

# Electric Mobility Opportunities and Challenges

## A Case Study on Cairo – Egypt



**RCREEE** 

Regional Center for Renewable Energy and Energy Efficiency  
المركز الإقليمي للطاقة المتجددة وكفاءة الطاقة

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## Introduction

According to Paris Declaration on Electro-Mobility and Climate Change, at least 20 percent of all road transport vehicles globally to be electrically driven by 2030. Transportation sector accounts almost one-quarter (23 percent) of the current global energy-related greenhouse gas emissions (GHG) and is growing faster than any other energy end-use sector. In addition, GHG emissions from transportation are anticipated to rise nearly 20 percent by 2030 and close to 50 percent by year 2050 unless major action is undertaken (UN Climate Change Conference, 2015).

Cairo is the capital of Egypt. Currently Cairo has a population that is estimated to be above 20 million. The expected population in 2030 will be nearly 30 million as depicted in figure 1 (Macrotrends LLC). This incremental increase requires hard work and good planning to increase the quality of life for Cairo’s inhabitants.

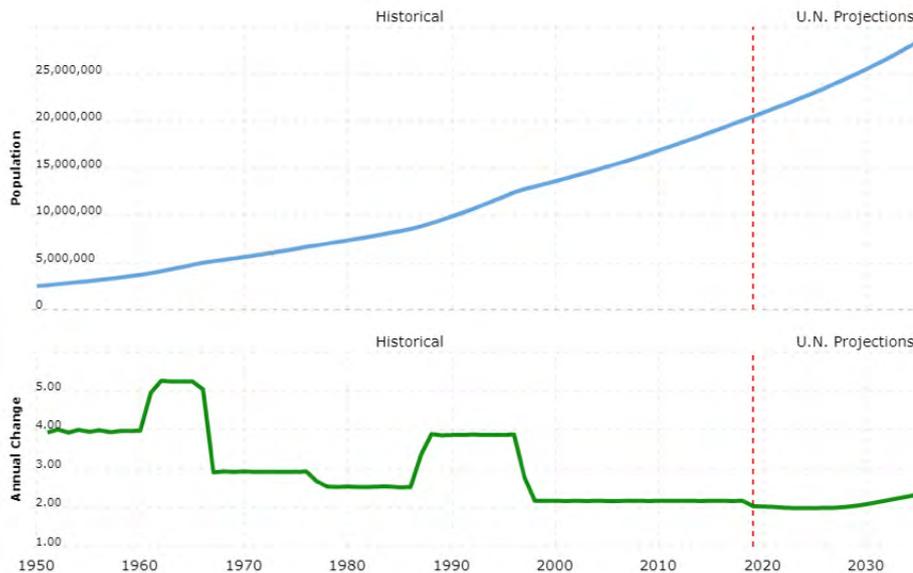


Figure 1, Projected population for Cairo, Egypt, Source Macrotrends

In 2017, Egypt had 9.9 million registered vehicles according to Central Agency for Public Mobilization and Statistics (CAPMS). Passenger cars are approximately half of this number. Cairo and Giza governorates (Greater Cairo) has the largest share with 3.3 million cars mostly working on gasoline (CAPMS, 2015). Needless to say, these cars emit several gases that pollute the environment and affect the air quality. For example, in December 2018, the average monthly reading for particulates matter that have diameter less than 10 micrometer (PM10) particles<sup>1</sup> in Tahrir square (Center of Cairo) was 200 µg/m<sup>3</sup>.day which was above the limit set by Ministry of Environment which is 150 µg/m<sup>3</sup>.day (Egyptian Environmental Affairs Agency, 2018). Figure 2 exhibits the reading of PM10 in Tahrir square. We can observe that the readings sometimes reach 400 µg/m<sup>3</sup>.day, that is more than double of the permissible limit. There is no doubt that cars emissions have great contribution to worsen the air quality and the current situation of climate change.

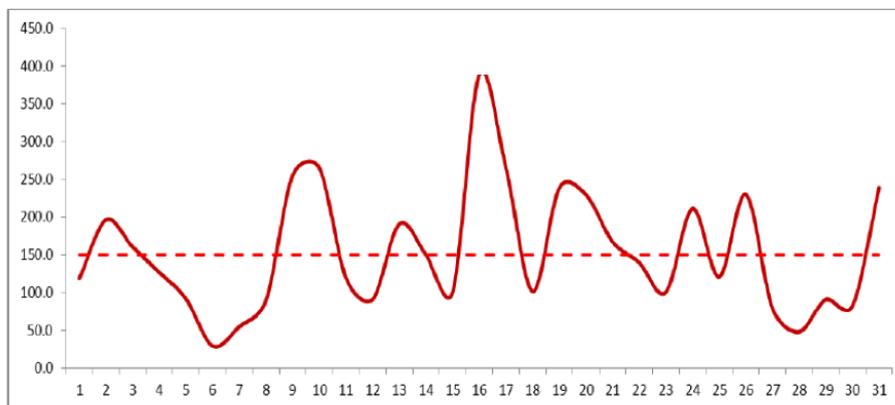


Figure 2, PM10 reading in Tahrir square, December 2018, Source: Egyptian Environmental Affairs Agency

<sup>1</sup> Besides gaseous pollutants, the atmosphere can also be polluted by particles. These particles (either in suspension, fluid or in solid state), have a divergent composition and size and are sometimes called aerosols. They are often catalogued as 'floating dust' but are best known as particulate matter (PM). PM10 is particulates matter with 10 micrometers or less in diameter

According to TomTom website<sup>2</sup> -which provide live traffic data- Cairo is very congested and ranked number 36 in 2019, and number 17 in 2018 over the world in the worst congested cities (TomTom International BV). Traffic Congestion is a chronic problem in Cairo with an adverse effect on the economy and quality of life. Time is wasted in the streets without any productivity, unnecessary fuel consumption, lower air quality, increased wear of the vehicles, and noise from cars' horn. All the above reduce the attractiveness of the city to the new businesses and opportunities. Next figure shows the amount of delays in the peak hours in 2019 in Cairo.



Figure 3, Amount of delays in the peak hours, Source: TomTom website

The main problem of congestion is the economic costs. In a study made by world bank after the request of the Egyptian government to estimate the economic costs of the congestion, the study found that the economic cost (in greater Cairo area, GCA) is around 47 Billion EGP this is equal to 3.6 percent of Egyptian GDP (World Bank, 2014). Mainly the inhabitants of GCA burden these congestion costs.

The expected economic costs in 2030 is massive and expected to be 105 Billion EGP (World Bank, 2014). Next table is from world bank report and is estimating the economic costs for congestion in 2030<sup>3</sup>.

Table 1, Summary of the Economic Costs of Congestion in 2030, Source: World Bank, 2014

Cost Component	Value	Annual Cost (Million USD)	Annual Cost (Billion LE)	Percent of Total Cost	Annual Cost Per Capita
Delay	4.5B hours	5,435.0	32.6	31%	192
Reliability	2.9B hours	3,391.7	20.4	19%	120
Fuel	4.0B liters	2,431.7	14.6	14%	86
CO <sub>2</sub>	14.9B kilograms	141.7	0.9	0.8%	5
Safety	0 fatalities -6,890, injuries 78,570 PDOs	- 191.7	-1.1	-1%	-7
VOC <sup>4</sup>	N/A	836.7	5.0	4%	30
Other Emissions	99.2 million kilograms	3,329.4	19.8	18%	117
Agglomeration/Productivity	N/A	1,677.4	10.0	11%	59
Suppressed Demand	N/A	418.1	2.5	3%	15
Housing Demand	N/A	10.7	0.1	0.2%	0.5
<b>Total</b>	<b>N/A</b>	<b>17,480.7</b>	<b>104.7</b>	<b>100%</b>	<b>617</b>

<sup>2</sup> [https://www.tomtom.com/en\\_gb/traffic-index/](https://www.tomtom.com/en_gb/traffic-index/)

<sup>3</sup> The costs in LE is currently different, Egyptian Government floated the currency several years after this study.

<sup>4</sup> Volatile Organic Compounds

Road traffic accidents result in 12,000 deaths each year in Egypt. The fatality rate is 42 deaths per 100,000 population. Majority of accidents are caused by passenger cars (48%), this information is according to the WHO Global Status Report on Road Safety published in 2012. The latest statistics for car accidents in the first half of 2019 refer that we have 870 accidents every month with accident severity rate 1.5 (deceased or injured/ accident) and cruelty of accidents 25.9 (deceased / 100 injured) in the first half of 2019 (CAPMS, 2019).

To summarize the above, Cairo has several problems when it comes to the usage of vehicles used for transportation. Problems can be classified into two categories; environmental and health and economic problems. Electric vehicles are a promising solution for these problems that can help to save the environment and promote the local economy. Next part of the report explains how electric vehicles can avoid these problems and achieve some sustainable development goals (SDGs).



## Electric Vehicles

Electric vehicle is a vehicle that uses electric motor -one or more- for propulsion. Electric vehicles have many types and range from hybrid EV, plug in hybrid EV, Battery EV, and Fuel cell EV. This report is concentrating on EV battery operated electric vehicles. EV has several advantages over fossil fuel powered vehicles which we can summarize as follows.

### Efficiency

EVs have higher efficiency when compared to fossil fuel powered vehicles using internal combustion engines (ICE). The well to wheel efficiency (W2W)<sup>5</sup> for EVs is much higher. W2W efficiency has two components; well to tank (W2T) and tank to wheel (T2W). Figure 4 exhibits the W2W, W2T, T2W concepts. For the latter, EVs operated by electric motors have a typical efficiency higher than 90% with relatively constant torque over the speed range. On the other side fossil fuel vehicles have an efficiency that is much lower than electric motors. Figure 5 shows different scenarios for W2W efficiencies in a study made to compare efficiencies of ICE with EVs that have an electricity powered from different sources (H. C. Righolt, 2013). Even EVs that are powered by coal have efficiency that is higher than ICE vehicles.

In addition to the above, EVs have regenerative braking system. Regenerative braking is to use the motor of the EV as generator then store the generated electricity in the EV's battery. Regenerative braking can save up to 20% of EV energy in real case study that was made in Rotterdam (Sterkenburg, 2011).

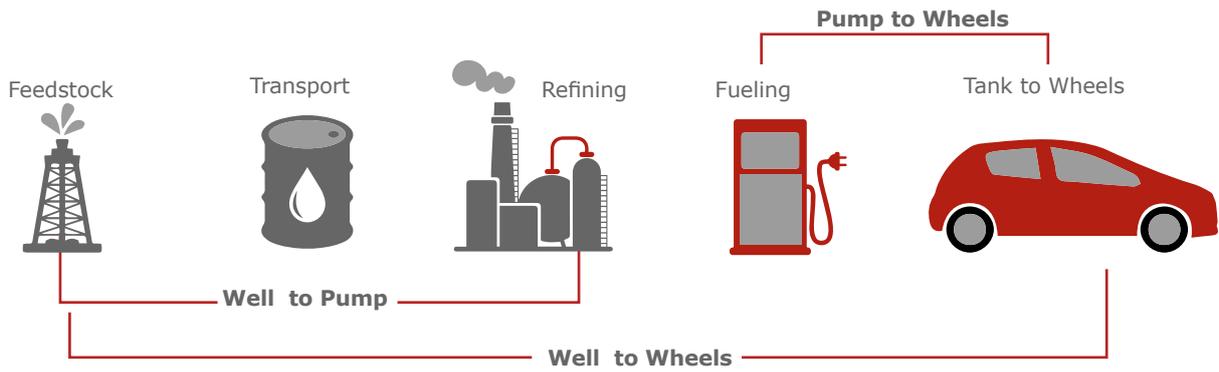


Figure 4, Well to Wheel efficiency, Source: Scott J. Curran, 2013

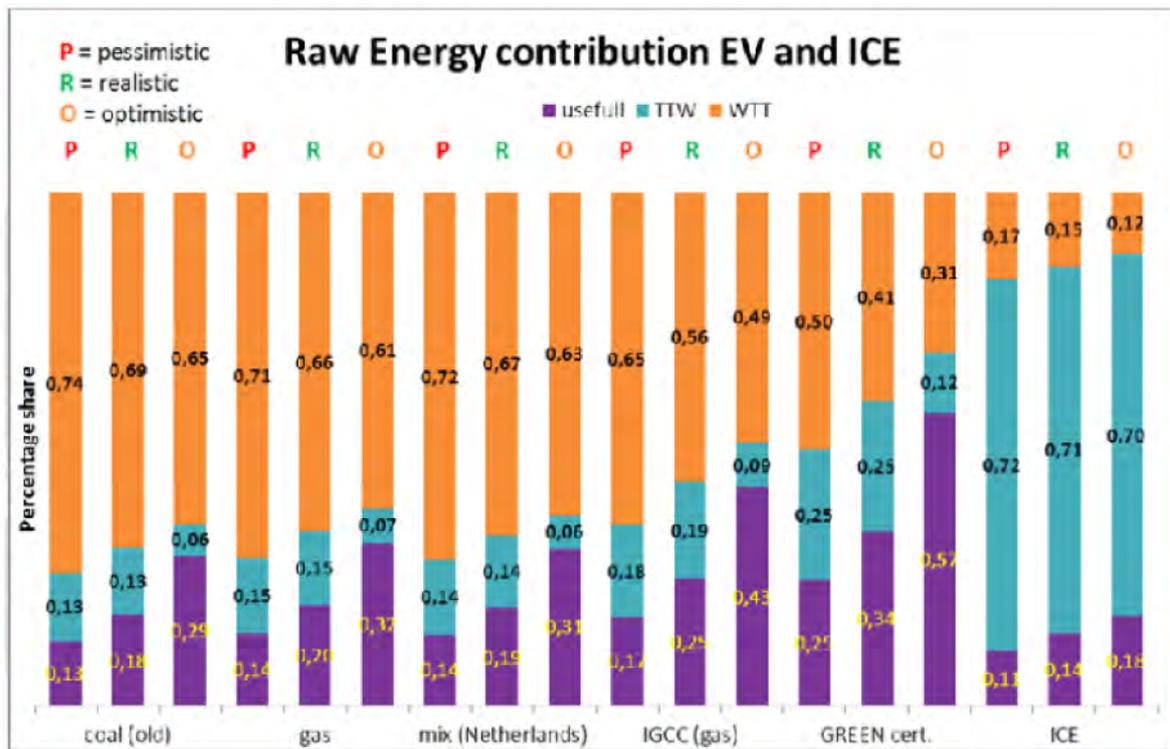


Figure 5, W2W efficiency, Source: (H. C. Righolt, 2013)

