Professional MBA
Automotive Industry

Electro Mobility and Possible Scenarios for Slovakia

A Master's Thesis submitted for the degree of
“Master of Business Administration”

supervised by
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Affidavit

I, **PHDR. MIROSLAV POLACEK**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ELECTRO MOBILITY AND POSSIBLE SCENARIOS FOR SLOVAKIA", 81 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 01.10.2018

Signature

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List of Abbreviations

AVERE	European Association for Electro-mobility
BEV	Battery Electric Vehicle
BMS	Battery Management System
CAFE	Corporate Average Fuel Economy Standards
CEF	Connecting Europe Facility
CNG	Compressed Natural Gas
CO2	Carbon Dioxyde
EDTA	Electric Drive Transportation Association
EREV	Extended-range Electric Vehicle
EU	European Union
FCHEV	Fuel Cell Hybrid Electric Vehicle
GM	General Motors
GWh	Giga Watt Hour
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
JRC	Joint Research Center
kWh	kilo Watt hour
LI-ion	Lithium-Ion battery
LPG	Liquid Propan Gas
MoE SR	Ministry of Economy of The Slovak Republic
MWh	mega Watt hour
NiCd	Nickel Cadmium battery
NiMH	Nickle-Metal-Hydrite battery
OECD	Organization for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
PHEV	Plug-in hybrid electric vehicle
SEVA	Slovak Electric Vehicle Association
TCO	Total Costs of Ownership
VAT	Value Added Tax

WEVA	World Electric Vehicle Association

Abstract

This master thesis set out several questions aimed at the situation at electromobility in Slovakia in the scope of mid-term horizon. Will be the country among leaders or followers regarding use of electromobiles? Following questions have been asked and there was put effort for trying to find relevant answers.

Questions and ansvers:

When will it be favourable for the average Slovak consumer to own an electric car?

Several types of calculations have been done to compare kind of total costs of ownership of vehicles with combustion engine and electromobiles during the life cycle of ten years. Acquisition cost of the electromobile and changing of battery during that time created advantage for clasic car ovnership. Comparation of the price of electromobile with average income in Slovakia have indicated, that aveage Slovak customer would have to work three to four years to be able to buy vehicle with electric engine. Electromobile can be more attractive in the case vhen its´ price decreases to the one of the clasic car in the same cathegory.

Can Slovakia's energy system cope with increased electricity consumption when the share of electric cars in the total number of passenger cars increases? Can the grid cope with peak loads caused by charging electric vehicles?

Slovakia has actually 9% underproduction of electric energy, however should have 9% of overproduction in 2022. If there would be 30% of electromobiles in 2030 (assumption of IEA), they consume 6% of the production. Electric power would be sufficient. The grid can cope with peak loads having 40 -50% reserve in immediate power production.

Will Slovakia have sufficient infrastructure to allow the development of electro-mobility and who will carry the largest share of costs in its creation?

Ansver to this question depends on activities of private sector, which will bear majority of the costs representing over 160 mil. Euro according to strategy paper issued by Ministry of Economy.

How will the state deal with the resulting decrease in excise duty on mineral oils - fuels?

Having 30% of electric vehicles the fallout in state buget income would be 2,5% - arroung 35 mil. Eur. It is very realistic, that state would like to ballance this ammount either through increasing excise tax on mineral oils, or increasing of the price of eletricity. Most probable is, that it can be applied on both.

Research Questions

This master thesis aims at delivering answers to several questions related to the development of electro-mobility in Slovakia in the future, namely:

When will it be favourable for the average Slovak consumer to own an electric car?

Can Slovakia's energy system cope with increased electricity consumption when the share of electric cars in the total number of passenger cars increases?

Can the distribution network and production capacity cope with gust loads at peak hours caused by larger numbers of electric vehicles connected to fast-charging stations?

Will Slovakia have sufficient infrastructure to allow the development of electro-mobility and who will carry the largest share of costs in its creation?

How will the state deal with the resulting decrease in excise duty on mineral oils - fuels?

Content and Methodology

The theoretical part of this paper maps the development and use of electric vehicles since the 19th century, when the first electric cars were developed, up to-day when every OEM manufacturer is already selling or has announced the launch of new electric car models. Just as interesting is the comparison of the different categories of electric cars according to how and up to what extent they use electric power. The paper also focuses on CO2 emissions and in this light compares regular, i.e. combustion engine cars and electric cars throughout the whole life cycle if the vehicle. As the battery constitutes a key part of an electric car, a separate chapter is devoted to all related aspects, such as the most popular types of batteries, their advantages, disadvantages, etc. In order for electro-mobility in Slovakia to develop, it is mandatory to know the support tools used in the countries that lead this sector.

As for its methodology, the theoretical part of this paper is based on studies and different documents elaborated by international institutions, renowned private companies, as well as electro-mobility oriented associations and platforms. Many of the answers to the research questions were obtained from interviews and consultations with key stakeholders dealing with electro-mobility issues in Slovakia, such as ministries, private companies, associations, distribution networks, etc. The different estimates and calculations are based on information from different publicly available sources, figures from the ministries, and reports published by public institutions.

Results

A comparison between the main costs of electric vehicles and those of conventional, combustion engine vehicles reveals that electric cars will become attractive for an average Slovak consumer when their price reaches the level of a regular car of the same class.

Slovakia’s energy system is confident it can cope with the expected increase in electricity consumption resulting from a growing share of electric cars in the total number of vehicles. The International Energy Agency estimated 30 percent share of electric cars in 2030 is not expected to cause any major problems.

In terms of peak and average consumption, coping with gust loads caused by electric vehicles is not expected to be a problem thanks to the existing production capacity and network security strategy. What could cause problems across the network is the operation efficiency of some exposed locations.

When the estimated 30 percent share of electric cars is reached, the state is likely to compensate the resulting reductions in excise tax by increasing the prices of fuel and electricity.

1. Introduction

Today, electric cars and electro-mobility are current topics that are perceived by many as a new and recent issue. The truth, however, is that the history of electric cars is as long as that of vehicles with a combustion engine. The first electric cars were developed in the 19th century by the pioneers of modern transport. At the beginning of the twentieth century, they were developed and manufactured simultaneously with combustion engine vehicles. In the inter-war period, electric cars were popular city vehicles as it was easier and more comfortable to start, service and drive them than other vehicles. It is little known, for instance, that the first vehicle developed by Ferdinand Porsche was, indeed, an electric car. Likewise, at some point Henry Ford and Thomas Alva Edison joined efforts to develop an electric car. Eventually, however, electric vehicles lost the race against cars using combustion engines, especially as the result of mass production, the discovery of the starter, the differences in range, and other technical advances.

From the 1930s to the end of the 20th century, electric cars remained in the background and appeared only occasionally as the result of the work of technical enthusiasts or to be displayed at some exhibitions and conferences on environmental issues.

The turn of the millennium saw the comeback of electric cars, first as hybrid vehicles combining combustion engines with electricity accumulated during braking. Eventually, other hybrid drive combinations appeared gradually until the very first pure battery vehicles made their apparition.

