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Chapter

Electric Vehicles Are a Zero-Emission Technology?

Alfredo Santana-Diaz

Abstract

Electric vehicles (EVs) are advertised as a zero-emission solution and as an alternative to the mobility problems of persons and goods in large cities. This chapter analyzes if these vehicles are really an option that would favor the green policies and environment of Latin American cities. The elements analyzed are the specific driving cycles for Latin American cities as well as geographical conditions, the access to technology, economic costs, and the infrastructure required to adapt EVs. These elements are are compared with the case of the countries of Northern Europe, where a greater circulation of these vehicles currently exists. The impact of transferring EV technology from one country to another, without considering specific situations, is also analyzed and, finally, some clues to be taken into account are stressed in order to determine if EVs in Latin America could be considered as green technologies.

Keywords: electric vehicles, driving cycles, mobility, zero-emission, transfer technology

1. Introduction

Global EV sales are increasing; annually, these global vehicle unit sales reached approximately 100,000 in 2012, 200,000 in 2013, and 300,000 in 2014, being the most important market in the USA, followed by Japan, Europe, and China [1]. Several automotive companies have wide programs to manufacture and sell electric vehicles; additionally, media reflects that the government, industries, as well as non-governmental organizations are pushing to have policies and benefits to adopt electric vehicle as a symbol of an eco-friendly transport technology. In particular, the actions of the governments of China, France, Germany, Japan, the Netherlands, Norway, the UK, and the USA are leading with policy incentives and infrastructure investments, and these countries make up over 90% of the world's electric vehicle market [1].

Countries of Northern Europe show important advances in spreading the use of electric vehicles. Countries with potential bigger markets as France, the UK, Japan, and the USA are developing consumer incentives and charging infrastructure support to increase the numbers of EVs in the cities.

India, China, and Latin American countries are rapidly changing to EV production and, in less proportion, to their use, as a result of two motivations: they are low-cost manufacturing countries and their hungriness to have access to the newest technologies. But, it is possible that the current state of this technology is not suitable for those countries, especially for Latin American ones.

In this chapter, the influence of geographic, economic, and social conditions is taken into account to determine the performance of EVs in Latin American countries; a case study of their behavior in Mexico City is also discussed.

Finally, a different scenario of their use and benefits is concluded; at this moment, the use of actual EVs conceived for different geographic, economic, and social conditions is not the best solution to really impact on the environment in Latin American countries.

2. Energy consumption in electric vehicles

To quantify the energy consumption in a vehicle, it is important to know three sets of key data:

- Vehicle dynamic characteristics
- Driving cycle
- Geo-environmental conditions

In particular, it is very important to also take into account the interconnected geographic and environmental conditions because, under real-driving conditions, EVs seem to be much more dependent on environmental conditions than fuel vehicles, especially in urban areas [2]. In those areas, the conditions of traffic obligate, sometimes, to make use of ventilation and air conditioning units; these conditions have an impact of approximately 10% of the fuel consumption on conventional vehicles [3], whereas it can be responsible of a range drop up to 40% for EVs [4]. Finally, the altitude of cities over the sea level and even the pavement deterioration are additional conditions that directly impact on the EV performance.

To ensure a good knowledge of energetic requirements of EVs, it is important to assume the range autonomy according to the purpose and the mobility needs of users. A utility vehicle will have a very different energy demand compared with a personal vehicle. Even for the same purpose, the traffic conditions shape different energy configurations.

2.1 Vehicle dynamic model

A classic vehicle dynamic model is shown in **Figure 1**, where acceleration force (Fa), drag force (Fd), roll force (Fr), mechanic force (Fm), and gravity force (Fg) are represented under an inclination θ (θ is the measured angle over the road).