## Emissions

Because EVs have higher efficiency, they have much lower emissions than ICE. EVs have no tail pipe emissions. However, to what extent the emissions from EVs are lower depends on the energy mix or the fuel source of the electricity grid that charge the EV's battery. Using a web site belonging to "Alternative fuels data center (US department of energy)<sup>6</sup>" we can compare the emission from both types with different energy mix. Using the national averages of electricity generation mix (renewables 16.84%, nuclear 19.4%), the emissions from EVs are less than half of gasoline vehicles (figure 6). Taking the worst case, which at Wyoming state that depend mainly on coal for power generation with a percentage that reach 86%. The emissions from EVs are still lower than the gasoline vehicles (figure 7).

<sup>5</sup> W2W: Well-to-wheel efficiency is the specific life cycle assessment used for transport fuels and vehicles considering all energy losses right from the source of fuel, all the way to the wheels of the vehicles. The well-to-wheel analysis is used to assess total energy consumption, energy conversion efficiency and emissions, including their carbon footprint.

<sup>6</sup> [https://afdc.energy.gov/vehicles/electric\\_emissions.html](https://afdc.energy.gov/vehicles/electric_emissions.html)

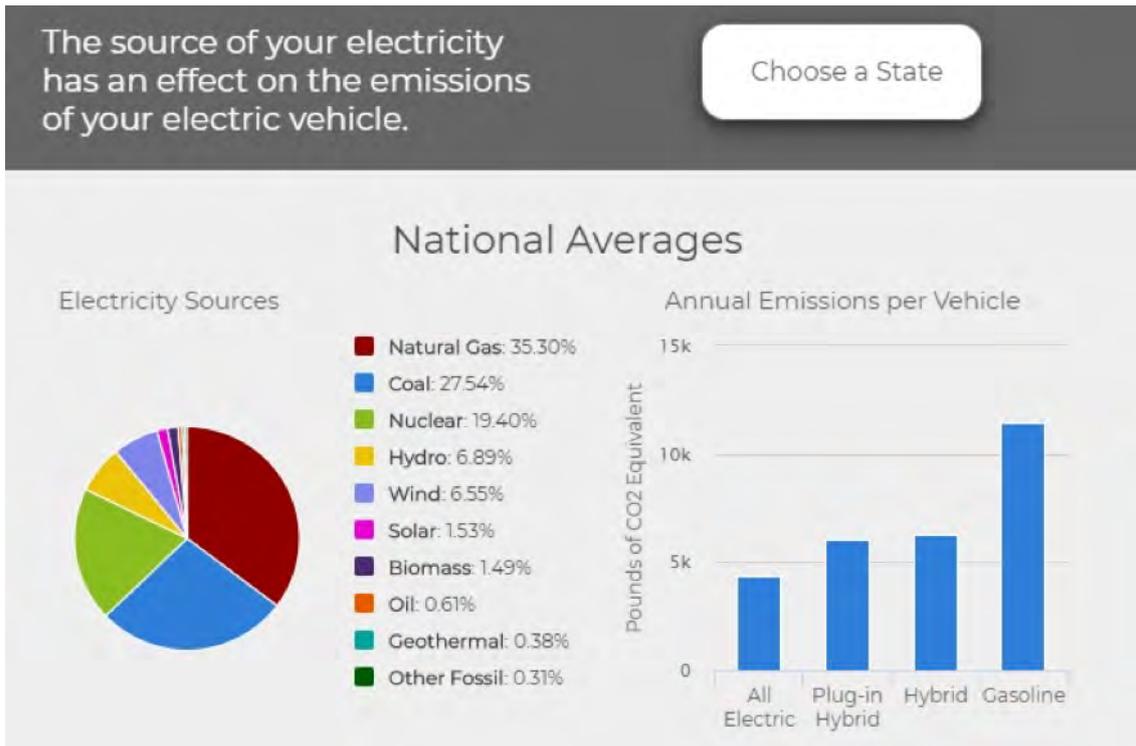


Figure 6, Emissions from different types of vehicles using national average of energy mix

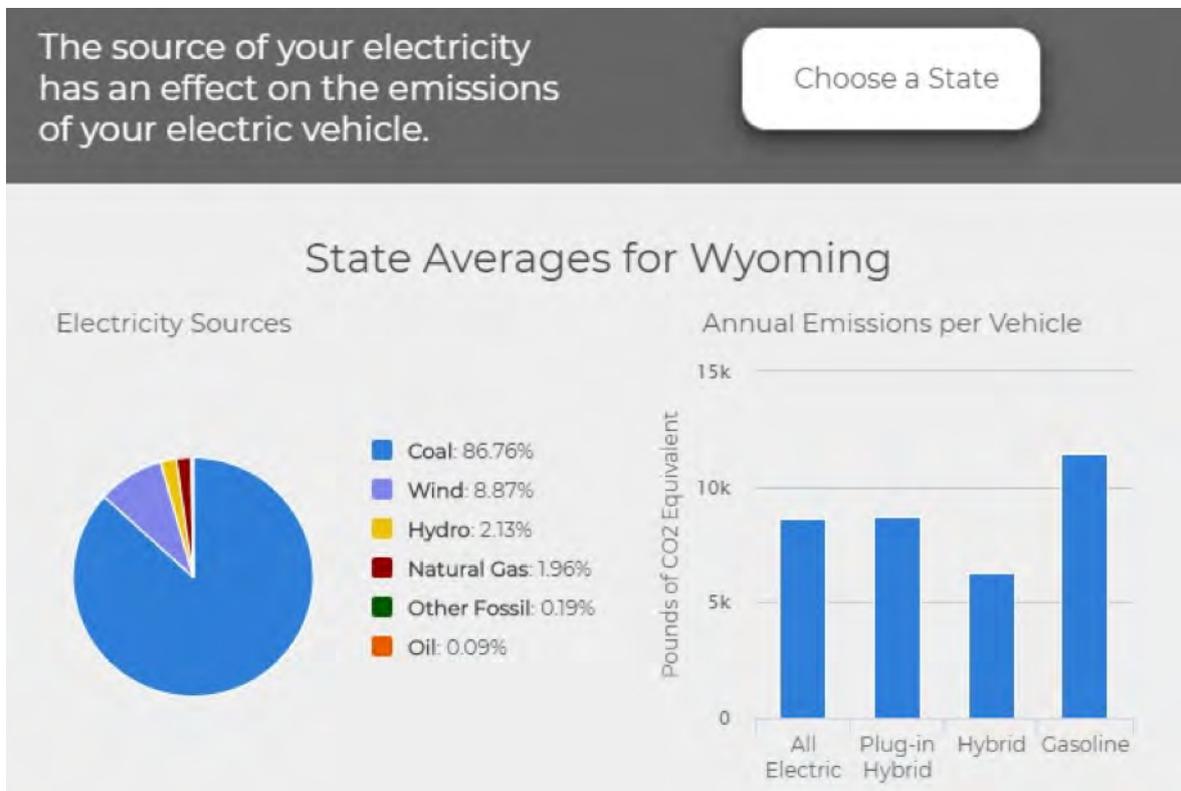


Figure 7, Emissions from different vehicles at Wyoming state

## Total Cost of Ownership

Total cost of ownership (TCO) is an indicator of how much will an EV cost through out its lifetime. TCO has two components; initial cost and operation cost. The initial cost of EV is higher than ICE vehicles. New technology comes with its costs. However, this is changing with the research. The major cost of EV is the battery (Kochhan, 2014). It represents 35-50 % of the cost of the cars (figure 8) (Kochhan, 2014). However, with the continuous research to bring the cost of battery down, the future is promising. Different studies showed that the prices for battery Pack will decrease significantly in the coming decade (Figure 9) (Lutsey, 2019).

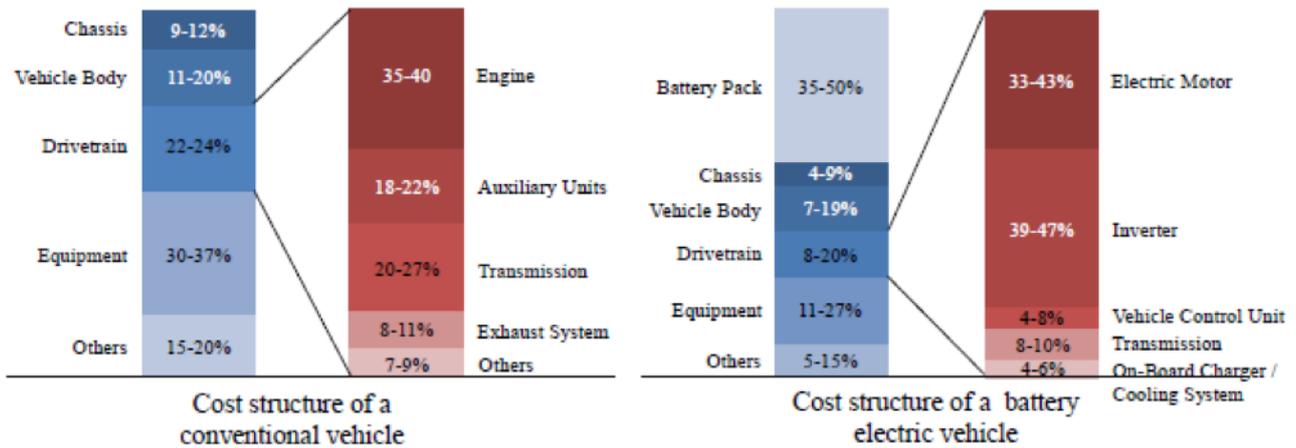


Figure 8, EV cost breakdown

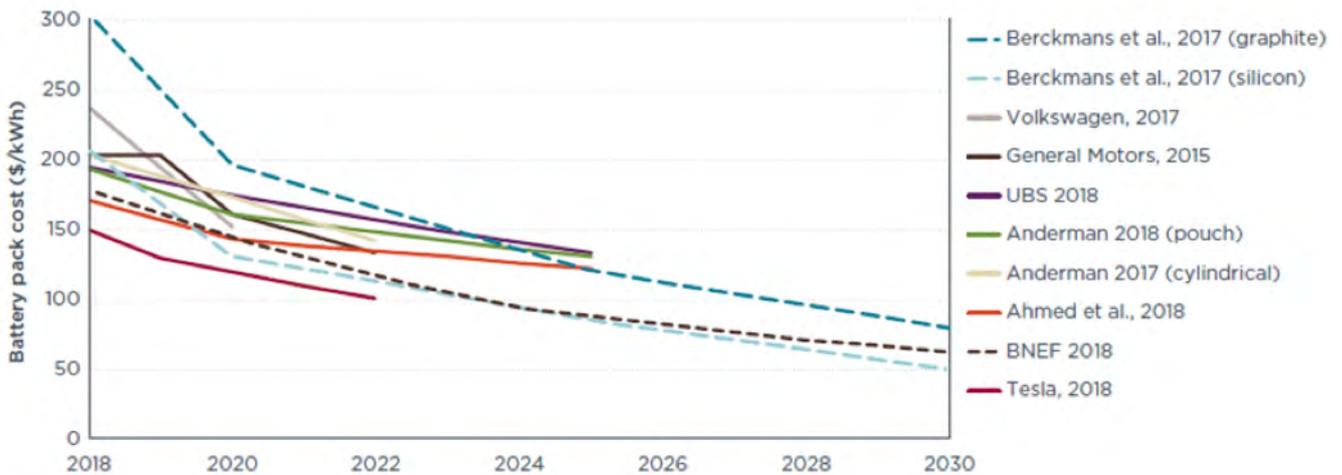


Figure 9, Development of battery pack prices

In addition, the research and development of other parts of EVs will bring the cost further down making EVs competitive with fossil fuel vehicles. We have seen already in luxury cars segment that EV is cheaper than their competitors. For example, Tesla Roadster has comparable or even superior performance compared to Bugatti Chiron with a price USD 200,000 compared to USD 3,000,000 for Bugatti (Figure 10) (Loveday, 2017). It is expected that in 2025, the cost of small range EV (up to 250 mile) will be the same or even lower than gasoline car (Figure 11) (Lutsey, 2019).