At the beginning of the 21st century, the development of electric car technologies experienced strong impulse from the side of governments and international institutions, which were carrying out constant efforts to reduce CO2 emissions mainly in all types of transport. The result is a continuously growing offer by all established carmakers, as well as new producers - such as Tesla - and some Chinese companies. At present, every car manufacturer is preparing to launch new electric car models in the near future.

According to the International Energy Agency (IEA), the number of electric vehicles and plug-in hybrids in 2017 exceeded three million, which represents a 54% increase against 2016. Sharp increases in numbers also concern buses. In fact, around 370,000 of them have been sold so far in the world, with China being the main market. The number of two-wheeled electric vehicles in the world is about 250 million.

The charging infrastructure is developing, too. According to IEA estimates, there are approximately three million private charging stations in the world. In 2017, there were around 430,000 publicly available charging stations in the world. A quarter of them are fast-charging stations, a very important factor in densely populated areas.

Electro-mobility is developing intensively mainly thanks to a variety of factors such as the policies of the different countries, the already mentioned efforts to reduce CO2 emissions, state efforts to restrict the use of cars with higher emissions, different regional, local and city restrictions for such vehicles, green public procurement, regulations supporting zero emission vehicles, and a variety of different incentives for low-emission vehicles.

The main goal of this Master Thesis is to objectively look at the advantages of electric vehicles, to learn from the best practice abroad, and to evaluate the degree up to which Slovakia is ready to introduce electro-mobility. Since Slovakia often lags behind in issues like modernisation, planning and introduction of innovations, especially from the side of public administration and government, the premises for the following theses determination were rather pessimistic than optimistic.

Determination of Theses

Nowadays, the number of electric vehicles you can come across on Slovakia's roads is growing constantly. The issue here are mostly hybrid vehicles from different manufacturers. This paper, however, rather focuses on pure electric vehicles, i.e. battery electric vehicles (BEV). Popular and specialised publications are more inclined to point out their benefits like zero emissions, low maintenance costs, low operation costs or costs per kilometre. On the other hand, it is more difficult to find articles dealing with their disadvantages, namely their relatively short range, long charging time - even with super fast chargers - and, especially, their high price. The average Slovak car owner is sensitive to transport related costs. Thus, this paper focuses on the advantages and disadvantages of an electric car with an emphasis on the acquisition and operating costs. When will an average Slovak consumer be inclined to own an electric car?

A very important element in the development of electro-mobility is infrastructure. In this respect, having sufficient charging stations is a key factor. The quality of the distribution networks and the readiness of power producers and distributors to satisfy a new type of consumption are also important aspects. Another chapter of this paper aims at answering the question whether there will be enough electricity when the share of electric vehicles in the market reaches a specific threshold. Coping with gust loads at peak hours can also be a problem. This has already occurred in countries with a high number of electric cars. Can Slovakia's energy system cope with this new kind of demand in the future? Is the state prepared for this situation?

A third question for this work is the fiscal dimension of electro-mobility. The state, like most countries in Europe, has relatively stable revenues from excise duty on fuels. If the number of electric cars increases and that of combustion engine cars decreases, how will the state cope with the resulting reduction in income to the state budget?

Methodology

Three methods have been used to prepare this master thesis. The first one is studying the available sources, such as analyses by the International Energy Agency, McKinsey, Fraunhofer, European Union Strategies and Legislation, as well as a wide range of other available information. The second method was interviewing experts from institutions dealing with electro-mobility, such as the Automobile Industry Association of the Slovak Republic, the Ministry of Economy of the Slovak Republic, ZSE (the Western Slovak electricity distribution co.), SEVA - the Slovak Electric Vehicle Association, infrastructure developing companies and other institutions, with the aim to find out the visions the key players in the area have. The third method was identifying possible scenarios using calculations, tables, and charts and evaluating their impact in the future.

2. History of Electric Cars

2.1. The First Electric Car Models

The concept of an electric car is older than that of a combustion engine car. The primacy in the development and production of the electric car is attributed to many inventors and manufacturers. Initially, electric cars were developed and produced simultaneously with the first steam-powered or combustion engine vehicles.

The first electric car, whose documentation has been preserved, dates back to 1835 in Groningen, Holland. It was designed by Professor Sibrandus Stratingh and constructed by his assistant Christoper Becker. It was followed by several prototypes in different countries and by different constructors, but it was not until 1884 that the first actually usable electric car was built by English engineer Thomas Parker. Among the pioneers of electro-mobility was the Benedictine priest and physicist Štefan Adrian Jedlík, the first person in the world to construct an electric engine in which the stationary and the revolving parts were electromagnetic. Later, in 1842, he used it to propel an electric cart that moved on rails. The first Czechoslovak constructor of an electric car was the Czech engineer Frantisek Krizik in 1885.

French physicist Gaston Planté designed a rechargeable lead-acid battery contributing in this way to the development of the electric vehicle. His compatriot Camille Alphonse Faure made some important improvements to his design. This resulted in a significant increase of the battery capacity making its serial industrial production possible.

In the UK, the construction of the London Underground also contributed to the development of the electric vehicle. In 1884, British inventor Thomas Parker developed his own model of an electric vehicle for the subway, using high-capacity batteries he had developed himself. Two years later, he produced the first electric Dog Cart in his Elwell-Parker Company factory. Just like most first cars, it was a coach driven by something else than horsepower.

Andreas Flocken, a businessman from Coburg, is considered to be the first German inventor of the electric car. In 1888 he designed his first electric car, which is considered by some authors to be the world's first real electric car.

For example, little is known that the very first car Ferdinand Porsche built was an electric one called Porsche P1 in 1898. Its output was 3 horses and it reached a maximum speed of 35 kmph and a range of 80 km. The first bearing test of this vehicle was the electric cars race in September 1899. The competitors had to go over about 40 kilometres carrying three passengers. As James R. Healey wrote in USA Today on 27th January 2014, the then 22-year-old Ferdinand Porsche won with an advantage of 18 minutes over the second one. More than half of the participating cars did not finish the race at all due to technical problems. The prototype was found over 100 years later in a warehouse. It had not been touched since 1902.

