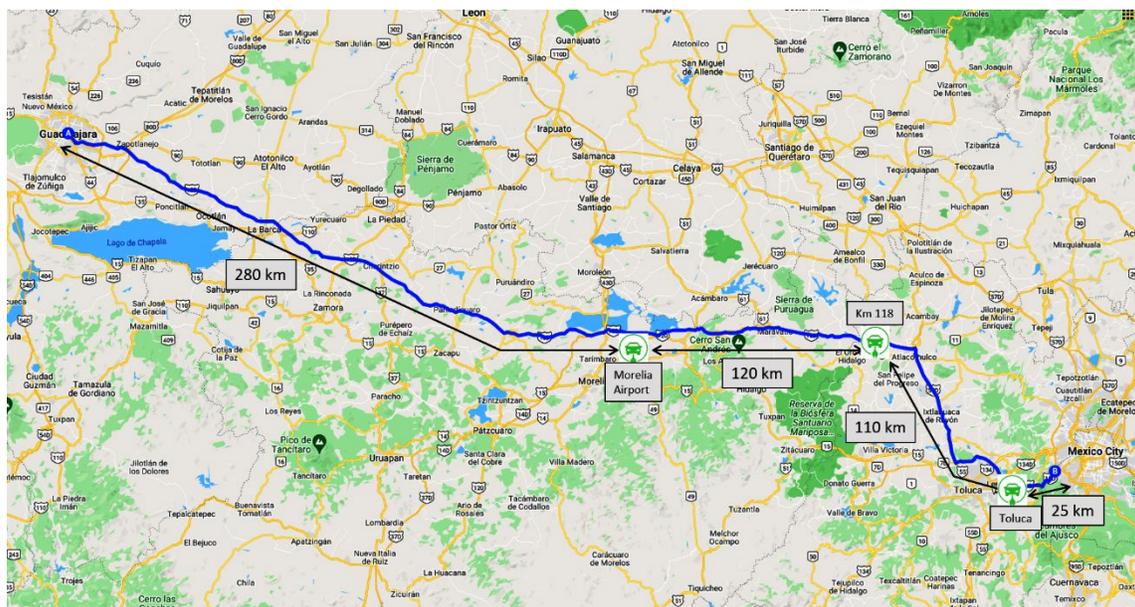


Figure 6. Path between Guadalajara and Mexico City and location of fast chargers.

Moreover, the chargers at Morelia Airport and Km 118 are Tesla Superchargers, which are not compatible with other vehicles. Hence, traveling between Guadalajara and Mexico City in a non-Tesla BEV would require a minimum range of 510 Km. None of the BEVs available in Mexico have this range, except for Tesla BEVs. The alternative to travel this route in a non-Tesla BEV is to deviate to other towns (e.g., Ocotlán, La Piedad, Zamora, Morelia), which might represent up to 60 additional Km, and use a slow charger that takes several hours to recharge the battery.

Figure 7 shows the paths and the location of fast chargers to travel to the main destination points in Jalisco based on intensive commercial and touristic activity. There are five routes shown in this figure: Route 1: Tlaquepaque (A)-

Tequila (B), Route 2: Guadalajara (C)-Mascota (H)-Puerto Vallarta (I), Route 3: Guadalajara (C)-Chapala (D)-Ajijic (E)-Mazamitla (F)-Ciudad Guzman (G)-Guadalajara (C), Route 4: Guadalajara (C)-Ocotlan (J)-La Barca (K), and Route 5: Guadalajara (C)-Tepatitlan (L)-San Juan de los Lagos (M)-Lagos de Moreno (N). Next, we describe the feasibility to travel each route based on the ranges shown in Table 2 (considering only the vehicles with the appropriate technology to use a fast charger) and the distances shown in Figure 7.