# Tesla Roadster vs Bugatti Chiron



1.9s

0-60mph

2.4s

8.8s

1/4 Mile

9.8s

4.2s

0-100mph

5s

250+mph

Top Speed

261mph

620mi

Range

286mi

4

Seating

2

(2 giant people squashed)

\$200,000

Price

\$3,000,000

Figure 10, Comparison between Tesla Roadster and Bugatti Chiron, Source: Loveday, 2017

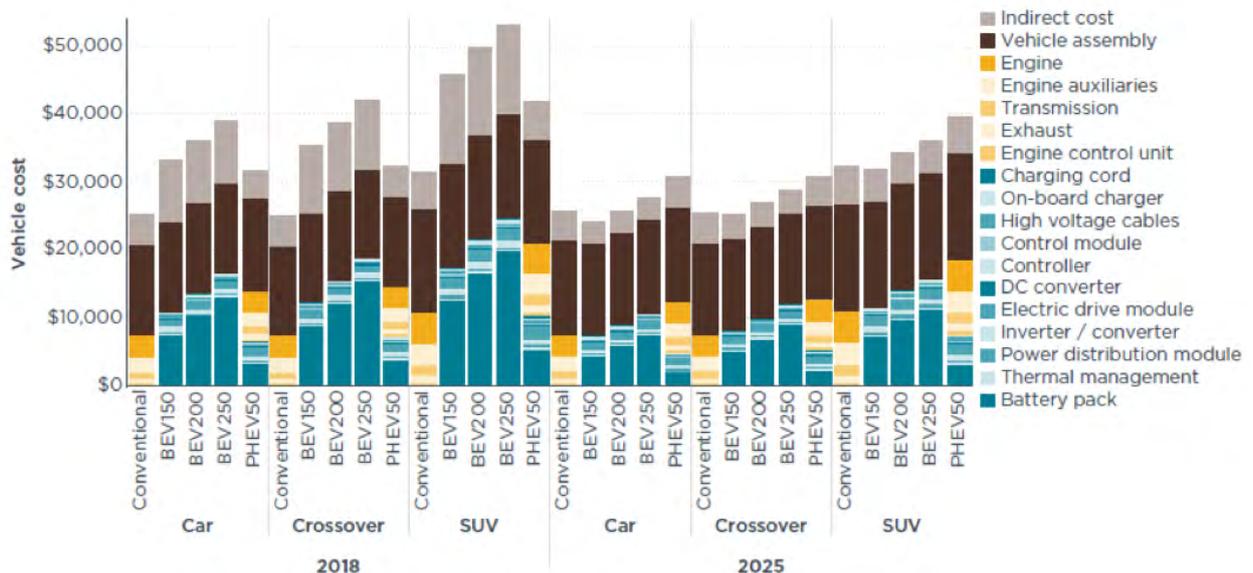


Figure 11, Future expected cost of EVs, Source: Lutsey, 2019

The second component of TCO is the operation cost. TCO varies greatly from location to another depending on gasoline/diesel prices, electricity prices, taxes, and maintenance cost. However, currently, in most cases using electricity to charge EV is cheaper than using conventional car. Usually EV requires lower maintenance because it has lower number of moving parts. The drive train is mainly electric motor that have stator and rotor. Nevertheless, the battery needs to be replaced every few years. But still the projection that TCO of EV will be lower than conventional car in this decade (figure 12) (Lutsey, 2019)

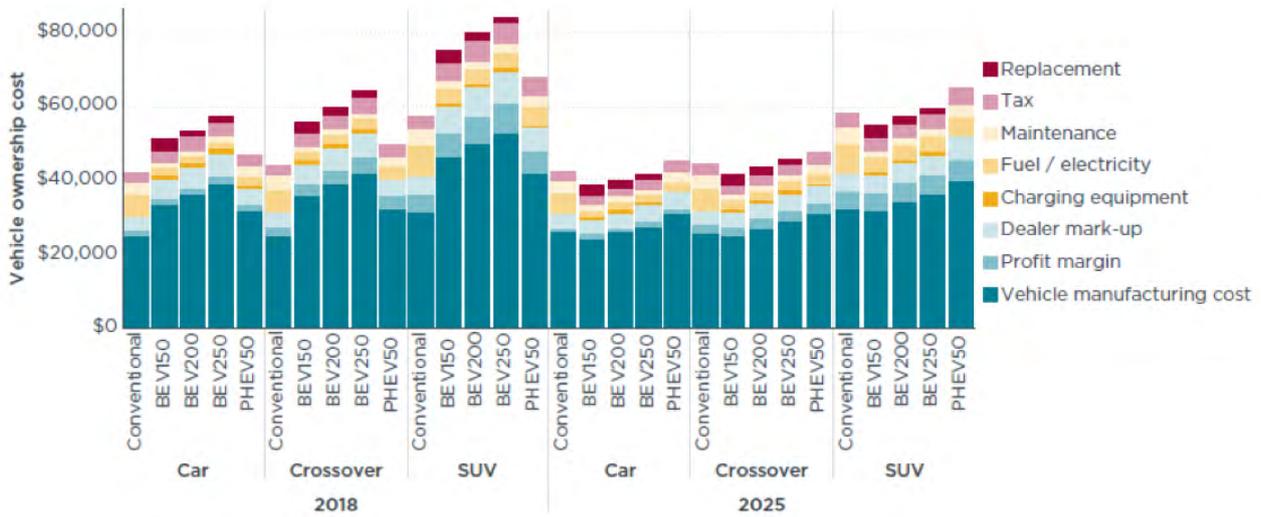


Figure 12, Future TCO for EVs, Source: Lutsey.2019

As discussed earlier, EVs have many advantages over conventional cars. Nevertheless, EVs have some challenges that need to be addressed like range concerns. EVs have lower range than conventional cars. Although most EVs in the recent years have comparable range. The lack of charging stations discourages people to consider EVs. Adapting EVs require some culture and routine change for the owner. Furthermore, adapting EVs will have an impact on electricity grid that need to be considered.

The question now, are electric vehicles suitable for Egypt and in particular Cairo city? In the next section, The report will discuss why EVs could help in promoting economy and enhancing the quality of life in Egypt.



## Electric Vehicles, Are They Suitable for Egypt?

In fiscal year 2016/2017, Egypt consumption of petroleum was 12,656 thousand ton. This value represents 15.95% of the total consumption. Transportation sector is the second consumer after electricity sector. The emissions from the transportation sector rank in the second position also with 18.49% after electricity sector. The amount is 38.83 million-ton CO<sub>2</sub> (CAPMS, 2016). In 2016, Egypt imported what worth 3550 million USD of petroleum products. That is nearly 5% of the total imports (CAPMS, 2017).

Natural gas is the most prominent fuel used for electricity generation. It represents 84.28% of the total fossil fuel used for power generation (Egyptian Electricity Holding Company, 2019). According to the latest reference, peak load reached 30,800 MW while the installed capacity available is 55,213 MW. (Egyptian Electricity Holding Company, 2019).

From the above stated facts, transforming to EVs will have two outcomes; the first outcome is to reduce the amount of imported fuel and to enhance the commercial balance. Second outcome is to reduce the emissions from the transport sector because electricity that will be used in EV is generated mostly from natural gas which is a cleaner that other fossil fuels. Both outcomes will lead to reducing economic cost caused by congestion as stated in table 1 above. Particularly in emissions and fuel cost components.

Some may argue -according to studies- that we should switch to compressed natural gas vehicle (CNGV) as W2W efficiency of CNGV cars are higher or similar to EVs that use electricity that is coming from natural gas as depicted in the next figure (Curran, 2014). However, the studies neglect two aspects. First, the renewable energy component that is continuously increasing. Egypt targets to reach 42% of renewable energy in power generation mix by 2035 (RCREEE, 2019). The efficiency can be even irrelevant if we used the electricity that is generated by RES during low load periods. Second aspect is; it is much easier to deal with the emissions that are generated at one location rather than several locations. We can apply different technologies at the chimney of power plants with cheaper cost and high control against controlling every car tail pipe.

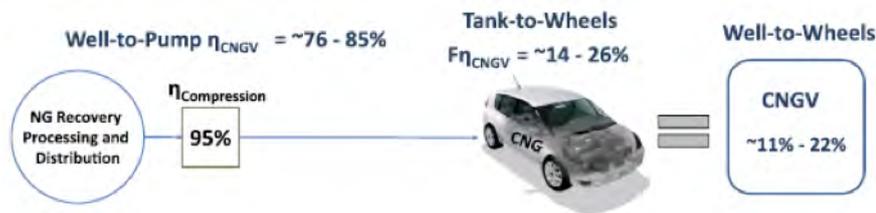


Fig. 3. WTW efficiency for CNGVs.

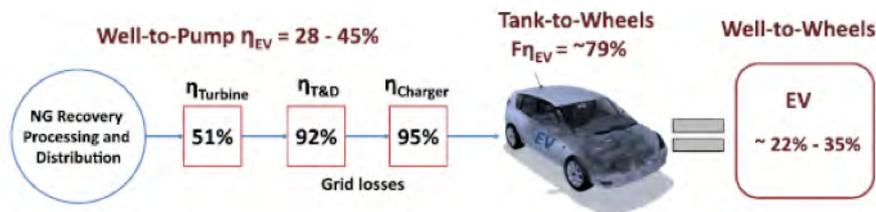


Figure 13, CNGV W2W efficiency

As said before, peak load reached 30,800 MW while the installed capacity available is 55,213 MW. (Egyptian Electricity Holding Company, 2019). This Installed extra capacity in Egypt raise the average cost of single kWh generated from all power plants. Imagine investing in equipment and use it for short time. That means the utilization factor <sup>7</sup> is low and the cost of production unit is very high. Transition to EVs would put those extra generation capacities in use. In addition, the negative impact of using EVs on the peak load will not be valid because of the extra capacity. The electricity grid is in position to accept the new loads. However, with the expansion of the EVs distribution network will need reinforcement or smart charging stations will be needed at this point.

<sup>7</sup> The utilization factor or use factor is the ratio of the time that a piece of equipment is in use to the total time that it could be in use

Egypt went under fuel subsidy reform to reach cost recovery level. According to the IMF press release on Saturday 06/04/2019:

‘The authorities are committed to reaching full cost recovery by the end of 2018/19 for all fuel products, except for LPG and fuel oil used in bakeries and electricity generation’

Using EVs -particularly in public transportation sector- will have numerous economic benefits for the country. These economic benefits will start from reducing the fossil fuel bill of the country, cheaper transportation for the citizen, reducing logistics cost, and creating new business line which will stimulate the economy. With a considerably large market size in a country like Egypt, it can be a leader of EVs manufacturing technology in the region.

As a conclusion, EVs is suitable for Egypt and particularly in greater Cairo that hosts the largest number of vehicles. We have introduced the economic, business, and environmental benefits from the transition to EVs. Nevertheless, various challenges are facing this transition. These challenges are mainly technological, economical, policy and cultural challenges. In the coming sections we will discuss them one by one.

## Technology Perspective

In this part, the report is suggesting the preferred technology that suits Egypt and cities like Cairo. introduces the different technologies that are used currently in electric vehicles. The efforts are to investigate on the best technologies that expected to work better than its alternatives.

## EV drive train Vs ICE drive train

EV<sup>8</sup> drive train is more efficient than the ICE drive train. The EV drive train is simpler and has fewer moving components. It contains electric motor and one step gear box. The speed is controlled by a variable speed drive. There is no idle losses because during stops the motor is not running. Figure 14 shows the losses in the EV drive train. The net efficiency is from 69% to 73% excluding the energy recovered from braking (regenerative braking) (US department of energy, office of energy efficiency and renewable energy).