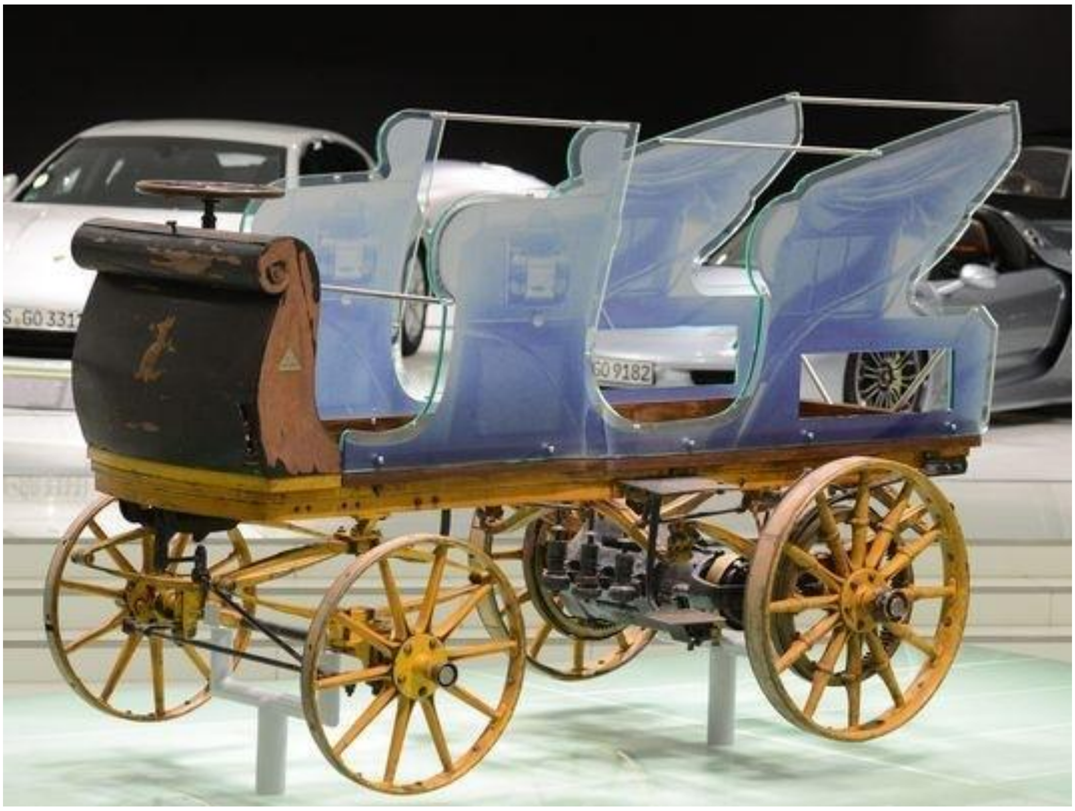

Figure 1 Porsche P1 Car (Photo: Franziska Kaufnann,epa)

At the turn of the nineteenth and twentieth centuries, in 1899 and 1900, a total of 4192 cars (American census) were produced in the United States, of which 28% were electric cars. Their price was higher than that of competing cars driven by steam or petrol.

An article in the New York Times from 1911 (New York Times, 20 January 1911, Electric Vehicles Attract Attention), dealing with a Motor Show that took place in the Madison Square Garden, reports that electric cars mainly raised the interest of female visitors. The article highlighted that it was mainly for their low noise, compactness and easy operation that they caught the attention of women. Worth mentioning is the fact that even prominent manufacturers of combustion engines used electric cars to move between their homes and companies because they were better suited for the conditions of a city.

The friendship between Thomas Alva Edison and Henry Ford is a generally known fact. Less well known is, however, that these two outstanding personalities of industrial research and production worked together on the development of an electric car. On 11 January 1914, Henry Ford told the New York Times that his company was working on the development of an electric vehicle designed for serial production. In the interview, he said he wanted to start production within a year. "The fact is that Mr Edison and I have been working for a few years on an electric car that would be cheap and practicable. The cars have been built for experimental purposes and now we are satisfied that the way is clear to success. The problem so far has been to build a storage battery of light weight which would operate for long distances without recharging. Mr. Edison has been experimenting with such a battery for some time."

It is certain that at least one experimental electric car was built involving several highly knowledgeable Ford employees as well as other constructers and engineers. The car used a Model T frame and batteries under the seat.

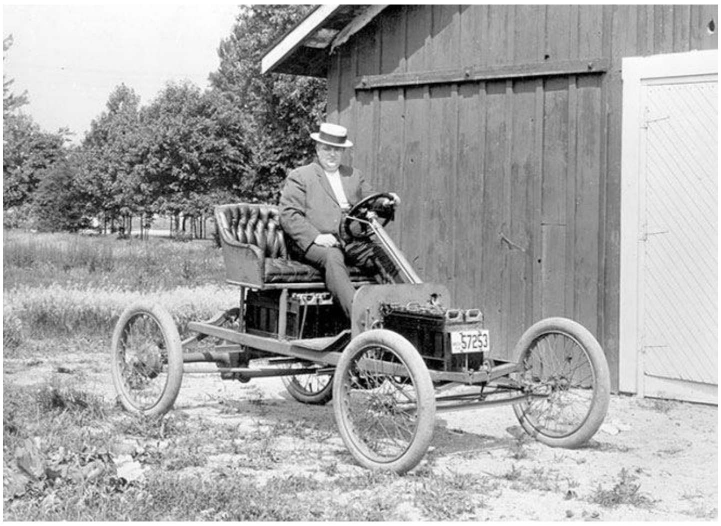

Figure 2 Ford-Edison Car, Source: www.wired.com

The Edison-Ford, as this electric car was commonly called, was surrounded by a lot of speculation and often unsubstantiated articles in periodicals. Production was put off from 1915 to 1916 and later. It would cost somewhere between $500 and $750, i.e. around $10,000 and $15,000 in today's prices. Ford spent $1.5 million developing an electric car, which today would be approximately $31.5 million (Ford Century, Russ Banham, 2002), and bought nearly 100,000 nickel-iron batteries from

Edison, which later turned out to be less competitive than the heavier lead-acid accumulator. The project was terminated without any official justification. Rumours have the oil cartels having them abandon their plans and the press even put this in connection with a fire in Edison’s works in December 1914. However, the project also had some successful outputs. The engineers who worked on it registered several patents in their name and in the name of the Ford company and were involved in the development of the electric starter and electric lighting systems.

The turn of the 19th and the first decades of the 20th century were favourable for the development of electric cars as they had some advantages against the competing steam and gasoline vehicles. They did not have the vibrations, smell or noise associated with gasoline cars. At the time, changing gear with petrol cars was the most difficult part of driving. Electric cars, on the contrary, did not require changing gears. Steam cars did not have gears either, but suffered from long start-up times of up to 45 minutes to reach service temperature in cold mornings. Steam vehicles had a shorter range per water tanking than electric vehicles per charge. Unlike combustion engines, electric cars did not need a crank starter, which required a lot of physical strength. The prices of electric cars oscillated between $1,000 and $3,000 and their design and comfort targeted the higher classes. They were massive vehicles made of expensive materials to match the target group. The boom of electric cars lasted until the end of the 1920s. The biggest number of cars sold was reached in the US in 1912. Electric vehicles were better fit for urban traffic due to their range, price, and the fact that better quality roads were available mostly in larger cities.

The following years saw a decline in the development and sales of electric vehicles as the result of several factors. The major ones are generally considered to be the following:

- After 1920, the system of roads connecting cities began to improve especially in the US, resulting in higher demand for vehicles with longer ranges.
- The newly discovered oil wells in Texas reduced the price of petrol, making it affordable to average customers.
- The discovery of the electric starter that Charles Pattering patented in 1912 eliminated the need for a crank starter for combustion engines, making the operation of this type of cars much easier.

- The introduction of mass production of combustion engine cars at Henry Ford's factory made these vehicles widely affordable at prices ranging from $500 to $1,000. On the contrary, the price of electric cars had kept rising steadily. For example, in 1912, electric cars were sold at an average price of $1,750, while gasoline cars cost around $650.