The mechanical power needed at the tire of the vehicle is the product of the speed (v) and the mechanic force. The expression that describes the power consumption is given by the following Eq. (1) [5]:

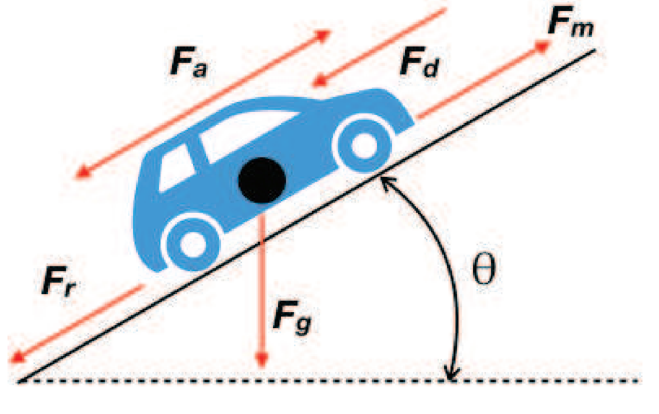

Figure 1.
Vehicle force diagram.

$$P_m = v F_m = v\left(F_a + F_d + F_r + F_g\right) \tag{1}$$

From Eq. (1), it is seen that the mechanic force required moving the vehicle is the sum of the acceleration force, the drag force, the roll force, and the gravity force; these forces are, respectively, depicted by Eqs. (2)–(5) as follows:

$$F_a = m_v \frac{dv}{dt} \tag{2}$$

$$F_d = \frac{1}{2}\rho_a A_f c_d v^2 \tag{3}$$

$$F_r = m_v c_r g \cdot cos\theta \tag{4}$$

$$F_g = m_v g \cdot sen\theta \tag{5}$$

where m_v is the vehicle mass, dv/dt is the longitudinal acceleration, A_f is the vehicle frontal area, c_d is the vehicle drag coefficient, ρ_a is the mass density of air, v^2 is the square of the speed, c_r is the tire's rolling coefficient, and g is the gravity force constant.

From Eqs. (1)–(5), it can be seen that the mass and the speed are the most important variables in the calculation of mechanic power for the vehicle. However, looking into each equation, there are other important parameters that usually influence consumption, for instance, the acceleration and the inclination of the road.

2.2 Driving cycle

An additional parameter that needs to be taken into account for the determination of the energy consumption is the driving cycle; in a few words, it is a data set showing the speed profile in function of driving.

In the driving cycles known as "New" European Driving Cycle (NEDC), the speed variations are considerably reduced [6]. Therefore, under this supposition, the driving cycle does not represent the real driving conditions in real-world vehicle usage as depicted in [7], and therefore the toxic emissions and fuel consumption of the vehicles are underestimated [8].

For this driving cycle, the influence of Eq. (2) over Eq. (1) is underestimated [9, 10]. An example of the NEDC results can be appreciated in **Figure 2**.

The driving cycle called the World-wide harmonized Light duty driving Test Cycle (WLTC) is a random cycle that proportionates nearest results to real driving conditions compared with those obtained in the driving cycle NEDC.

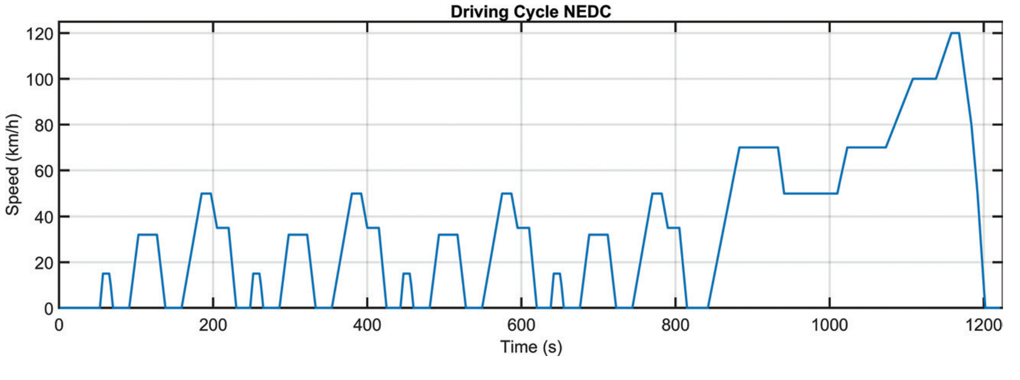

Figure 2.
Driving cycle NEDC.