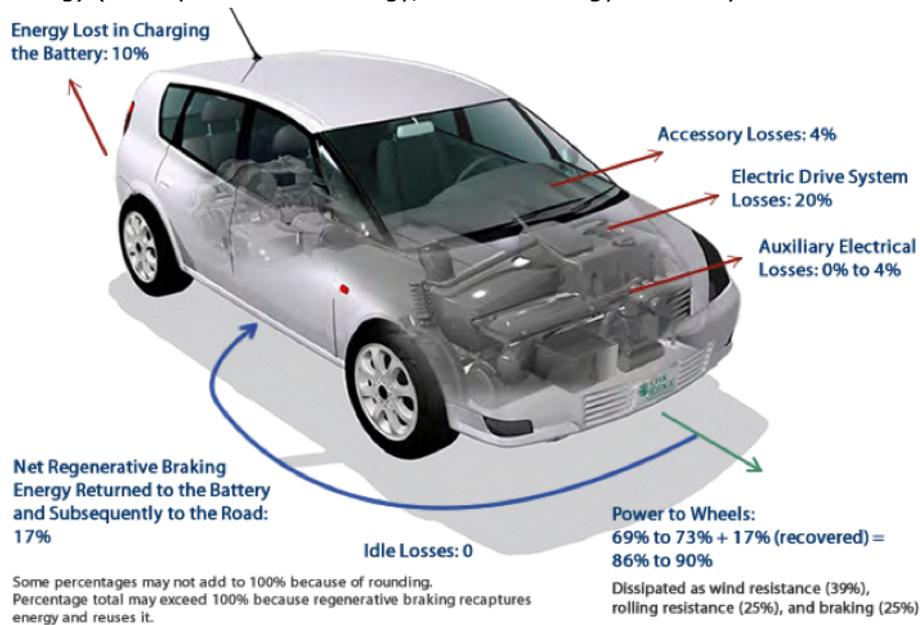


Figure 14, EV drive train, Source: US department of energy, office of energy efficiency and renewable energy

<sup>8</sup> Here we are concerned with battery electric vehicle.

The ICE vehicles have more moving componanets and more losses. The engine is working most of time and during idle<sup>9</sup>. The gearbox has several steps (gears). The estimated efficiency is between 16% and 25%. Figure 15 dipects the losses in the ICE vehicles drive train. This point was explained earlier but in a wider prospect which was well to wheel efficiency. Losses in drive train represent a part of tank to wheel efficiency. In a study made to compare performance of ICE vehicle powered by deisel engine and EV, the results found that the ICE car consumed on average double the power of EV for the same speed (Jorge Martins, 2013). Figure 16 shows some of the study results.

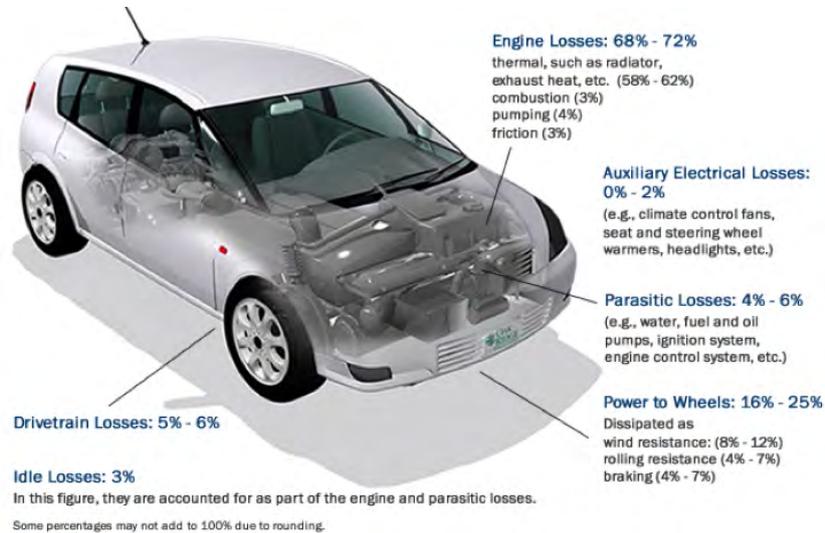


Figure 15, ICE drive train, Source: US department of energy, office of energy efficiency and renewable energy

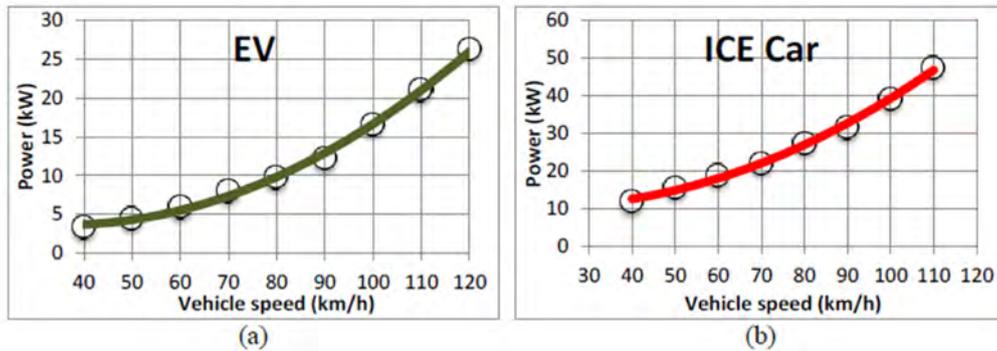


Figure 16, ICE car Vs EV power consumption

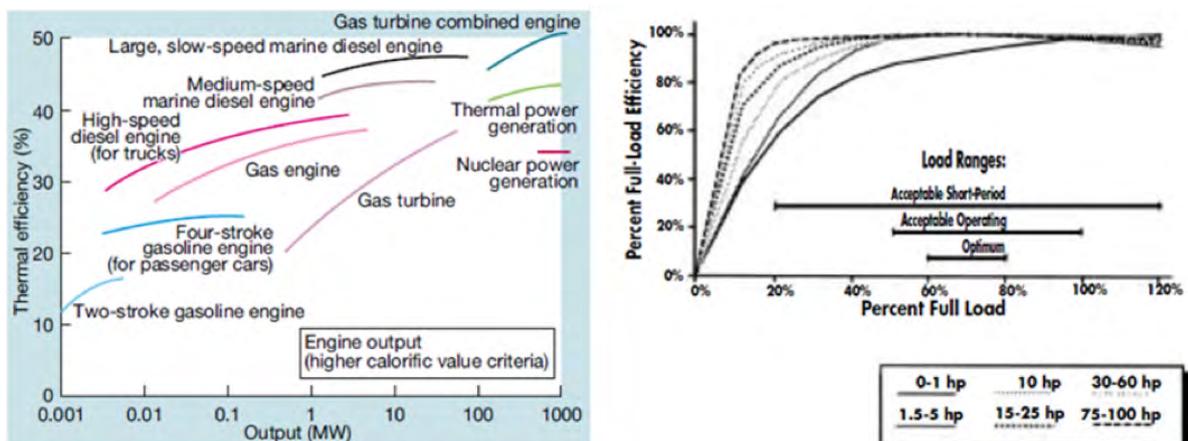


Figure 17, ICE efficiency versus electric motor

<sup>9</sup> Some high-end ICE cars have systems that stop the engine completely during traffic stops. However, most cars don't have these system

## ICE Motor Vs Electric Motor

Electric motors can have superior performance when compared to ICE. For example, efficiency of electric motors is above 90% across different loads. While ICE efficiency for cars is around 20-40 %. Figure 17 explains the electric motors and ICE efficiencies across different loads. Another advantage, maximum torque exists from starting speed in electric motors then starts to decrease at base speed, however the power reaches the maximum point at this point. In ICE, torque and power are not available from starting, they build up with speed until they reach maximum point then begin to decrease again.

There are four main types of electric motors that are used today in EV: Induction motors, permanent magnet motors, synchronous reluctance motor, and brushed motors. Table 2 summarize the advantages and disadvantages of each type and cars that use this technology (Fuad Un-Noor, 2017)

Table 2, Types of electric motors used in EVs

Motor Type	Advantage	Disadvantage	Vehicles Used In
<b>Brushed DC Motor</b>	<ul style="list-style-type: none"> <li>• Maximum torque at low speed</li> </ul>	<ul style="list-style-type: none"> <li>• Bulky structure</li> <li>• Low efficiency</li> <li>• Heat generation at brushes</li> </ul>	Fiat Panda Elettra (Series DC motor), Conceptor G-Van (Separately excited DC motor)
<b>Permanent Magnet Brushless DC Motor (BLDC)</b>	<ul style="list-style-type: none"> <li>• No rotor copper loss</li> <li>• More efficiency than induction motors</li> <li>• Lighter</li> <li>• Smaller</li> <li>• Better heat dissipation</li> <li>• More reliability</li> <li>• More torque density</li> <li>• More specific power</li> </ul>	<ul style="list-style-type: none"> <li>• Short constant power range</li> <li>• Decreased torque with increase in speed</li> <li>• High cost because of PM</li> </ul>	Toyota Prius (2005)
<b>Permanent Magnet Synchronous Motor (PMSM)</b>	<ul style="list-style-type: none"> <li>• Operable in different speed ranges without using gear systems</li> <li>• Efficient</li> <li>• Compact</li> <li>• Suitable for in-wheel application</li> <li>• High torque even at very low speeds</li> </ul>	<ul style="list-style-type: none"> <li>• Huge iron loss at high speeds during in-wheel operation</li> </ul>	Toyota Prius, Nissan Leaf, Soul EV
<b>Induction Motor (IM)</b>	<ul style="list-style-type: none"> <li>• The most mature commutatorless motor drive system</li> <li>• Can be operated like a separately excited DC motor by employing field orientation control</li> </ul>		Tesla Model S, Tesla Model X, Toyota RAV4, GM EV1
<b>Switched Reluctance Motor (SRM)</b>	<ul style="list-style-type: none"> <li>• Simple and robust construction</li> <li>• Low cost</li> <li>• High speed</li> <li>• Less chance of hazard</li> <li>• Long constant power range</li> <li>• High power density</li> </ul>	<ul style="list-style-type: none"> <li>• Very noisy</li> <li>• Low efficiency</li> <li>• Larger and heavier than PM machines</li> <li>• Complex design and control</li> </ul>	Chloride Lucas
<b>Synchronous Reluctance Motor (SynRM)</b>	<ul style="list-style-type: none"> <li>• Robust</li> <li>• Fault tolerant</li> <li>• Efficient</li> <li>• Small</li> </ul>	<ul style="list-style-type: none"> <li>• Problems in controllability and manufacturing</li> <li>• Low power factor</li> </ul>	
<b>PM assisted Synchronous Reluctance Motor</b>	<ul style="list-style-type: none"> <li>• Greater power factor than SynRMs</li> <li>• Free from demagnetizing problems observed in IPM</li> </ul>		BMW i3
<b>Axial Flux Ironless Permanent Magnet Motor</b>	<ul style="list-style-type: none"> <li>• No iron used in outer rotor</li> <li>• No stator core</li> <li>• Lightweight</li> <li>• Better power density</li> <li>• Minimized copper loss</li> <li>• Better efficiency</li> <li>• Variable speed machine</li> <li>• Rotor is capable of being fitted to the lateral side of the wheel</li> </ul>		Renovo Coupe

In our view, induction motors are the best option to be used in the Egyptian case for the following reasons:

- They are among the cheapest technologies to be used in EV. Cost is one of the key barriers that hinder the spreading of EVs.
- It has a good power to weight ratio when compared to other technologies. Only DC brushless motors have better value.
- Induction motors technology is matured and used widely in other applications. It is easy to maintain with low cost. It requires no special training for maintenance.

## EV Batteries

Battery is the most important part in EVs and the most expensive also. It determines a lot of EV's features like range, cost, and acceleration. Currently, there are different mature battery technology that can be used in electric vehicles. But each type has its pros and cons. Table 3 exhibits cross comparisons of the main types of batteries that can be used in EVs (Pillot, 2015).

Lithium-ion batteries are the dominant technology nowadays due to its advantages that are shown in table 3. It has replaced the lead-acid counterpart and became a mature technology itself. Their popularity led them to be the most used technology in EVs, for example, Nissan Leaf and Tesla Model S—all use these Li-ion batteries. Lithium batteries also have lots of scope to improve. Li-ion batteries have a promising future due to continuous R&D, so it can be said that lithium batteries will dominate the EV scene for some time to come.

High temperature affects the applications of Li-ion batteries due to the temperature-dependent performance. The optimal operating temperature range of Li-ion batteries is generally limited to 15–35 °C which will be perfect during the winter (Ma, 2018). High temperatures can be due to other response than the outside temperature, it also can be due to the heat development in the battery because of the internal resistance. Temperature can affect battery power, capacity, and lifetime. Due to the previous reasons, in summer batteries will need thermal management system. This can be done by air or liquid cooling.

EVs are exposed to start/stop situation frequently, especially in crowded city like Cairo and other urban cities. This means that battery discharge is variable and the average power required from batteries is low. Nevertheless, during acceleration or conditions like hill-climb a high power is required in a short duration of time. The peak power required in a high-performance electric vehicle can be up to sixteen times the average power (Chan, 2002). Ultra-capacitors fit in perfectly in such a scenario as it can provide high power for short durations. It is also fast in capturing the energy generated by regenerative braking. A combined battery and ultra-capacitors (battery-UC) system negates each other's shortcomings and provides an efficient and reliable energy system (Fuad Un-Noor, 2017).