Electric cars slowly disappeared from the market and roads around 1935, and until the 1960s there was practically no development or production of electric vehicles for personal transport.

2.2. Electric Cars in the Second Half of the Twentieth Century

In the 1960s and 1970s the world started looking for alternative fuels. This was the result of the efforts carried out by developed countries wanting to minimise their dependence on foreign sources and reduce the amount of harmful emissions from combustion engines into the air. Attempts to produce a practical electric car were reassumed in the sixties.

In the early sixties, three American and British companies joined, namely Boyertown Auto Body Works, Smith Delivery Vehicles and the Electric Battery Company. The Battronic electric truck was built in 1964 as a result of this collaboration. This truck reached a maximum speed of 40 kmph and had a range of approximately 100 km and a carrying capacity of approximately 1.1 tons. Battronic worked in the US with General Electrics from 1973 to 1983 and manufactured 175 vans that were used in network industries to demonstrate the capabilities of battery-powered vehicles. In the mid-seventies, Battronic also produced approximately 20 buses.

Another US company, Jet Industries, specialised in converting serial cars into electric drive. The company produced a number of vehicles, including one called Electrica. Most cars with this name used Ford Escort and Mercury Lynx chassises, which they bought from Ford without a motor. The drive units were a combination of mass-produced parts such as the 96-volt Prestolite electric engine, 6-volt lead-acid batteries and their own battery boxes.

At the same time, Sebring-Vanguard produced over 2000 "CitiCars" - mini-cars that reached a maximum speed of about 70 kmph and a range between 80-100 km. Another company, Elcar Corporation from the US, produced a similar Elcar car that reached a maximum speed of about 70kmph and a range up to 100km, costing between $4000 and $4500.

In 1973, rising oil prices and petrol shortages ended up in the Arab oil embargo. The United States tried to reduce its dependence on foreign oil resources and started looking for domestic fuel sources. The American Congress passed the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976. This made it possible for US institutions, in particular the Department of Energy, to support the development of electric and hybrid cars. At that time, many US companies began to engage themselves more seriously in the development of vehicles for alternative fuels, including electricity. General Motors developed a city electric vehicle that was first exhibited at the Environmental Protection Agency symposium on low-pollution systems in 1973.

The American Motor Company developed an electric jeep, which in 1975 was used by the American Post as a test program. The Post bought 350 such electric vehicles to test and support the idea of electro-mobility. These jeeps reached a maximum speed of 80 kmph and a range of about 65 km. Charging took approximately 10 hours.

Figure3 Electric Postal Jeep, Source: www.trucks.com

NASA also contributed to the development of electric cars and their popularisation. Indeed, its Lunar rover was the first electric car and the first ever vehicle on the moon.

The first long-range electric car test was conducted in Arizona, when the Arizona Public Service tested the electric car MARSII manufactured by Electric Fuel Propulsion from Detroit. The journey began on September 20, 1967, in Detroit, and ended on Oct. 5 in Phoenix. MARS II went over 3500 km making 37 stops, using lead-cobalt batteries and a fast charger from the same manufacturer.

In the late seventies, Unique Mobility Inc. Colorado developed the Unique Mobility Electrek. It was a two-door, four-seat vehicle with a plastic body reinforced with glass fibre powered by sixteen 6-volt batteries. It reached speeds of up to 120 kmph and a range of 120 km in the city.

The vehicles developed in the 1970s still had a number of disadvantages against cars with combustion engines. At that time electric cars had very limited performance and were able to drive at a maximum speed of about 70 kmph and an average range of 60 kilometres per charge.

The transition between the mid-generation electric cars and modern electric cars was the Evcort vehicle, which was manufactured from 1981 to 1994 by Electric Vehicle Associates in Ohio and later by Soleq Corporation in Chicago. The vehicle used the Ford Escort chassis and body, was driven by electricity, and each component was produced specifically for this type of vehicle. This electric car used modern features such as regenerative braking or a multistage charging algorithm, which are also used in modern electric vehicles. The intention was to produce a practicable car with alternative drive with similar features to comparable combustion engine cars. Evcort was used to test and promote electro-mobility by several institutions, including some organisations at the US Department of Energy.

2.3. Electric Cars at the Turn of the Millennium

Legislation was another key factor in the development of electro-mobility. Among the main accelerators was the Clean Air Act of 1990 adopted in the United States, as well as the Energy Policy Act of 1992 or the Regulations on Clean Air adopted in California.

In the United States, the Big Three, namely Ford, GM and Chrysler, united with the Department of Energy and many companies involved in vehicle conversion and created a Partnership for a New Generation of Vehicles. Several popular mass models were transformed into electric cars, and completely new prototypes were developed, ranging from 80 to 250 km on a single charge and reaching speeds above 100 kmph.

One example is Geo Metro transformed by the company Solectria Corp. It was an electric four-seat sedan powered by AC lead-acid batteries. Its range was about 80 km and charging took less than 8 hours. During the 1994 electric car race, this electric vehicle reached a range of over 320 km per charge using nickel-based batteries.

The Big Three also developed electric vehicles in the nineties. Ford Ecostar was a utility vehicle powered by AC sodium-sulphur batteries, which reached a maximum speed of around 110 kmph and a range of 160 km. Although approximately 100 pieces of this vehicle were produced, it was still considered an experimental car and was never sold for commercial purposes.

Figure 4 Ford Ecostar, source: http://carhistory-plate.blogspot.com

General Motors decided to develop a brand new electric car instead of converting mass production models, giving origin to the EV1, a two-seat sports car. It reached a maximum speed of 130 kmph and had a similar range, which were the standard features of the time, but was able to go from zero to 100 kmph in just 6.3 seconds. The battery box, which consisted of lead-acid accumulators, weighed 1100 kg. Later, General Motors used new nickel-based batteries that increased the range under optimum conditions up to 320 kilometres and reduced the weight of the battery pack to about 700 kilograms.

Figure 5 General Motors EV1, Source: www.digitaltrends.com

Chevrolet’s first electric vehicle of this generation was the electric version of the Dodge Caravan. This vehicle was a five-seat van powered by lead-acid batteries with a range of about 80 kilometres, a maximum speed of 100 kmph and a maximum load capacity of over 350 kg. The new version of the Dodge Caravan Epic, which used NiMH batteries, had a range of over 130 km and a speed of 130 kmph.

At that time, manufacturers from Europe and Japan were already developing, testing and offering electric cars. Toyota offered the RAV4 and Honda the EV Plus sedan. Both vehicles used NiMH battery packs. Nisan offered the Altra EV station wagon using lithium-ion batteries. The Toyota RAV4 reached a range of about 150 kilometres and a maximum speed of about 130 kmph.

Among the first attempts made by BMW, the Mini E was a two-seater powered by lithium-ion batteries reaching a maximum speed of about 130 kmph and a travel distance of almost 200 km.

Figure 6 Mini E car, source: www.greencarreports.com

2.4. Current Electric Car Concepts

The beginning of the 21st century brought about a new era in the development of electric vehicles. As it is clear from the previous chapter, at the end of the twentieth century governments, carmakers as well as various new manufacturers and research institutes turned towards alternative vehicles. There were different reasons for this, such as the environment, the oil dependency strategy, the diversification of vehicle propulsion types, and the effort to differentiate themselves from the competition with a new type of vehicle. The common denominator in all the activities oriented towards developing electric cars was the environment, especially the struggle to reduce greenhouse gas emissions in transportation. In fact, several documents of transnational organisations such as the UN, the OECD, or the EU dealt with this issue.