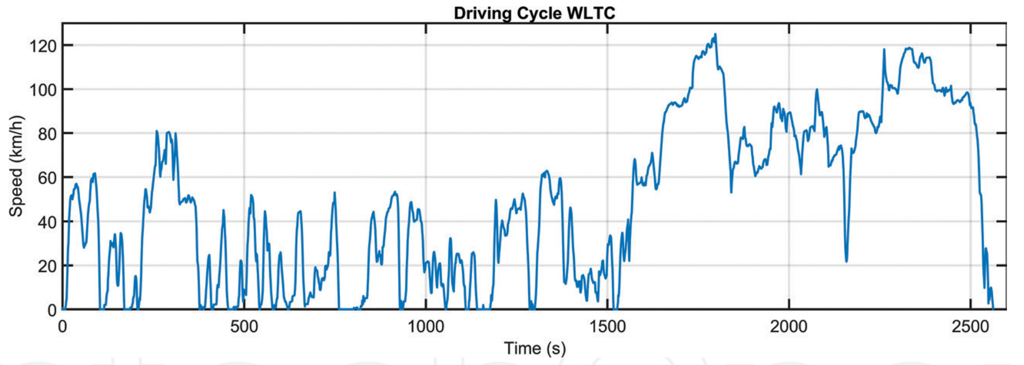

Figure 3.
Driving cycle WLTC.

Several works [11, 12] have shown closer results to real conditions using the WLTC because the consideration of the changes in accelerations and the different speed phases has a wide-range operation of vehicle. This year, WLTC becomes accepted as a better driving cycle [13]. As can be seen in **Figure 3**, the driving cycle WLTC provides more detailed information than driving cycle NEDC (**Figure 2**).

2.3 Geo-environmental conditions

Geo-environmental conditions are not, so often, taken into account on consumption analysis. This analysis is strongly influenced by the θ angle, because the elevation could dramatically change during the displacements, but in many cases, the angle is simplified to zero; then the force of gravity (Eq. (5)) is not more taken into account to calculate the power consumption (Eq. (1)). In the next section, the importance of this contribution would be emphasized.

2.4 Computing energy requirements

By integrating the power consumption (Eq. (1)), the required energy could be determined; during the cycle, it is possible to determine the maximum, the average, and the required power at each point.

After obtaining energy requirements, another parameter could be also determined, for example, the net energy required on the system during the cycle, the energy required per kilometer traveled, the energy recovered by regenerative brakes during the cycle, and the number of batteries.

A second iteration has to be done considering the new weight of the vehicle with the inclusion of the number of batteries calculated in the initial step. From these results, the real autonomy expected for the driving cycle is determined.

3. Main characteristics of commercial electric vehicles

The commercial electric cars have been designed to operate with NEDC driving cycles in the best geographical environmental conditions, ergo low traffic and without altitude changes (θ angle considered as zero) in order to facilitate comparisons between different vehicle companies.

The electric motors of vehicles have around 60 kW of power. The battery stack installed is about 24kWh. The automotive companies try to give to the consumer at least the same characteristic of performance of a combustion engine car, see **Table 1**.

The marketing of electric cars uses the traditional features of conventional gasoline cars. These accessories allow maximum comfort, such as air conditioning

	Car model	Company	Capacity (kWh)
1	Leaf	Nissan	24
2	iMiEV	Mitsubishi	16
3	E6	BYD	75
4	Tesla model S	Tesla	85
5	Chevrolet spark	GM	21
6	Fiat 500e	Chrysler	24
7	BMW i3	BMW	33
8	Focus	Ford	33

Table 1.
Commercial battery electric vehicles [14–16].

and electric screens for handling; however, in an electric car, this represents an additional spending of energy and bigger weight of the vehicle, so a greater number of batteries are necessary, and the cost of the vehicle substantially augments.

From these facts, Are then all these features necessary? Maybe EVs must be designed differently.

4. Environment conditions in different metropolises

Latin American cities have different conditions compared with cities of Europe or the USA, first of all, the traffic and road conditions, the elevation of a geographic location in cities, and finally the economic and social aspects of populations of these cities.