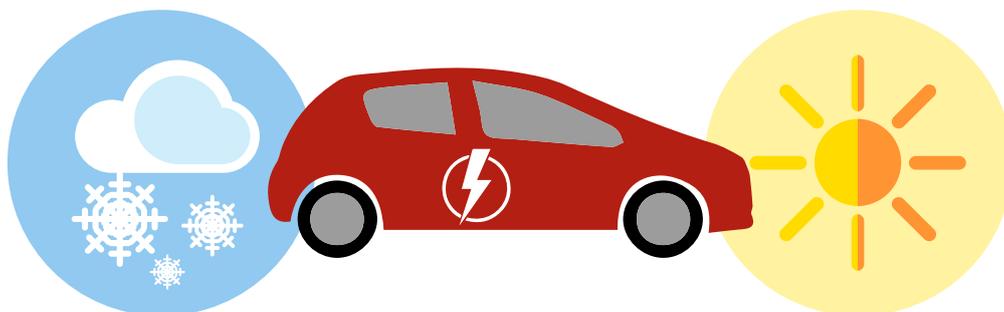


Table 3, Cross comparisons of batteries technologies Source: Pillot, 2015

Advantages Over	Lead-Acid	Ni-Cd (Nickel-Cadmium)	NiMH (Nickel-Metal Hydride)	Li-Ion (Lithium-Ion)	
				Conventional	Polymer
Lead-acid		<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Range of operating temperature</li> <li>• Rate of self-discharge reliability</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Rate of self-discharge</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Rate of self-discharge</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Rate of self-discharge</li> <li>• Design features</li> </ul>
Ni-Cd (Nickel-Cadmium)	<ul style="list-style-type: none"> <li>• Output voltage</li> <li>• Cost</li> <li>• Higher cyclability</li> </ul>		<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Rate of self-discharge</li> <li>• Output voltage</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Rate of self-discharge</li> <li>• Design features</li> </ul>
NiMH (Nickel-Metal Hydride)	<ul style="list-style-type: none"> <li>• Output voltage</li> <li>• Cost</li> <li>• Higher cyclability</li> </ul>	<ul style="list-style-type: none"> <li>• Range of operating temperature</li> <li>• Cost</li> <li>• Higher cyclability</li> <li>• Rate of self-discharge</li> </ul>		<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Range of operating temperature</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Range of operating temperature</li> <li>• Rate of self-discharge</li> <li>• Design features</li> </ul>
Li-Ion (conventional)	<ul style="list-style-type: none"> <li>• Cost</li> <li>• Safety</li> <li>• Higher cyclability</li> <li>• Re-cyclability</li> </ul>	<ul style="list-style-type: none"> <li>• Range of operating temperature</li> <li>• Cost</li> <li>• Safety</li> <li>• Higher cyclability</li> <li>• Recyclability</li> </ul>	<ul style="list-style-type: none"> <li>• Cost</li> <li>• Safety</li> <li>• Rate of discharge</li> <li>• Re-cyclability</li> </ul>		<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density (potential)</li> <li>• Cost</li> <li>• Design features</li> <li>• Safety</li> </ul>
Li-Ion (polymer)	<ul style="list-style-type: none"> <li>• Cost</li> <li>• Higher cyclability</li> </ul>	<ul style="list-style-type: none"> <li>• Range of operating temperature</li> <li>• Higher cyclability</li> <li>• Cost</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Cost</li> <li>• Higher cyclability</li> </ul>	<ul style="list-style-type: none"> <li>• Range of operating temperature</li> <li>• Higher cyclability</li> </ul>	
Absolute advantages	<ul style="list-style-type: none"> <li>• Cost</li> <li>• Higher cyclability</li> </ul>	<ul style="list-style-type: none"> <li>• Cost</li> <li>• Range of operating temperature</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Range of operating temperature</li> <li>• Rate of self-discharge</li> <li>• Output voltage</li> </ul>	<ul style="list-style-type: none"> <li>• Volumetric energy density</li> <li>• Gravimetric energy density</li> <li>• Range of operating temperature</li> <li>• Rate of self-discharge</li> <li>• Output voltage</li> <li>• Design features</li> </ul>



## Charging System

There are two systems for EV charging: AC and DC systems. Each system has different voltage level for charging. Table 4 and 5 summarize the different voltage level for charging for AC and DC respectively.

Table 4, Voltage level for AC charging

AC Charging System	Supply Voltage (V)	Maximum Current (A)	Branch Circuit Breaker Rating (A)	Output Power Level (kW)
Level 1	120 V, 1-phase	12	15	1.08
	120 V, 1-phase	16	20	1.44
Level 2	208 to 240 V, 1-phase	16	20	3.3
	208 to 240 V, 1-phase	32	40	6.6
	208 to 240 V, 1-phase	≤80	Per NEC 635	≤14.4
Level 3	208/480/600 V	150–400	150	3

Table 5, Voltage levels for DC charging

DC Charging System	DC Voltage Range (V)	Maximum Current (A)	Power (kW)
Level 1	200–450	≤80	≤36
Level 2	200–450	≤200	≤90
Level 3	200–600	≤400	≤240

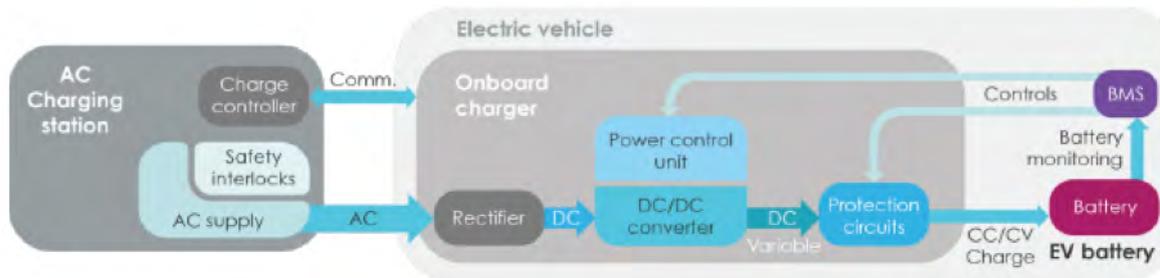
Table 6, Charging standards, Source: Hussain Shareef, 2016

Standard	Abbreviation	Scope
IEC 61851: conductive charging systems	IEC 61851-1	Defines cables and plug setups
	IEC 61851-23	Describes electrical safety, harmonics, grid connection, and communication architecture for DCFC station (DCFCS)
	IEC 61851-24	Explains digital communication for DC charging control
IEC 62196: Plugs, socket-outlets, vehicle connectors and inlets	IEC 62196-1	Explains general requirements for EV connectors
	IEC 62196-2	Describes coupler types for different charging mod
	IEC 62196-3	Defines connectors and inlets for DCFCS
	IEC 60309-1	Explains general requirements for CS
IEC 60309- Plugs, socket-outlets and couplers	IEC 60309-1	Explains general requirements for CS
	IEC 60309-2	Describes different sizes of plugs and sockets with different number of pins based on current supply and number of phases, also defines color coded connector based on voltage range and frequency
IEC 60364		Describes about electrical installations for buildings
SAE J1772: conductive charging systems		Defines connectors for AC charging Describes new Combo connector for DCFCS
SAE J2847: Communication	SAE J2847-1	Describes the communication medium and criteria for the EV to connect to the utility for AC Level 1 and AC Level 2 energy transfer
	SAE J2847-2	Defines additional messages for DC energy transfer
SAE J2293	SAE J2293-1	Describes the total EV energy transfer system and allocates requirements to the EV or EVSE for the various system architectures
SAE J2344		Describes guidelines for electric vehicle safety
SAE J2954: inductive charging		Under development

From the above table it can be seen that DC charging has higher voltage levels, thus the charging process is much faster. However, DC charging requires special transformer and cables which lead to more costs that will be brought to the charging stations. Various charging standards have been developed to govern charging process. The standards covers every aspect like charging plug, communication between station and EV, and mode of charging. Table 6 summarize charging standards (Hussain Shareef, 2016).

Different types of plugs are used by different manufacturers. And this is a problem for charging station to decide which type of plugs to be installed. For AC charging, the charging process exploits the on-board charger that exist in the EV, see figure 18.

Figure 18, Ac charging



There are four types of plugs that are used in DC charging:

- The Type 1 connector, which is mostly used in USA & Japan
- The Type 2 connector, which is mostly used in Europe, including those of Tesla cars
- The Type 3 connector, used in Europe but is being increasingly phased out by Type 2 connectors
- And finally, the proprietary connector used by Tesla for its cars in the USA

Besides this, China has its own standard for AC charging, which is like Type 2 connectors. Figure 19 shows the different types of plugs for AC charging.



Figure 19, AC charging plugs

There are four types of plugs that are used in AC charging:

- The CCS-combo 1, which is mainly used in the US, The Type 2 connector, which is mostly used in Europe, including those of Tesla cars,
- The CCS-combo 2, which is mainly used in Europe, And finally, the proprietary connector used by Tesla for its cars in the USA,
- The Chademo connector, used globally for cars built by Japanese automakers.
- The Tesla DC connector, which is used for AC charging as well
- And finally, China has their own DC connector, based on the Chinese GB/T standard.

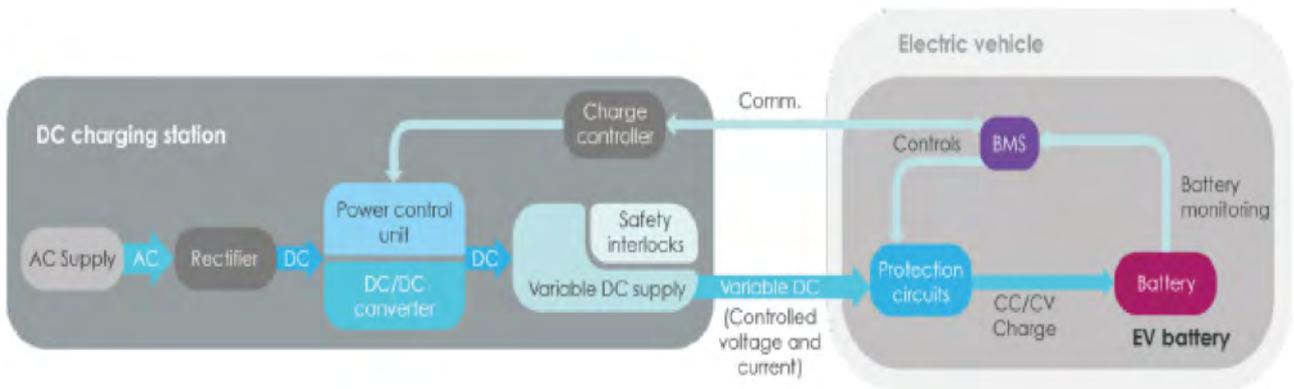


Figure 20, DC charging



Figure 21, DC charging plugs



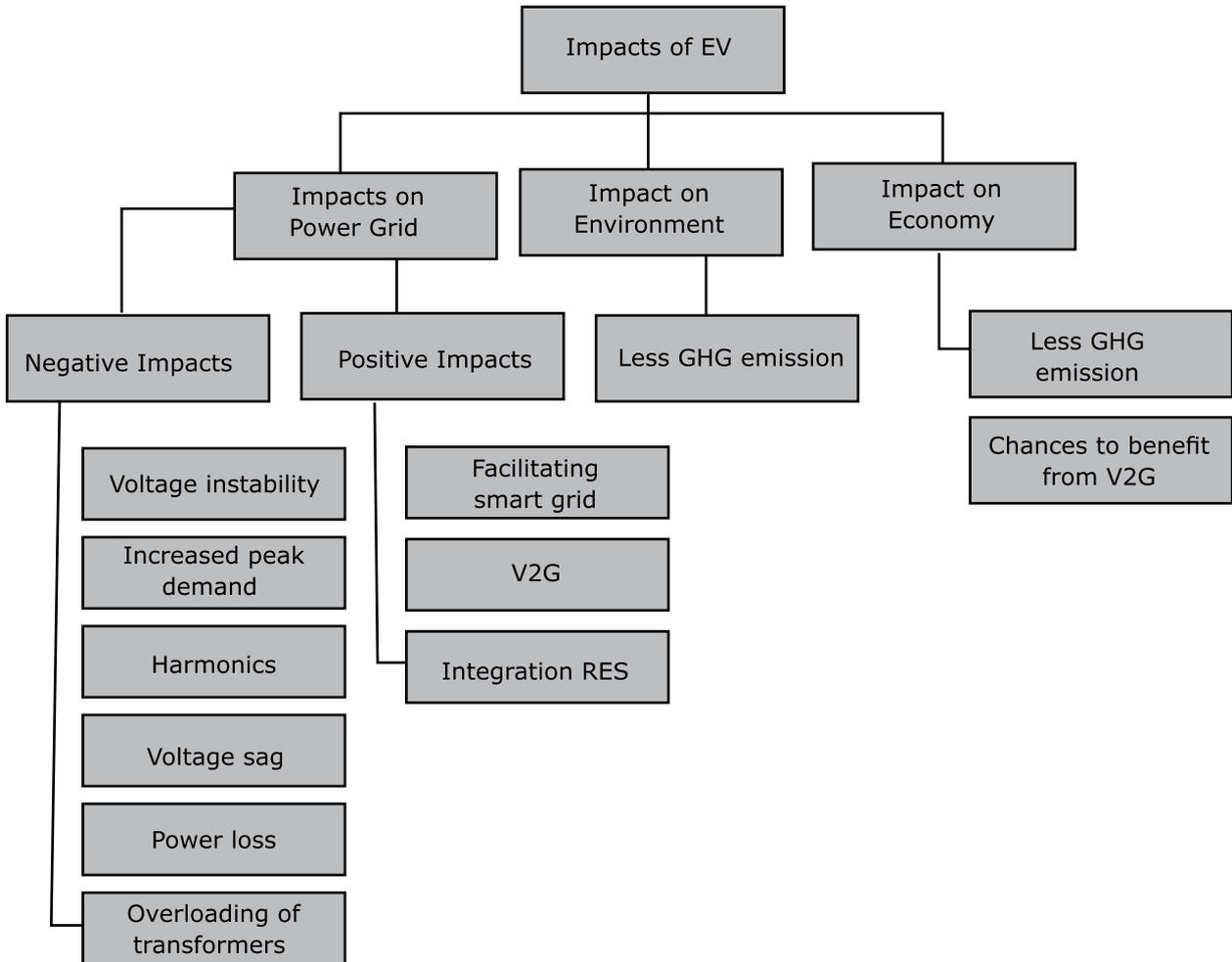


Figure 22, EVs impacts

EVs are used for transportation, however, they will affect a lot of other areas. The shift towards EVs is driven by EVs impacts on the environment and the economy. EVs are gaining popularity because of the benefits they provide in all these areas, but with them, there come some problems as well. Figure 22 illustrates the impacts of EVs on the power grid, environment and economy.