In 2015, the UN adopted a resolution entitled “Transforming Our World: The 2030 Agenda for Sustainable Development", which set 17 Sustainable Development Goals. It is a comprehensive agenda for the sustainable development of people and planet while securing economic, social and environmental balance. This document deals with the environment in many respects, one of the tools of environmental protection being eco-innovation. It is possible to include electric cars in this category as one of the goals of their wider application in everyday life is to reduce emissions, especially in places with high concentration of vehicles. The UN activities were followed by the OECD and EU documents on “Green Growth”, and these, again, by the strategies and activities of other countries.

The main motive triggering the development of alternative propulsion vehicles is the premise that oil reserves are final and, therefore, we need to prepare for a time when it will no longer be possible to produce fuel from oil. Producing synthetic fuels or fuels based on bio-sources from renewable sources is uneconomic and, in addition, cultivating monocultures and the subsequent production process are detrimental to the environment. The International Energy Agency (IEA), established within the OECD, publishes yearly studies with estimates of oil stocks. Its latest study estimates oil reserves to be at 1651 billion barrels (see Table below).

Table 1 Worldwide Oil Reserves as of January 1, 2018

Region	Proved oil reserves (bill. Barrels)
Western Hemisphere	540,9
Western Europe	10,2
Asia-Pacific	45,6
Eastern Europa and Former Soviet Union	120
Middle East	807,7
Africa	127,4
Total World	1651,8
Total OPEC	1217,9

Source: PennWell Corporation, Ois&Gas Journal, vol 115.12 (December 4th, 2017)

Another reason to develop electric cars was the desire of the manufacturers to differentiate themselves from the competition or to take the lead with a new viable concept. As mentioned in the previous text, from the 1930s to the end of the 20th century electric cars were developed solely as an attempt to show interest in the environment or as experiments with vehicles of the distant future. At the turn of the millennium, although almost every major manufacturer was already developing electric cars, these efforts were still part of their long-term objectives. At the same time, several concepts of clean and especially hybrid electric vehicles were being developed.

3. Pros&Cons of e-mobiles

3.1. Comparation of basic types of e-mobiles

Nowadays we are witnessing the development of different types, forms and models of electric vehicles for a variety of purposes. The major goals are economy, reduced environmental impact and performance. The different electric car technologies and types still need a lot of improvement before all vehicles on the roads use only electricity, are environmentally neutral and have zero emissions.

In the meanwhile, hybrid cars and their variations will play an important role. The technology that come into consideration depends on the requirements on the different types of vehicles such as size and range. According to the standard characteristics of today, such as range, price, operating costs and reduced emissions, the use and share of electric vehicles could look as follows:

Battery Electric Vehicle (BEV)

Vehicles driven exclusively by electricity are generally considered to be most suitable for urban environments. Their lesser range and relatively long charging time, up to a few hours, predetermines them to be small-size urban vehicles intended for short trips. Zero emissions make them ideal for driving in the city. Another restriction is the relatively scarce network of charging stations outside the city. New commercial and transport models such as car sharing currently help to offset the disadvantage of the relatively high price of electric cars against comparable combustion engine cars. These models take full advantage of the benefits of electric cars while eliminating the necessity to spend large amounts of money to purchase them. Users can keep their regular or hybrid vehicles for long journeys. BEVs are also considered to have an advantage over conventional cars as the fuel and maintenance costs can to a certain extent offset the higher initial acquisition cost.

Hybrid Electric Vehicle (HEV)

Hybrid electric vehicles are the most common form of hybrids, alongside small commercial vehicles and buses. Their advantage is that they can make use of the existing network of petrol stations and at the same time require lower operation costs than those of vehicles with a combustion engine only. HEVs are expected to become more numerous on the roads in the near future than they are at present. However, they still depend on fossil fuels, so they may become the transient technology between regular cars and a market in which completely electric cars predominate (BEVs).

Range – Extended Electric Vehicle (REEV)

This type of vehicle has a combustion engine to increase the range of the electric one and can function as a standard hybrid for longer journeys. However, it depends on the same infrastructure as purely electric cars, what makes them more suitable to be used as small family cars intended for the city and its immediate vicinity. They are also considered a transitory technology in the development of purely electric vehicles.

Plug-in Hybrid Electric Vehicle (PHEV)

This kind of hybrid vehicle is a more economical version of the BEV and the fuel-cell hybrid we can expect to see on the roads in the short and medium term. Most current forecasts do not expect electromobiles to become a viable replacement for regular combustion engine cars until 2025. Similarly to pure electric cars (BEVs), this type of hybrid is best suited for urban traffic characterised by shorter distances and low average speeds. PHEVs have less battery capacity than pure electric cars, allowing them to reach a range of about 40-60 km on the electric motor. Another advantage is their significantly lower carbon dioxide emissions.

Fuel Cell Hybrid Electric Vehicle

The range and performance of FCHEVs are comparable to those of conventional combustion engine cars. These features make them the solution with the lowest emissions in the mid and large size segment with a longer range. Insufficient infrastructure and the resulting higher overall operation costs, however, have prevented this type of hybrids from becoming more popular. Tanking hydrogen accounts for about five percent of the total procurement and operation costs of FCHEVs. Infrastructure issues in cities and urban agglomerations represent a short and perhaps mid-term factor restricting the development of the market for this type of hybrids. Estimates and different scenarios for the future do not expect this segment to develop until after 2030.

Let us take a look at a report elaborated by McCinsey in cooperation with the Amsterdam Round Table on the benefits and disadvantages of some selected types of electric vehicles.

Table no 2 Comparison of the advantages and disadvantages of electric vehicles

	PHEV	REEV	BEV	FCEV
Environment	Reduced emissions due to battery and e-motor. ICE remains primary mover	Ample emission reduction against ICE – emission only when using range extender	Zero emission. More efficient life cycle than ICE	Zero emission. More efficient life cycle than ICE
Advantages	Uses existing fuel infrastructure. Same range as ICE	Extender allows longer range than BEV Real electric car Less range concern	Purely electric. Zero emission. Charging at home or office possible. Growing infrastructure	High Range Refueling in just minutes
Hurdles	Low range on e-motor ICE remains primary mover High emission on longer trips	Added complexity and costs against BEV Extender provides limited extra range	Longer refueling time. 20- 30 minutes even with fast charge Relatively low current range Scarce infrastructure available but growing	Hydrogen production is demanding Scarce infrastructure

Source: McKinsey, Electric Vehicles in Europe: Gearing Up For A New Phase?, 2014

3.2. Emissions Associated with Electric Vehicle Operation and Production

The advantages and disadvantages of electric cars can be evaluated from a variety of perspectives. Among the features of electromobiles, it is possible to take into account the vehicle's range, battery capacity, battery charging time, available charging station network, emissions and environmental impact, economy of operation, amount of material used in manufacturing vehicle and components, etc. At present, communication with the public on electro-mobility lays more emphasis on the advantages of owning and operating an electric car, yet manufacturers and research teams still need to solve many issues.