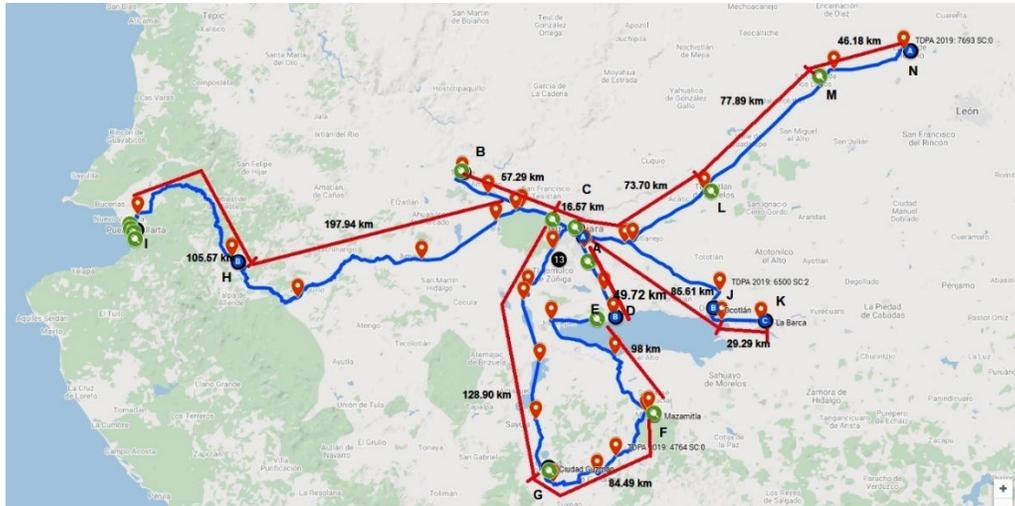


Figure 7. Main interstate highways and destinations in Jalisco. A: Tlaquepaque, B: Tequila, C: Guadalajara, D: Chapala, E: Ajijic, F: Mazamitla, G: Ciudad Guzman, H: Mascota, I: Puerto Vallarta, J: Ocotlán, K: La Barca, L: Tepatitlán, M: San Juan de los Lagos, N: Lagos de Moreno.

- Route 1: Any vehicle could make a round trip departing with a full charge.
- Route 2: A single way trip requires at least 310 Km of range to travel between Guadalajara and Puerto Vallarta. The two most popular models (61.4% of reported sales) have 240 Km and 260 Km of range, respectively. These models would need to be charged at Mascota. However, there are not fast chargers in Mascota. Hence, these models could not complete this route.
- Route 3: This route begins and ends in Guadalajara. The total route consists of 370 Km and there are four locations with universal fast chargers. The largest distance between chargers is 129 Km. Therefore, any vehicle could complete this route. However, vehicles with low range (between 240 Km and 360 Km) would need at least one charging stop.
- Route 4: The round trip of this route consists of 230 Km, just below the range of a Nissan Leaf. In theory, this type of vehicle could make a round trip departing with a full charge. However, it is very likely that they would need one charging stop. Nevertheless, there are not fast chargers along this route, and it would be very risky to try to complete a round trip using this type of BEV.
- Route 5: A single way trip requires 198 Km of range. Any vehicle could complete a single way trip departing with full charge. In order to complete the round trip, vehicles with low range would require at least one charging stop. There are two locations of fast chargers, one is a Tesla Supercharger and another one is a universal charger. Hence, any vehicle could complete the round trip. However, BEV's drivers need to plan accordingly the charging stops to avoid compatibility issues.

Based on this analysis we observe that the current charging infrastructure is still scarce to enable any BEV to complete interurban trips of relatively small distance. Moreover, charging infrastructure might exist, but compatibility issues would reduce the feasibility to complete the trips.

5. Conclusion

Electric mobility has been penetrating the markets worldwide at a high speed. Nevertheless, the pace of adoption of EVs in developing countries is slow. One of the main barriers is related with the scarce charging infrastructure and low range of BEVs, which produce range anxiety on the driver and hinders interurban traveling. In this paper, we analyzed the sales of EVs in Mexico and we fitted forecasting models to predict the incorporation of EVs on the roads of the country. In addition, we analyzed the feasibility to complete interurban trips using the state of Jalisco as a case study.

The sales of EVs in Mexico follow a linear trend with seasonal patterns. The first and the fourth quarters of the year are the seasons with the largest sales. So far, most of the EVs sold are in states with high economic development, including Mexico City, Estado de Mexico, Queretaro, Jalisco and Nuevo Leon. According to the prediction model, in the next five years about 16,000 new EVs are expected to be sold. If this prediction occurs with a high level of accuracy, by 2025 there would be about 30,000 EVs on the roads of Mexico. This number is still very low compared with the 35 million of light passenger vehicles registered by the beginning of this year. Hence, incentives with greater impact must be implemented to accelerate the replacement of ICE vehicles. These incentives could be related with the deployment of charging infrastructure and the reduction of upfront cost of vehicles with high range.

Most vehicles sold in Mexico are models with low range. In addition, charging infrastructure is mainly located in urban zones. Therefore, completing interurban traveling is challenging in Mexico. In the analysis presented for the state of Jalisco, we realize that current charging infrastructure is not enough to allow any BEV to complete trips within the state, and between the capital city Guadalajara and Mexico City. This problem is due not only to the lack of charging infrastructure, but also it is due to compatibility issues of fast chargers.

Future research lines extend to analyzing the main highways in Mexico to determine the feasibility to complete the trips and formulating an optimization model for the location of new chargers considering ranges of existing BEVs and compatibility issues.

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