However, using smart charging EVs negative impacts can be mitigated and even transferred to opportunities to make power systems more agile. If charging stations are transferred to be bidirectional instead of unidirectional, EVs will be able to provide valuable service to the grid. The above concept is called V2G.

V2G or vehicle to grid is a method where the EVs can provide power to the grid. In this system, the vehicles act as loads when they are drawing energy, and then can become dynamic energy storages by feeding back the energy to the grid. Table 7 exhibits the characteristics of unidirectional and bidirectional V2G systems (Jia Ying Yong, 2015).

Renewable energy sources (RES) can be more promising with EVs integrated into the system. EVs owners can benefit from RES to locally charge their EVs. Parking lot roofs can install PV panels which can charge the vehicles parked underneath it as well as supplying the grid in case of excess generation. The V2G structure is further helpful to integrate RES for charging of EVs, and to the grid as well, as it enables energy arbitrage, the selling of energy to the grid when there is surplus, for example, when vehicles are parked and the system knows the user will not need the vehicle before a certain time. V2G can also enable increased penetration of RES in the grid. Table 8 summarizes the interaction of EVs with RES (Jia Ying Yong, 2015).

Table7, Unidirectional and bidirectional V2G characteristics, Source: Jia Ying Yong, 2015

V2G System	Description	Services	Advantages	Limitations
Limitations	Controls EV charging rate with a unidirectional power flow directed from grid to EV based on incentive systems and energy scheduling	Ancillary service—load levelling	-Maximized profit -Minimized power loss -Minimized operation cost -Minimized emission	Limited service range
Bidirectional	Bidirectional power flow between grid and EV to attain a range of benefits	-Ancillary service spinning reserve -Load leveling -Peak power shaving - Active power support - Reactive power support/Power factor correction - Voltage regulation -Harmonic filtering -Support for integration of renewable	-Maximized profit - Minimized power loss -Minimized operation cost -Minimized emission -Prevention of grid overloading -Failure recovery Improved load profile -Maximization of renewable energy generation	Fast battery degradation Complex hardware High capital cost Social barriers

Table 8, Interaction of EVs with RES, Source: Jia Ying Yong, 2015.

Interaction with RES	Field of Application	Contribution
Solar PV	Smart home	-Implementation of PV and EV in smart home to reduce emission -Development of standalone home EV charger based on solar PV system -Development of future home with uninterruptable power by implementing V2G with solar PV
	Parking lot	-Analysis of EV charging using solar PV at parking lots -Scheduling of charging and discharging for intelligent parking lot
	Grid distribution network	-Assessment of power system performance with integration of grid connected EV and solar PV -Development of EV charging control strategy for grid connected solar PV based charging station -Development of optimization algorithm to coordinate V2G services
	Micro grid	Development of generation scheduling for micro grid consisting of EV and solar PV
Wind turbine	Grid distribution network	-Determination of EV interaction potential with wind energy generation -Development of V2G systems to overcome wind intermittency problems
	Micro grid	Development of coordinating algorithm for energy dispatching of V2G and wind generation
Solar PV and wind turbine	Smart home	Development of control strategy for smart homes with grid interactive EV and renewable sources

EV owners believe that EVs provide less operating cost because of their superior efficiency and structure. As explained before, EVs efficiencies can be up to 70% where ICE vehicles have efficiencies in the range of 20 % to 30%. The current high cost of EVs is likely to come down from mass production and better energy policies which will further increase the economic gains of the owners. Implementing V2G also allows the owners to obtain a financial benefit from their vehicles by providing service to the grid.



## EV Economics and Business perspectives

EV purchasing price is higher than gasoline and diesel vehicles. It is considered as one of the main hurdles to EV adoption. Nevertheless, EV advocates suggest that total cost of ownership (TCO) for EV is lower than ICE vehicles. TCO include all expenses from purchasing the car till the end of vehicles' lifetime. It includes sticker price, financing cost, fuel cost, insurance, maintenance, taxes, and depreciation. In practice, this is not the case in every geographical area. For example, in California the TCO for e-golf car over 5 years is USD 32,076 vis-à-vis USD 43,316 for regular golf car (EVs20). Table 9 exhibits the different component of TCO. In Belgium, a TCO study analysis for EV, Diesel vehicles, and gasoline vehicles over 15 years shows different results. For small vehicles segment, TCO for an EV is a little better than gasoline and a little higher than diesel vehicles. For medium segment, EV is better than both. For big vehicle segment, diesel is much better than EV and gasoline vehicles (Laurent Franckx, 2019). Figure 23 exhibits the results of this study. Another study considering the future Netherland market (from 2016 until 2031) shows that EVs have much lower TCO than gasoline vehicles (Auke Hoekstra, 2017). These discrepancies are expected. Each country has different conditions such as fuel price, spare parts and maintenance cost, and most importantly the incentive schemes that are implemented in each country.

Table 9, TCO comparison, e-Golf Vs Golf

Description	E-Golf (\$)	Golf (\$)
Vehicle	16,190	18,143
Electricity	4,377	0
Gasoline	0	11,719
Maintenance	3,092	5,508
Insurance	8,416	7,946
<b>Total</b>	<b>32,076</b>	<b>43,316</b>

Graph 6 TCO of cars in 2017 (annual mileage of 10 000 km and lifetime of 15 years)  
Y-axis: EUR

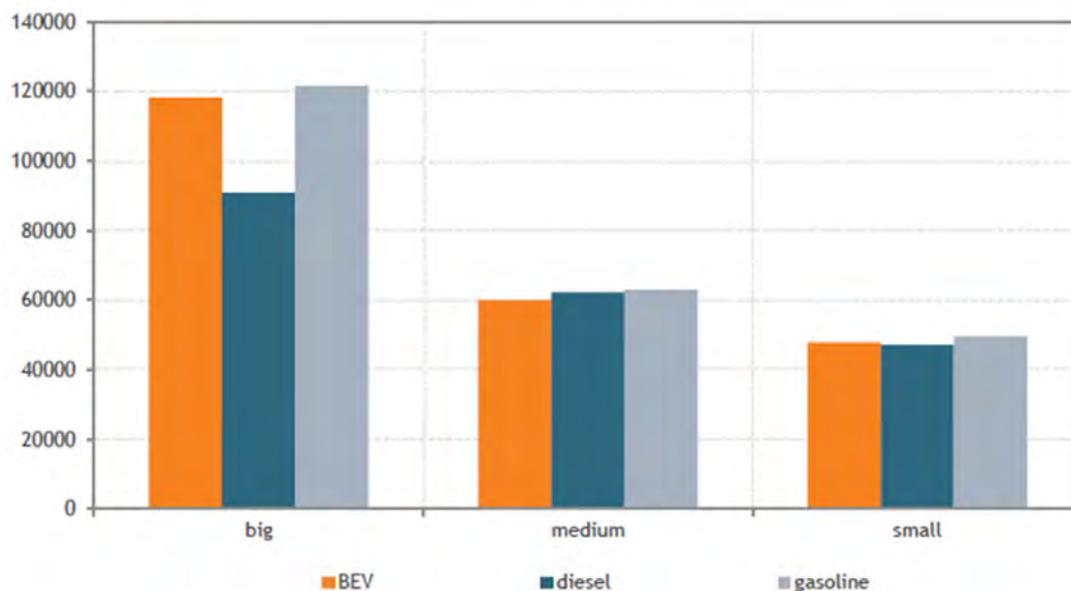


Figure 23, TCO in Belgium

It is beyond the scope of this report to carry out a detailed TCO analysis. However, preliminary calculation can give an overview on the situation in Egypt. Our analysis will account for purchasing cost and operating cost (fuel and maintenance) only as they represent the largest bulk of TCO. Calculation assumption are represented in table 10.

Table 10, TCO comparison,

Description	Golf	E- Golf
Purchasing price (EGP) <sup>10</sup>	420,000	600,000
Fuel consumption <sup>11</sup>	6 Liter\100 km	0.2 kWh\km
Fuel cost (EGP) <sup>12</sup>	8.75 EGP\L (Gasoline 95)	1.45 EGP\ kWh
Distance traveled (KM)	120,000	120,000
Maintenance cost for 120,000KM	EGP 46,760 <sup>13</sup>	EGP 10,200 <sup>14</sup>
Oil cost	8,640 <sup>15</sup>	-

From the above table we can calculate fuel cost for 120,000KM which accounts nearly for 5 years of usage. The fuel cost for ICE golf is EGP 63,000 while for e-Golf is EGP 34,000. By adding the other components, we can find out that TCO for regular Golf is EGP 538,400 and for E-Golf EGP 644,200.



From the above calculations we can conclude the following points

- Operating costs for EVs is approximately 60% cheaper than ICE vehicles
- Simple payback period will be in year 13 because sticker price for EVs is much higher compared to ICE vehicles
- With incentive schemes, simple payback period can be decreased considerably
- More distance traveled means more savings which make transportation sectors great candidates for electrification

The last point explains why Tesla is interested in truck electrification. In November 2017, two concept vehicles (Tesla Semi Truck) were unveiled and limited production was planned by the end of 2020, the truck range will be 500 miles and it will be able to travel 400 miles after 30 min charge. Tesla used the current active laws in their favor. For example, under the current European law it is mandatory 45-minute break periods for each 4.5 hours of driving, and a new 4.5-hour period does not begin until a full 45 minutes of rest time has been accomplished (European Commission). Which allows the car drivers to charge the trucks more than 80% using fast charger. Economics of logistics will be distributed if Tesla succeeded to present reliable solution.

Until we figure out what tesla will achieve, the local transportation system in Cairo can benefit from e-mobility. Let us have a look on some statistics that are available at CAPMS on Cairo local transportation system. In 2016 Cairo had 4,900 buses and vans divided over 473 lines with a total distance of 13,588 km. In the same year they served 550,764,000 passengers. Out of the 4,900 buses and vans in 2019, vehicles older than 15 years represent 41.2% of the total number. 4,407 vehicles are using diesel as fuel and only 326 using Natural gas. The total amount of distance traveled was 188,175,000 km with total working hours 9,630,000 hour. The operation cost (only fuel and oil costs) was EGP 75,922,000 and the other operation costs (spare parts, water...) was EGP 140,961,000 (CAPMS, 2016).

<sup>10</sup> These prices are estimated from the market because no brand-new e-golf is available

<sup>11</sup> Average actual fuel consumption from several sources which are slightly higher than advertised

<sup>12</sup> Price of gasoline 95. Price of highest residential tariff block

<sup>13</sup> Cost are compiled from car dealer, does not include taxes

<sup>14</sup> Represent service expenses at the car dealer

<sup>15</sup> Cost for 4-liter Mobil 1 oil is EGP 720, change interval every 10,000km

From TCO analysis we knew that EV operation cost is 60% lower than ICE vehicle. Adding to that, 41% of the vehicles is older than 15 years which means that the engine efficiency is not the optimum and the combustion emission at its maximum. Replacing old vehicles with electric ones will save 50% of operation cost at minimum. Which is around EGP 108, 441,500 and represent around 18% of the revenue from tickets and subscriptions (CAPMAS, 2016). Two examples can demonstrate our proposal.