Numerous studies have concluded that electric vehicles are more efficient and, therefore, produce less greenhouse gases than combustion engine vehicles. The European Commission's Joint Research Centre Directorate for Energy and Transport, worked out the Well-to-Wheels Report, which has been updated several times. This report compares the benefits of alternative fuels against conventional fuels used to drive combustion engine cars. The present paper does not deal with alternative fuels like LPG, CNG, synthetic diesel or the like. The study also includes a comparison of the emissions of an electric car and a regular car according to the source of the electricity used by the electric car. It compares not only car consumption, but the whole process from the moment the natural resource is obtained, i.e. mined, through the processing, transfer to pumping points, and the consumption of the car itself.

The study showed that a combustion engine car consumes 26 megajoules of energy in the processing and transport of the fuel it needs for a 100-kilometre long trip. Driving those 100 km consumes 142 megajoules. An electric car, on the other hand, consumes 74 megajoules of energy in producing and transporting the energy it needs for the same distance, while the journey itself requires 38 megajoules. Therefore, electric cars make more efficient use of the energy they consume. This comparison is processed in the table below.

Table no 3. Comparison of Energy Consumption of Regular Car vs. Electric Car

Five seat sedan / 100 km	**Energy production and transportation (MJ)**	**Energy consumption(MJ)**	**Total consumption (MJ)**
ICE	26	142	168
Battery BEV	74	38	112

Source: Worked Out Based on JRC Data.

The table shows that a typical European vehicle, a five seat sedan, whose consumption was taken into account is a third more efficient in terms of energy consumption when it is a purely electric vehicle (BEV).

Another criterion is the volume of emissions generated during the vehicle production and operation. Some critical views claim that when electricity is generated for an electric vehicle, the resulting emissions are only moved to the place where the energy is generated. As it has been clearly established, if an electric car consumed energy from the same source as a conventional combustion engine car, its energy consumption would be considerably less. A real advantage is that emissions from combustion engines that have been replaced by electric cars are eliminated from roads, streets, residential areas and schools. In any case, it is interesting to compare the volume of emissions produced depending on the energy mix used to charge the battery of an electric car. This comparison is presented in the following table.

Table no 4. Vehicle Emissions By Power Source

Type of Car	C02 Emmisions-g/km
Petrol-powered car	**125**
Range-extender with electricity from Oil	102
Pure electric car with electricity from Oil	**91**
Hybrid	83
Plug-in hybrid with electricity from Oil	82
Plug-in hybrid with electricity from EU-mix	74
Range-extender with electricity from EU-mix	73
Plug-in hybrid with electricity from Nuclear	59
Plug-in hybrid with electricity from Wind	59
Pure electric car with electricity from EU-mix	**57**
Range-extender with electricity from Nuclear	26
Range-extender with electricity from Wind	24
Pure electric car with electricity from Nuclear	2
Pure electric car with electricity from Wind	0

Source: The Guardian

The table clearly shows that in order to make comprehensive and objective assessments of the emissions the different types of cars produce according to their type of propulsion, it is imperative to know the source of the electricity that drives them. Interestingly, this comparison reveals that a purely electric car using electricity generated from oil would have a more negative emission balance than a regular hybrid vehicle, namely by almost 10%. Only an electric car using wind generated electricity really has zero emissions.

Therefore, the volume of emissions resulting from the operation of an electric car depend mainly on the energy mix used in that specific country. In practice, this means that the operation purity of an electric car depends on the country's energy policy and on the types of electricity generation that prevail in it. The EC Joint Research Centre in its Well to Wheels study identifies four basic types of electricity production - fossil fuels, water, nuclear and renewable resources. In this comparison Norway is one of the best countries as its electricity is generated mainly at hydroelectric power plants. In this respect, France is also a leading country for nuclear power plants dominate its production. Surprisingly, Japan produces the vast majority of its energy from fossil fuels, just like China, of which this is a generally known fact.

Table no 5 Selected Countries in Terms of Energy Source

	Electricity production **Kw hours bill.**	**Coal** **% of total**	**Nat. gas** **% of total**	**Oil** **% of total**	**Hydro** **% of total**	**Renewable sources** **% of total**	**Nuclear power** **% of total**
	2014	**2014**	**2014**	**2014**	**2014**	**2014**	**2014**
Australia	248.3	61.2	21.9	2.0	7.4	7.5	0.0
Austria	61.6	8.0	8.8	1.0	66.6	14.6	0.0
Brazil	590.6	4.5	13.7	6.0	63.2	9.9	2.6
Canada	656.1	9.9	9.4	1.2	58.3	4.5	16.4
China	5,665.7	72.6	2.0	0.2	18.6	4.1	2.3
Czech Republic	85.0	51.5	1.9	0.0	2.2	8.5	35.7
France	557.0	2.2	2.3	0.3	11.3	5.1	78.4
India	1,287.4	75.1	4.9	1.8	10.2	5.2	2.8
Italy	278.1	16.7	33.7	5.1	21.1	22.3	0.0
Japan	1,035.5	33.7	40.6	11.2	7.9	6.1	0.0
Mexico	301.5	11.2	57.0	10.9	12.9	4.6	3.2
New Zealand	43.6	4.5	16.3	0.0	55.9	23.2	0.0
Norway	141.6	0.1	1.8	0.0	96.0	1.7	0.0
Russian Federation	1,062.3	14.9	50.2	1.0	16.5	0.1	17.0
Slovak Republic	27.1	12.4	6.0	1.1	15.5	7.4	57.1
Sweden	153.6	0.6	0.3	0.2	41.5	14.3	42.3
Switzerland	70.1	0.0	0.7	0.1	54.3	3.8	39.3
United Kingdom	336.0	30.4	30.0	0.5	1.8	17.7	19.0
United States	4,319.2	39.7	26.9	0.9	6.1	6.9	19.2
World	23,863.9	40.7	21.6	4.1	16.2	6.0	10.6

Source: World Bank, Development Indicators 2017

Fossil fuels also predominate in Ireland, Mexico, Australia and India. Canada, New Zealand and Brazil benefit from plenty of hydropower. The United States of America also uses fossil fuels to a large extent, but the situation varies considerably among the different states. While southern states like California use a lot of energy from renewable sources, northern states rely more on fossil fuels. The United Kingdom and Germany get about half their power from fossil fuels and half from the other three sources. Germany plans to replace nuclear power with renewable resources. Slovakia produces more than half of its electricity in nuclear power plants. Production from fossil fuels has fallen recently in favour of renewables and water.

It is also interesting to compare the total energy consumption by type and source of production of fuel and electricity, and how effectively they are consumed in the vehicle. The efficiency of the different types of vehicles depends on the energy source or energy mix supplied to the electric vehicle. In the case of combustion engine cars relatively little energy is used to produce fuel. Their operation, however, requires more of it than that of electric cars. Vehicle efficiency increases depending on the composition of the hybrid drive, i.e. which component predominates. At the same time, their total energy consumption depends on the relevant energy source and mix. This comparison can be seen in the table below.