	Metropolitan Area	Population	Country	GDP (in billions USD)	Altitude Capital (m)	Difference (m)
1	São Paulo	21090792	Brazil	430.5	760	140
2	Mexico City	20892724	Mexico	403.6	2216	300
3	Buenos Aires	13693657	Argentina	315.9	10	74
4	Rio de Janeiro	12280702	Brazil	176.6	19	969
5	Lima	9904727	Peru	176.5	107	868
6	Bogotá	9286225	Colombia	159.9	2619	1141
7	Santiago	6683852	Chile	171.4	521	1783
8	Belo Horizonte	5829923	Brazil	84.7	877	684
9	Caracas	5322310	Venezuela	51.8	909	2506
10	Guadalajara	4796603	Mexico	80.7	1516	887
11	Porto Alegre	4258926	Brazil	62.1	1	301
12	Brasília	4201737	Brazil	141.9	1092	220
13	Fortaleza	3985297	Brazil	35.2	21	80
14	Salvador	3953290	Brazil	38.5	1	116
15	Recife	3914397	Brazil	40.5	1	116
16	Medellín	3777009	Colombia	43.5	1568	1737
17	Santo Domingo	3658648	Dominican Republic		42	145
18	Curitiba	3502804	Brazil	57.7	913	178
19	Campinas	3094181	Brazil	59.3	670	1372
20	Guayaquil	2952159	Ecuador		47	485
21	Puebla–Tlaxcala	2941988	Mexico	38.1	2175	422
22	Cali	2911278	Colombia		758	1209
23	Guatemala City	2749161	Guatemala		1529	866
24	Quito	2653330	Ecuador		2850	2396

Table 2.
Latin American metropolitan areas.

	City	Population	Country	Gross Domestic Product ($BN)	Altitude Difference (m)
1	London	8136000	UK	879.5	142
2	Berlin	3470000	Germany	215.2	71
3	Madrid	2824000	Spain	225.9	148
4	Roma	2649000	Italy	166.8	92
5	Paris	2244000	France	850	160
6	Hamburg	1705000	Germany	120.1	58
7	Barcelona	1455000	Spain	167.8	137
8	Milan	1306000	Italy	214.5	69
9	Munich	1195000	Germany	190	52
10	Birmingham	1021000	UK	81.8	87
11	Stockholm	952058	Sweden	180	105
12	Turin	921000	Italy	76.9	146
13	Frankfurt	717624	Germany	230	61
14	Oslo	634293	Norvege	74	369
15	Helsinki	629512	Finland	90.8	114
16	Copenhagen	583525	Denmark	134.3	53
17	Dublin	527612	Ireland	127.8	101
18	Edinburgh	482005	UK	41.8	112

Table 3.
European cities.

In **Table 2**, main Latin American metropolises are listed in function of their population; also the gross domestic product and the elevation in the cities are shown [17].

As it can be seen in **Table 2**, last column, several Latin American metropolises have considerable elevation differences on the same city; in these cases, the vehicles are confronted to important slopes, where the θ angle is not negligible affecting then the autonomy of electric vehicles.

By the other side, as it can be seen in **Table 2**, the big populations in these metropolises are related with high traffic density, and then, the average speed is lower, and acceleration changes could be important.

Comparing data reported in **Table 2** with European cities as reported in **Table 3** [17], it can immediately be remarked that elevation differences in European cities are lower than Latin American ones, considering the population density is also lower in European cities. The energy requirements are then different for the same category and use of vehicles in European or Latin American countries.

Besides these geographic and social differences shown in **Tables 2** and **3**, another notorious difference is the gross domestic product (GDP) between countries; in general, GDP are lower in Latin American cities.

Therefore, the electric vehicles in Latin American cities must have different characteristics making them more expensive. Then, the overcrowding of EVs in Latin American cities could be farther than European cities for economic factors. Since the EV market is smaller in Latin American cities, the infrastructure to have cleaner electric energy is also poorest.

5. Case study in Mexico City

Mexico City's government through Science and Innovation Development Agency (SECITI) sponsored the development of an electric taxi for the city in order to reduce pollution emissions. The group developing the cab for Mexico City was formed by the companies Moldex, Giant Motors, and the Research Center in Mechatronic Automotive from Tecnológico de Monterrey.

In the frame of this project, during 2016 and 2017, several tests under real driving conditions were running to design a specific electric taxi for Mexico City, taking into account the traffic, slopes, and operation conditions for the main commercial and residential areas.

Table 4 shows some results from these tests. First, it is clear that at a determined cycle, when slopes are not considered, the energy consumption is underestimated of around 16%. Then, the range autonomy will be shorter than that expected if the geographic data is not considered.