In December 2017 at contract renewal, the Vervoerregio Amsterdam (the Transport Region of Amsterdam) and Schiphol took the decision to switch their fleet to be emission free in their hope to make Schiphol airport to be CO<sub>2</sub>-neutral by 2040. The electric VDL Citea buses being used at Schiphol operate 24/7 and have a battery capacity of 170 kWh. The maximum action radius of a fully charged bus is 80 km, at 2 kWh per km. The buses are charged by Heliox fast and slow chargers. Fast charges are at a rate of 450 kWh, take no more than 15 to 25 minutes and happen during the day, between journeys. Slow charges are at a rate of 30 kWh, take between four and five hours, and happen at night, at the bus depot. The electric buses emit no CO<sub>2</sub>, and at Schiphol they are recharged using electricity from 100% Dutch wind power (Royal Schiphol Group, 2018).



Figure 24, Electric buses at charging depot

The other example which is more impressive comes from china. At the end of 2017, Shenzhen city has all its fleet (more than 16,000) as electric buses. While this transformation of an electric bus cost 1.8 million yuan, nearly double the price for an ICE bus powered by diesel, the use of every 1,000 e-buses could save 500 barrels of oil consumption a day and reduce the choking smog that envelopes major cities (Ren, 2018). In 2019 The Transport Commission of Shenzhen announced that 99 percent of the city's more than 21,000 cabs are now powered by batteries. Shenzhen's traffic authority claims that electric taxis are 70 percent more energy-efficient compared to those powered by fossil fuel. The entire fleet of electric cabs is estimated to cut carbon emissions by 856 thousand metric tons a year for Shenzhen (Liao, 2019).



Figure 25, Buses in Shenzhen Bus Company's main charging depot

With some planning and cost benefit analysis, authorities may find it is better to switch to electric fleet. From CAPMAS data we know that the distance traveled of the buses inside Cairo is not larger than 50 KM which will lower the requirement of the batteries. Chargers can be installed at the line terminals where the buses wait at least 30 minutes between rounds. Another solution is flash charging that last for only 15-20 second. The idea is when the bus stops at station it will be charged during this stop. This will make the battery smaller. A demonstrator has been running in the Swiss city of Geneva since May 2013 (ABB, 2019).

## Other Business Opportunities

We have seen two business opportunities which are switching the fleet to be electric and selling EVs. Different business models for e-mobility are needed in the coming section we will discuss them in brief. We excluded business models that are not applicable in Egypt. For example, energy arbitrage<sup>16</sup> requires smart grid and electricity spot pricing. Both are not available in Egypt.

**Charging Infrastructure** is needed to charge EVs. Currently it is chicken-egg problem. EV charging stations need EVs and EVs need charging station. The government should step in and have a role in this (this point will be discussed in the coming section). charging stations can be categorized into two sections: destination charging and fast charging. Destination charging has three sub section which are residential charging, work charging, and street charging. Let us first talk about fast charging.

Fast charging is best suited at highways or interstates corridors. That because when people become experienced with EVs they will adjust their behavior to charge at home (residential charging) which is cheaper. Research shows that experienced EV drivers (even the Tesla drivers with fast chargers and big batteries) still want chargers at home. The owner of fast chargers will get their revenues from the premium they add to electricity price. They can get more revenues from offering other services like car cleaning and tire pressure adjusting.

Street charging is probably the most debated topic in countries that has considerable share of EVs. The problem is that in cities most citizens do not have a private parking place, so they have to park their car in the street. If they cannot charge an EV there, they will not buy an EV. For instance, cities in the Netherlands work with a process where someone who is buying an EV can request a charging point near their home. This strategy has proven to be successful with small numbers of EVs. In our case this can be a source of revenue for municipalities. If municipalities started to plan and organize the best strategy to install EVs charger, they can profit from installing the stations, and selling the electricity.

**Charge Point Manufacturing** can be another source of economic income. By following the charging standards (see table 7) local companies can take the lead and start manufacturing different sizes and types of charging station. By taking the lead, they can optimize the price and start to export their production.

**Car/ Car Battery Leasing** is one of the options to make EVs more attractive for consumers. In August 2018, a new leasing law has been ratified (Law No. 176 of the year 2018) regulating both financial leasing and factoring activities, promulgating financial leasing Law No. 95 of the year 1995, which aims at steering economic volume and increasing production of small and medium enterprises. Car dealer can lease the car or at least car batteries that represent the largest share of the car cost. For instance. Renault leases the car battery in Germany to lower the initial purchase price of a Renault EV to be as close as possible to that of an equivalent diesel vehicle (Randall, 2019).

It is worth noting that all the above opportunities require support from the government and commitment towards this transition. The next section will suggest several policies that aim to promote EVs market and capture the economic and environmental values.

<sup>16</sup> Energy Arbitrage: Is buying energy when prices are low and selling it when prices are high

## Policy perspective

There are several economic and environmental opportunities from EVs adoption. However, without government's commitment, regulatory framework, and incentive policies nothing can be achieved. In this section, the report aims at giving overview on the current situation then advise on the proposed policies that can be implemented to promote EVs market.

In February 2018, Egyptian trade minister has inaugurated the first EVs charging station in Egypt. Currently, three companies are offering charging services: REVOLTA<sup>17</sup>, INFINITY-e<sup>18</sup> and Drshal<sup>19</sup>. On the former website (Revolta), around 130 charging points covering 18 cities are available. However, when company representative was asked, he replied that only 30 stations exist. The latter has 17 locations presented at their website. The largest power capacity for charging is 22 kW AC charging. Currently no fast charging station is available in Egypt. The current fees of charging are different, for REVOLTA the customer has to pay EGP 28,000 registration fee then charging fees is approximately 2 EGP/min. For INFINITY there is no registration fees and they are waiting for the regulations to set up charging price. While the third company has EGP 700 annual registration fees and 1.5 EGP/kWh charging fees. The above information was extracted from auto zone magazine (Abdallah, 2019).

A decree has been issued exempting imported used EVs from custom duties (on condition that they are no more than 3 years old). This was an exception knowing that Egyptian regulations do not permit the import of used cars. This decision was made to encourage EVs market by reducing the sticker price. Currently all private cars imported from Europe and Turkey are exempted from customs. However, they are subjected to other duties namely a value added taxes (VAT) of 14 %, an industrial and commercial profit tax of 0.5 %, a resources development fee of 3 %, and a table tax 1 %, bringing the total duties to a total of 18.5 % (LYNX, 2019).

Several announcements have been made for several agreements and plans for manufacturing and importing EVs to the Egyptian market. These plans will not be realized without serious regulations and policies. For example, no clear regulation on EVs license registration process, fees, and renewal fees. What really happens, the traffic authority determine the motor power of the EV then see what is the comparable ICE vehicle capacity for the same power (for example if EV has 50kW motor, that will be equal to 68HP which will be fitted in 1000-1300 CC ICE car) and the registration and renewal fees will be for the comparable car. And it doesn't end here, the EV owner have to renew the license every month. Such absence of regulation discourages EVs purchases.

The government declared the intention to develop an e-mobility strategy to promote the usage of EVs vehicles on Egyptian roads. Ministry of Electricity and Renewable Energy has assigned a task force to make a plan to determine the places for establishing charging centers for electric vehicles the was done in the efforts to develop an electric charging policy to align the rollout of charging infrastructure with the emerging needs of EVs in the market (egypt today, 2019).

Currently, Egypt doesn't have any mandates or targets for e-mobility. Egypt has targets for renewable energy percentage in 2022 and 2035 (RCREEE, 2019). In accordance with Decisions 1/CP.19 and 1/CP.20, the Arab Republic of Egypt submitted its report on the Intended Nationally Determined Contributions (INDCs) towards achieving the objectives of the United Nations Framework Convention on Climate Change (UNFCCC) set forth in Article 2 thereof. Regarding transportation sector, the intended measure is energy efficiency improvement ( Egyptian Ministry of State for Environmental Affairs, 2017).

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<sup>17</sup> <https://revoltaegypt.com/>

<sup>18</sup> <http://infinitye.com/home>

<sup>19</sup> No website was found

California was the first, in 1990, to install Zero-Emission Vehicle (ZEV) regulations and it is still expanding that effort to meet its air quality and greenhouse gas emission reduction goals. An estimation about the results of the regulation predicts that 8 percent of California new vehicle sales in 2025 will be ZEVs and plug-in hybrids (California Air Resources Board).

On September 2017, China's Ministry of Industry and Information Technology (MIIT) finalized the New Energy Vehicle (NEV) mandate policy 2. The NEV mandate in China is a modified version of California's Zero Emission Vehicle (ZEV) mandate, with goals of promoting new energy vehicles and providing additional compliance flexibility to the existing fuel consumption regulation (International Council on Clean Transportation, 2018). Many European countries set their targets for EVs and used several incentives to achieve those targets.

Clearly from the above points Egypt needs incentive policies to promote EVs adoption. Such schemes are implemented in countries that currently have high share of EVs. It is worth noting that cost-benefit analysis is required to assess the viability of the policies. When evaluating policy, it is important to consider whether policies are economically efficient, or, in other words, whether the benefits of the policy exceed the cost. Advocates of increased rates of EVs adoption argue that EVs provide substantial benefits to society. Often, EVs are credited for enabling reduced dependence on foreign energy sources, reduced levels of greenhouse gas (GHG) emissions and local air pollution, and potentially increase economic growth and welfare (Malmgren, 2016).

Governments design policies to encourage or discourage different types of economic behavior. And that by the nature change the allocation of resources in the society. For example, by imposing taxes governments discourage activities that are not beneficial to society. These changes must be taken in account when evaluating whether or not a policy is desirable. Another important consideration is the impact of the policy on the distribution of income. Policies that can shift income away from high-income people and toward low-income people are generally referred to as progressive. In contrast, policies that shift resources toward high-income people and away from low-income individuals are referred to as regressive. Those concerned about the distributional effects of policy tend to favor progressive policies over regressive ones (Ryan C Bosworth, 2017).

Most financial incentive schemes for EVs, such as subsidies, involve some transfer of taxpayers' money to a specific group of early adopters. Both for private users and firms, the decision to be an early adopter is a combination of image or status and affordability. In practice, early private adopters are mostly found in the high-income and high-educated segment of the population. Figure 26 shows rough estimates for the stages of new technology is adoption. Depending on the duration and scale of income transfer to this privileged group, the majority of the population may feel left behind. If that happens, the government is at risk of eroding public support for the new technology.

The main challenge for a government is to optimize social welfare from an economic perspective. It is, therefore, crucial to design a financial incentive scheme in such a way that it is clearly limited in time and in the extent of income transfer. Limited in time does not necessarily imply short duration, as innovative technologies that are in the interest of society as a whole may take many years to be embraced. The duration of the financial incentive scheme should be aligned with the time needed to increase the efficiency of the new technology through upscaling and incremental improvement, and to reduce the costs to the extent that the new technology is made affordable for the population at large.

Incentive scheme can be financial and non-financial. The report will examine the financial schemes that can be implemented in Egyptian case first and then non-financial schemes. With each scheme, the report will also explain the pits and falls of each one that should be avoided.

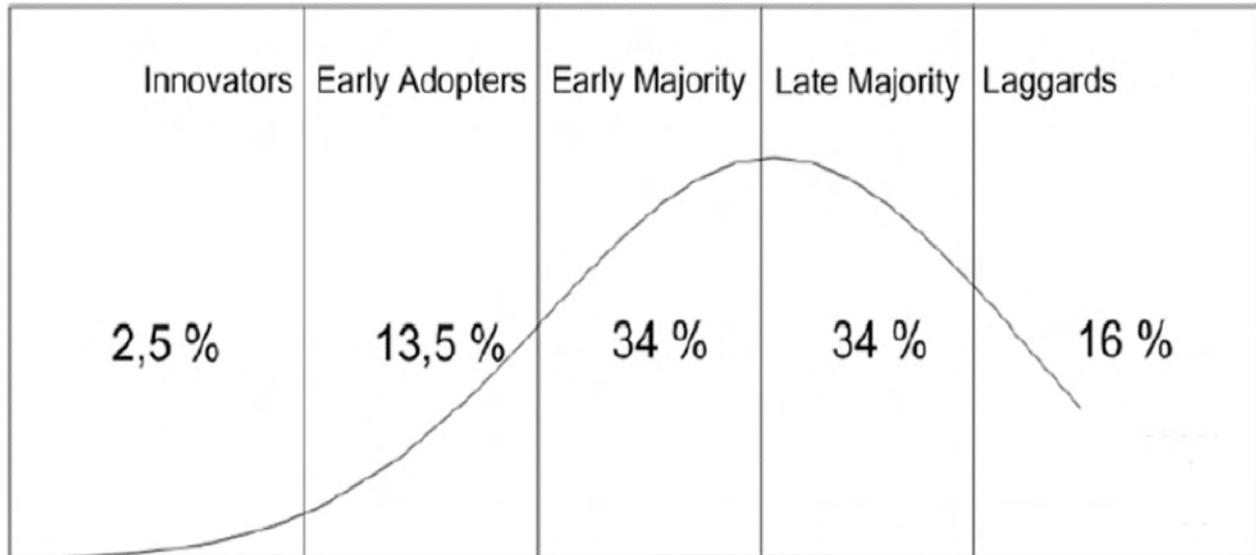


Figure 26, Adoption curve, Source: Door Vvdberg op de Nederlandstalige Wikipedia, CC BY-SA 3.0

## Financial Policy Schemes

Purchasing cost is the main hurdle for the consumer to buy EVs. Reducing the sticker price will encourage consumer to consider EVs and reduce payback period. This can be done by lowering the customs<sup>20</sup>, reducing VAT, eliminating both industrial and commercial profit taxes, resources development fee, and a table tax. This can bring the initial cost by 18%, which is not a small portion. Another sort of incentive can be post purchase such as tax reduction for the companies that will buy EVs and reduce VAT on the spare parts.