Table no. 6 Energy Consumption of Different Types of Vehicles By Source

Car Type	**Energy Consumption MJ/100km**
Petrol powered car	169
Range-extender with electricity from Nuclear	166
Pure electric car with electricity from Nuclear	155
Range-extender with electricity from EU-mix	139
Range-extender with electricity from Oil	128
Pure electric car with electricity from EU-mix	124
Plug-in hybrid with electricity from Nuclear	119
Pure electric car with electricity from Oil	112
Plug-in hybrid with electricity from EU-mix	111
Hybrid	111
Range-extender with electricity from Wind	69
Pure electric car with electricity from Wind	43

Source: The Guardian

It is noteworthy that while nuclear power produces relatively low emissions, energy consumption from this source is relatively high even in the case of purely electric cars - BEV. The production and transport of electricity from nuclear sources is, therefore, energetically demanding. The least demanding is the production of electricity from wind. It means that this source is the most efficient in terms of both emissions and consumption.

The emission comparison of conventional cars and electric cars focuses on the overall CO2 emission footprint. Several studies examine the greenhouse gas emissions produced throughout a vehicle's life cycle. According to a study by the British Low Carbon Vehicle Partnership worked out by the company Ricardo in 2014, manufacturing an electric car produces more CO2 than producing a regular car. However, an electric car offsets this disadvantage thanks to its environmentally friendlier operation.

Table no. 7 Total Emission Footprint of Vehicles

Type of vehicle	**Estimated lifecycle emmision in production (CO2 tones)**	**Proportion of emissions in production**	**Estimated emissions in production (tonnes CO2e)**
Standard gasoline vehicle	24	23%	5.6
Hybrid vehicle	21	31%	6,5
Plug in Hybrid vehicle	19	35%	6,7
Battery electric vehicle	19	46%	8.8

Source: Low CVP, 2014

According to this study, a regular middle-class vehicle with an internal combustion engine generates about 24 tons of CO2 during its life cycle while an electric car produces around 18 tons over the same period. In the case of a pure electric car (BEV), 46% of the carbon footprint is generated in the factory it is produced before it touches a road.

The production of a standard middle-class vehicle with a combustion engine produces about 5.6 tonnes of CO2, three quarters of them being generated to produce the steel for it. From an environmental point of view, this highlights the importance of lighter models and the necessity to replace steel with lighter and environmentally friendlier materials.

A similar electric car produces 8.8 tonnes of CO_2, 43% of which is generated to produce the battery. Therefore, if the carbon footprint of an electric car is to be reduced, it is necessary to minimise the impact of the battery production and to optimise the energy mix by increasing the share of water and other renewable resources.

To conclude this chapter, it is possible to state that as of today there is no carbon footprint-free car. In order to establish the impact of the different types objectively it is necessary to take into account the whole lifecycle of each of them. An even higher level of objectivity in assessing the impact of the different types of vehicles can be achieved by identifying the point at which the carbon footprint is generated such as the production of the different materials and components, the exploitation and transport of the raw materials, the generation of the energy and its delivery to the place of consumption, as well as the operation of the vehicle itself. The fewer components in the life cycle of the vehicle are taken into account, the less objective are the comparisons of their impact on the environment. Different sources report slightly different data on the amount of greenhouse gases generated producing a regular and an electric car, but they all agree that producing an electric car has a more negative impact on the environment than producing a combustion engine car. Thus, if electric cars were to consume electricity produced mainly from coal, gas or oil, then their positive environmental impact would be highly questionable. Together with the introduction of electric cars, national policies should also consider improving their energy mix in favour of renewable energy sources, which have a minimal impact on the environment.

3.3. Electric Car Range

One of the discussed features that is perceived as a disadvantage of electric cars is their range. In the introductory chapters, electric vehicles were divided into categories according to the share electricity accounts for in their propulsion. This section deals exclusively with BEVs, i.e. purely electric cars, as it is possible to objectively compare range for this category of vehicles. Taking different hybrid electric vehicles into consideration would make it necessary to take into account the volume of the different engines, tanks and other features, which would make such a comparison far less objective. In addition the existing gas station infrastructure makes range less important an aspect for hybrid cars. In fact, range is rarely taken into account when selecting a hybrid or a regular car, but is one of the key factors at the moment of choosing an electric car. There are even cost per kilometre calculations. As the prices of electric cars differ in the different markets, these calculations have not been included in this section. At first sight, it may seem that the most expensive cars have the highest range. This belief is mainly the result of Tesla's pricing policy. On the other hand, the development of batteries and the continuous optimisation of propulsion has put more affordable electric car models at the leading positions in range. To illustrate the current situation, information concerning the range of the twenty best selling cars on the European and American markets has been collected from different assessment websites. The data used for this purpose is not the maximum range indicated by the manufacturer because the actual range depends on the style of driving and how much additional equipment the vehicle uses at that particular moment. Other similar information such as average consumption, combined consumption and the like, which are commonly used for combustion engine cars, still need to be sufficiently developed and objective.

Table No 8 Range of Selected Types of Electric Vehicles in 2017

Model	range miles	km
Tesla Model S	315	507
Tesla Model X	295	475
Renault ZOE	250	402
Tesla Roadster	244	393
Chevrolet Bolt	238	383
Tesla Model 3	215	346
BMWi3	195	314
Volkswagen e-Golf	186	299
Hyunai Ioniq Electric	150	241
Kia Soul EV	132	212
Mitsubishi iMiEV Sport	124	200
Ford Focu EV	115	185
Nisan Leaf	107	172
Smart For Two	100	161
Mitsubishi iMiEV	99	159
Volkswagen e-Up!	99	159
Mercedes Benz B-Class	87	140
Peugeot ion	80	129

Source: Calculations using Assessment Website Information

Range evaluations differ among the different websites even though they concern the same year. For this reason, these figures are considered to have a merely illustrative character. What is really important is the fact that the average range of cars has increased by almost 60% in the last six years. According to Electrec editor-in-chief, Frederic Lambert, a research carried out by the US Department of Energy showed that only three of the purely electric cars available in the market in 2011 offered a range between 100 and 150 kilometres (https://electrek.co/2017/12/26/average-electric-car-range/, Dec. 26th 2017 7:44 am ET). Today around 15 to 20 electric vehicles offer a range between 100 and 500 kilometres. While in 2011 the average mileage of electric cars on the US market was 117 kilometres, in 2017 it was 183 kilometres. It should be borne in mind that it was only recently that the established OEM manufacturers started to develop electric cars for the real market. This means that their development for serial production and sales is just in its initial phase. Their rapid development makes it possible to assume that the range of electric cars will still see substantial increases.

In 2011, ScienceDirect published a study carried out by a team of authors examining the average daily driving distances of American drivers (Nathaniel S. Pearre et al., Electric Vehicles, Volume Direct, Volume 19, Issue 6, December 2011, pages 1171-1184). On a sample of 484 vehicles, they calculated their usual daily ride as well as their behaviour over longer periods of time. The survey showed that 9% of vehicles never exceeded a daily limit of 161 km (100 miles), and 21% of drivers do not drive more than 241 km (150 miles) daily. The survey is not up-to-date and the number of cars monitored might not be enough to be representative but, nevertheless, it still gives some insight into the market potential of lower-range electric cars. It can be assumed that in Europe, where the average daily and annual driving distance is even lower, the potential can be much bigger.