The energy consumption was also determined from the study of the same car in a chassis dynamometer under different driving cycles (see **Table 5**). The real driving cycle, shown in **Table 4**, has an energy consumption value similar to that obtained from WLTC 3 (**Table 4**), but concerning parameters as speed average and maximum speed, the values from real driving cycle are nearest to WLTC 2; then the traffic conditions (see **Figure 3**) shape the energy requirements in an important way. Limiting speed (60–100 km/h) allows energy savings of around 32%.

Concerning the energy consumption obtained from NEDC, and reported in **Table 5**, a difference of 17% with WLTC 3 results was founded, indicating that energy consumption is underestimated with NEDC cycles.From **Tables 4** and **5**, it could be perceived that the quantity of batteries, calculated from NEDC driving cycle, is underestimated, 16% caused by slopes and 17% caused by speed and acceleration.

In general, several commercial vehicles have been modeled using the NEDC driving cycle. Its performance would be far away from the published standards of operation.

5.1 Electric energy for electric vehicles

In Mexico, the main electric energy comes from thermal methods, then electric vehicles do not considerably reduce the pollutions caused by fossil fuels, and the emissions are only moved from cars to electric production centers.

From the analyses of electric taxi project in Mexico City, photovoltaic solar panel with battery support was not an economically feasible solution because the initial investment is very expensive; from additional calculations it was found that more than 7 years of daily use of vehicle is necessary to equal the electric cost offered by the

	Speed average (km/h)	Maximum speed (km/h)	Maximum acceleration (m/s^2)	Energy consumption (kWh/km)	Difference between energy consumption (%)
Real cycle (reference)	30.57	95.10	2.2	186	
Real cycle without slopes	30.57	95.10	2.2	156	−16%

Table 4.
Real driving conditions.

	Speed average (km/h)	Maximum speed (km/h)	Maximum acceleration (m/s^2)	Energy consumption (kWh/km)	Difference between energy consumption (%)
WLTC 3 without slopes	49.34	139.18	2.38	196	
NEDC (without slope)	32	120	1.04	163	−17%
WLTC 2 without slope	35.69	85.2	1	133	−32%

WLTC 3 was analyzed at maximum speed superior than 100km/h, and WLTC 2 at maximum speeds comprised between 60 and 100km/h.

Table 5.
Driving conditions in a dynamometer.

electric company. The hypothetical electric energy requirements of an important number of EVs (1000 or more) cannot be assured with the actual capacity in Mexico City.

Finally, when the price of electric vehicle for personal use is compared versus engine vehicles, they are three times more expensive.

6. Conclusions

If the automotive companies kept betting on personal EVs for Latin American cities, then those cars would require more energy (between 16 and 33%) than European ones, and therefore they would be more expensive or with a reduced autonomy. In order to adapt the EVs, they would have to be designed to be smaller and lighter.

Therefore, EVs for Latin American metropolis have to follow a different strategy from Europe looking in order to really obtain an environmental purpose.

The following declarations are proposed as recommendations to be implemented in Latin American cities:

First, EV manufactures have to determine the real cycle for these cities in order to keep the ethical use of the vehicle.

Second, the EVs for personal utilization are not suitable at that moment due to the current state of technology. The utility cars and the public transport could represent a better solution to the EV market, and the green effects could be more important.

Third, more efforts in research to enhance energy systems shall be done with an ecological approach instead of the economic motivation.

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Notes

Moldex Company

Moldex is a Mexican company manufacturing electric vehicles for utility purposes (http://moldexmexico.com/en/vehiculos-electricos/).

Giant Motors Company

Giant Motors is a Mexican company assembly light trucks (http://www.fawtrucks.mx/).

Research Center in Automotive Mechatronics (CIMA), Instituto Tecnológico de Monterrey

CIMA is a research center in automotive mechatronics from Tecnológico de Monterrey located in Toluca that focus in forming engineers and applied research for design, manufacturing, and energy issues for automotive industries (http://cima.tol.itesm.mx/).

Author details

Alfredo Santana-Diaz
Instituto Tecnológico de Monterrey, Research Center in Automobile Mechatronics, Toluca, México

*Address all correspondence to: asantana@itesm.mx

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