One thing is to be considered when applying this scheme that incentives should be dependent on income or on the purchase price of the vehicle. For example, the scheme should not subsidize a consumer who is going to buy luxury car like Tesla model S. In Germany cars that costs more than €50,000 are not eligible for any incentive scheme.

### **Emission Taxes**

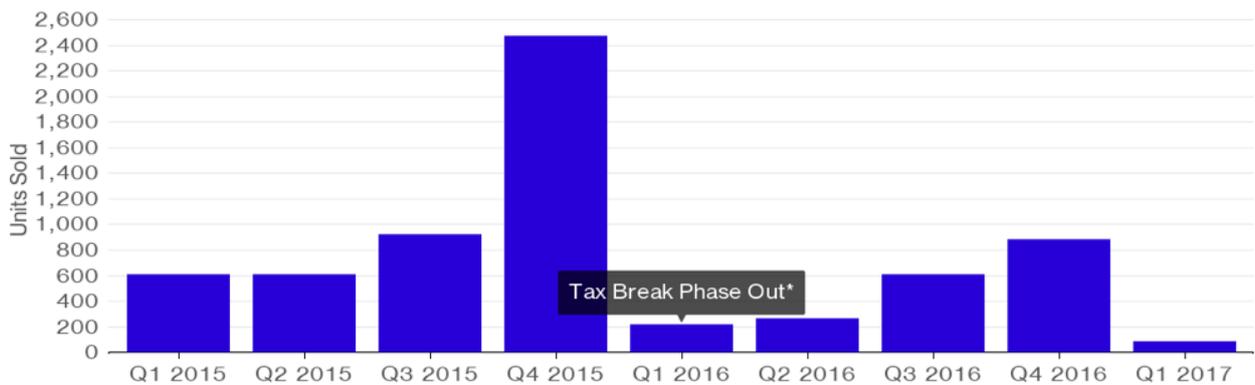
It can be considered as disincentives. Imposing taxes on ICE vehicle that uses fossil fuels such as Diesel and gasoline<sup>21</sup> will shift consumer towards EVs. Taxes should be ascending depending on how much emission the car emits. Taxes can be at purchasing or at license renewal. These taxes will help the government to recover the forgone revenues from applying the above schemes.

### **Electricity Cost**

Lowering the electricity cost for EVs will have several benefits. First it will make TCO for EVs more attractive. Secondly and more importantly, it will increase the number of charging stations. As the installer of these station will be able to recover his cost faster. Here is another point that should be considered, the charging price should be calculated on energy drawn and time. That is because an EV owner can plug his car in the charger and leave it even after the charging process is complete. This may lead to congestion and underutilizing the charging infrastructure.

As said before the incentive scheme should be limited in time with clear vision on how it will last. The incentive should last until the EVs no longer need financial support. Phasing out incentives should not happen abruptly. Too early removal could mean a market collapse. A gradual phase-out is considered more efficient. Take Denmark as an example, Figure 27 shows the plummeted EVs sales after incentives were suddenly phased out (Berggreen, 2017).

<sup>21</sup> Cars that are working on NG should be exempted from emission taxes.



Source: ACEA

Figure 27, EVs sales after phasing out incentives in Denmark

Bloomberg 

## Non-Financial Policy Schemes

### Charging infrastructure

This situation can be described as egg-chicken dilemma. Government and local municipality should intervene and support charging infrastructure development in the early days. Charging station should be available at places where cars parked most of the times because charging process takes long time. This means near homes, at work, and/or places like shopping malls. Local governments with the aid of the Ministry of Electricity and Renewable Energy should step in and provide charging infrastructure for those relying on on-street parking and charging near their home or workplace.

### Granted access privilege

Granting access to places where other cars can't go will be a helpful policy to lure EVs sales. For example, center of Cairo is very polluted because of traffic congestion (see figure 2). Banning ICE vehicles from such places (completely or partially) and granting access to EVs will help to improve quality of air and encourage EVs sales. In addition, exempting (or reducing) EVs from road tolls and/or parking fees has proved to be effective. In addition, reserved parking places in congested areas should be another privilege.

### Interoperability of charging Stations

Currently there are three companies that offer charging services. However, each one has their own stations and car owner must pay certain fees to get access to other companies' charging stations. This means if a car owner wants the maximum charging station availability, he/she must subscribe with the three companies. A regulation to organize the access to all charging stations with subscription with one company only is needed. This will expand charging infrastructure, increase the utility of EV's owner, and reduce costs.

When applying incentives schemes, several general points should be considered:

- Incentive schemes are most effective when they are combined. Mixing financial and non-financial incentives greatly encourages the customers towards EVs.
- Incentive should be introduced in many regions as possible to grant the maximum impact, in terms of geographical coverage.
- Transparency is very crucial. Customers should be aware of the duration and eligibility of the incentives
- Phasing out should be done gradually to avoid market collapse.
- Continuous evaluation for the impact of the incentives on the market and if they need to be prolonged
- Benefits of using EVs (like TCO) should clearly communicated to the consumers

## References

[Online] // EV saving calculator. - 4 2, 2020. - [https://ev.pge.com/vehicles/Volkswagen\\_e-Golf\\_BEV\\_2019](https://ev.pge.com/vehicles/Volkswagen_e-Golf_BEV_2019).

Egyptian Ministry of State for Environmental Affairs EGYPTIAN INTENDED NATIONALLY DETERMINED CONTRIBUTION [Report]. - Cairo : Egyptian Ministry of State for Environmental Affairs, 2017.

ABB [Online] // ABB. - 3 7, 2019. - 4 3, 2020. - <https://new.abb.com/news/detail/17282/abb-flash-charging-ibus-solution-reaches-a-new-milestone-of-half-a-million-km>.

Abdallah Tarek [Online] // Auto Zone. - Charging Electric Cars in Egypt - <https://www.autozone-mag.com/topic-%D8%B4%D8%AD%D9%86-%D8%A7%D9%84%D8%B3%D9%8A%D8%A7%D8%B1%D8%A7%D8%AA-%D8%A7%D9%84%D9%83%D9%87%D8%B1%D8%A8%D8%A7%D8%A6%D9%8A%D8%A9-%D9%81%D9%8A-%D9%85%D8%B5%D8%B1-charging-electric-cars-in-egypt>.

Annual bulletin of Environmental statistics [Report]. - Cairo : CAPMS, 2016.

Annual Bulletin of Foreign Trade [Report]. - Cairo : CAPMS, 2016.

Annual Report 2017/2018 [Report]. - Cairo : Egyptian Electricity Holding Company, 2019.

Auke Hoekstra Anand Vijayashankar, Vedant Linesh Sundrani Modelling the Total Cost of Ownership of Electric Vehicles in the Netherlands [Conference] // EVS30 Symposium. - Stuttgart : Researchgate, 2017.

Berggreen Jseper [Online] // CleanTechnica. - 10 1, 2017. - 4 4, 2020. - <https://cleantechnica.com/2017/10/01/denmark-goes-backward-lowers-tax-dirty-cars-wha/>.

California Air Resources Board [Online] // Zero-Emission Vehicle Program. - 4 4, 2020. - <https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program/about>.

CAPMS [Online]. - January 1, 2020. - <https://www.capmas.gov.eg/>.

CAPMS annual statistics for local transportation inside and outside cities [Report]. - Cairo : CAPMS, 2016.

CAPMS Car and Train accidents Report, First half 2019 [Report]. - Cairo : CAPMS, 2019.

CAPMS semiannual vehicle inventory 2015 [Report]. - Cairo : CAPMS, 2015.

Chan C.C The state of the art of electric and hybrid vehicles. [Conference] // IEEE. - [s.l.] : IEEE, 2002. - Vol. 90.

Curran Scott J. Well-to-wheel analysis of direct and indirect use of natural gas in [Journal] // EL SEVIER. - 2014.

egypt today [Online] // egypt today. - 11 13, 2019. - 4 4, 2020. - <https://www.egypttoday.com/Article/3/77708/Electricity-Min-identifies-places-to-establish-electric-vehicles-charging-stations>.

European Commission [Online] // MOBILITY AND TRANSPORT. - 4 3, 2020. - [https://ec.europa.eu/transport/modes/road/social\\_provisions/driving\\_time\\_en](https://ec.europa.eu/transport/modes/road/social_provisions/driving_time_en).

Fuad Un-Noor Sanjeevikumar Padmanaban , Lucian Mihet-Popa A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development [Journal]. - Switzerland : Energies, 2017. - Vol. 10.

H. C. Righolt F. G. Rieck Energy chain and efficiency in urban traffic for ICE and EV [Journal]. - [s.l.] : World Electric Vehicle Symposium and Exhibition (EVS27), 2013.

InsideEvs [Online]. - January 4, 2020. - <https://insideevs.com/news/336803/supercars-beware-new-tesla-roadster-compared-to-bugatti-chiron/>.

INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION CHINA'S NEW ENERGY VEHICLE MANDATE POLICY [Report]. - [s.l.] : INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, 2018.

- Jorge Martins Francisco P. Brito, Delfim Pedrosa, Vítor Monteiro, João L. Afonso REAL-LIFE COMPARISON BETWEEN DIESEL AND ELECTRIC CAR ENERGY CONSUMPTION [Journal]. - New York : Nova publisher, 2013.
- Kochhan Robert An Overview of Costs for Vehicle Components, Fuels and Greenhouse Gas [Journal]. - 2014.
- Laurent Franckx Total cost of ownership of electric cars compared to diesel and gasoline cars in Belgium [Report]. - Brussels : Federal Planning Bureau, 2019.
- Liao Rita [Online] // TechCrunch. - 14, 2019. - 4 3, 2020. - <https://techcrunch.com/2019/01/04/shenzhen-electric-taxis-push/>.
- Lutsey Nic Update on electric vehicle costs [Report]. - [s.l.] : INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, 2019.
- LYNX Industry Notes // ELECTRIC VEHICLES IN EGYPT, OPPORTUNITIES AND CHALLENGE. - Cairo : LYNX, 2019. - Vol. LYNX Strategic Business Advisors 2019.
- Ma Shuai, Modi Jianga, Temperature effect and thermal impact in lithium-ion batteries: A review [Journal]. - [s.l.] : ELSEVIER, 2018. - Vol. 28.
- Macro Trends [Online]. - January 1, 2020. - <https://www.macrotrends.net/cities/22812/cairo/population>.
- Malmgren Ingrid Quantifying the Societal Benefits of Electric Vehicles [Journal]. - Canada : World Electric Vehicle Journal, 2016. - ISSN 2032-6653 : Vol. Vol. 8.
- Monthly Air Quality Report [Report]. - Cairo : Ministry of Environment, 2018.
- Randall Chris [Online] // electrive.com. - 11 26, 2019. - 4 3, 2020. - <https://www.electrive.com/2019/11/26/renault-zoe-now-only-available-with-a-battery-in-the-uk/>.
- Maged Mahmoud, Ali Habib, "Arab Future Energy Index - Renewable Energy 2019", RCREER <https://www.rcreee.org/content/arab-future-energy-index-renewable-energy-2019-report>
- Ren Daniel [Online] // South China Morning Post. - 10 23, 2018. - 4 3, 2020. - <https://www.scmp.com/business/china-business/article/2169709/shenzhens-all-electric-bus-fleet-worlds-first-comes-massive>.
- Royal Schiphol Group [Online] // Europe's largest fleet. - 2018. - 4 3, 2020. - <https://www.schiphol.nl/en/schiphol-group/page/europes-largest-fleet-of-fully-electric-buses/>.
- Ryan C Bosworth Grant Patty, The Current State of Electric Vehicle Subsidies: Economic, Environmental, and Distributional Impacts [Report]. - Strata, 2017.
- Sterkenburg Van Analysis of regenerative braking efficiency - A case study of two electric vehicles operating in the Rotterdam area [Journal]. - 2011.
- TomTom [Online]. - January 2, 2020. - [https://www.tomtom.com/en\\_gb/traffic-index/cairo-traffic](https://www.tomtom.com/en_gb/traffic-index/cairo-traffic).
- UN Climate Change Conference Paris Declaration on Electro-Mobility and Climate Change & Call to Action [Conference] // COP21. - Paris : UN Climate Change Conference, 2015.
- US department of energy office of energy efficiency and renewable energy EPA [Online]. - March 25, 2020. - <https://www.fueleconomy.gov/feg/atv.shtml>.
- World Bank Cairo Traffic Congestion Study [Report]. - Cairo : World Bank, 2014.
- World Population Review, [Online]. - January 1, 2020. - <http://worldpopulationreview.com/world-cities/cairo-population/>.

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