Electric car range is a limiting factor when choosing the type of electric vehicle or when choosing between a regular and an electric car. Although this parameter is continuously improving, it can be said that wherever the range of the best electric vehicle ends, the regular car’s range begins. Alongside other disadvantages of electric cars - such as acquisition and total price, battery capacity, etc. - the lack of infrastructure is still a major limiting factor.

3.4. Batteries

Batteries constitute an essential component of electric cars as they store the electricity needed to power the vehicle. Alongside electric cars, different types of batteries have been developed with different capacity, weight, responsiveness to load, charging and discharging rates/times, and memory effect - a reduction in capacity when recharging before the battery is completely discharged.

Basic Types of Battery Used in Vehicles

Lead-acid Battery

This type of battery is mostly used in conventional cars for startup, ignition, lighting and other functions requiring electricity. They were used in the early development stages of electric car technology. Their production is not particularly costly, but they are too heavy and do not have sufficient power for larger electric vehicles.

Nickel-Metal-Hydride Battery (NiMH)

This type of battery is one of the two most popular types used for electric cars. They are mainly found in hybrid electric cars because they can keep energy longer than their lead-acid equivalents, have a much longer life cycle, and are significantly lighter. However, their service life is reduced if exposed to repeated rapid discharges with high loads for driving and acceleration. Therefore, NiMH batteries are better suited for hybrid vehicles than for purely electric vehicles.

Nickel Cadmium Battery (NiCd)

This type of battery has a longer life cycle and can tolerate a deep discharge longer than a NiMH battery. At the same time, it is lighter than a lead-acid battery. On the other hand, it has a relatively low electrical capacity. Low electrical capacity can cause the battery to crumble, melt or catch fire when exposed to deep discharges and fast chargings within a short period of time. Their memory effect is another disadvantage against NiMH batteries. This occurs when the battery is charged before it is fully discharged.

Lithium-Ion (LI-ion) Battery

Alongside NiMh batteries, this type is the leading solution used in electromobile technologies. This type of battery has a number of advantages against nickel ones, such as higher capacity, lighter weight, low self-discharge and good thermal characteristics. Since almost all its parts are recyclable, it also has an advantage over the other types from an environmental point of view. Although it is the most expensive type of battery, it is the most commonly used in electric cars and hybrid vehicles.

Besides these four types of batteries, other types are used, too. They combinesodium and nickel, for example Na-NICl2 batteries, or lithium and sulphur. e.g. Li-S batteries. Different manufacturers also add different additives to their batteries, such as cobalt, aluminium, magnesia, and so on to strengthen some of the battery's properties or to offset some of their insufficiencies.

Another very important factor is the battery pack used in the vehicle. Tesla uses small-format Li-ion batteries (Panasonic 18650). This type of battery has been used in industry, mainly in consumer electronics, for over two decades and the production amounts make them cost efficient (economy of scale). Their disadvantage is that they tend to overheat, so the battery boxes need to be equipped with advanced cooling and battery management systems (BMS). This type of battery boxes was chosen by Mercedes (B-Class) and Toyota (Rav4). All other manufacturers of OEM series use large battery/cell formats. They have a lower energy density, but are less prone to overheating and other unwanted potential consequences such as ignition or explosion. Their disadvantage is their higher price against small-format Panasonic 18650 based battery packs.

Factors Reducing Battery Performance and Life

Extreme temperatures can degrade batteries operating an electric car. Even parking the vehicle in the sun for a long time may have similar effects. Operating the vehicle at extremely low temperatures requires the battery to warm up to the optimum temperature before it can achieve the required power.

Over Voltage / High Voltage*.* Charging the battery beyond its voltage limit may cause internal resistance within it. Most batteries used in electric cars have a built-in battery management system (BMS), so overcharging rarely occurs. However, it is good advise not to recharge the batteries up to 100% of their capacity if possible.

Deep Discharge / Low Voltage. The repeated exhaustion of most or all of the battery capacity results in overall capacity reduction over time. This way, the life and capacity of the battery are significantly reduced.

Large Current Draw. Drawing too much current from the battery within a period of time may have undesirable effects in its life and performance. Therefore, aggressive driving on an electric car can significantly reduce its battery parameters.

Electric car manufacturers use different types of batteries, but in general small electric cars include battery packs with a 12-18 kWh capacity, while family sedans use 22-32 kwh. Tesla is the only car maker that offers a battery pack with a capacity of 60-85 kWh . The higher the capacity, the greater the weight of the batteries, and the more a vehicle weighs, the more energy it consumes and, consequently, the lower its range. High-capacity batteries usually need longer charging times.

When assessing battery efficiency, parameters such as Ampere-hours per cell (Ah/cell) or Watt hours per kilogram Wh/kg also need to be taken into account. For example, the Tesla S model, which uses a 90 kWh battery, has a range of nearly 450km. However, the battery weighs 540 kilograms increasing its power consumption to 238 Wh / km, which is one of the highest among electric cars. For comparison, the BMW i3 is one of the lightest electric cars and consumes 160 Wh/km. Its 22kWh battery pack delivers 130-160 kilometres. From this derives that a lower-capacity battery pack weighs less, which results in the vehicle consuming less energy per kilometre. On the other hand, however, it has a shorter range.

Manufacturers of electric cars calculate the rage of their cars under optimal conditions. However, the actual distance they can reach may be over 30 percent shorter than promotional materials claim. This is caused by additional energy burden such as lighting, wiper operation, cabin heating or cooling and other equipment being used in the vehicle. Aggressive riding or hilly terrain also result in significant range reductions.

Cold weather also shortens a vehicle’s range. Manufacturers often avoid mentioning the fact is that charging a battery under cold weather conditions can be a problem. Likewise, most Li-ion batteries cannot be charged at temperatures below 0°C. Some battery packs have a heating device to make it possible to charge them even in low temperatures. In addition, BMS deliver less charging current to the batteries if the temperature is low. Fast charging Li-ion batteries at low temperatures causes dendrites to growth in them, reducing their safety.

Table no. 9 Battery Capacity and Energy Consumption for Selected Electric Vehicles

Electromobile	Battery	Range km (mi)	Wh/km (mi)
BMW i3	22kWh	135km (85)	165 (260)
GM Spark	21kWh	120km (75)	175 (280)
Fiat 500e	24kWh	135km (85)	180 (290)
Honda Fit	20kWh	112km (70)	180 (290)
Nissan Leaf	30kWh	160km (100)	190 (300)
Mitsubishi MiEV	16kWh	85km (55)	190 (300)
Ford Focus	23kWh	110km (75)	200 (320)
Smart ED	16.5kWh	90km (55)	200 (320)
Mercedes B	28kWh	136km (85)	205 (330)
Tesla S 60	60kWh	275km (170)	220 (350)
Tesla S 85	90kWh	360km (225)	240 (380)

Source: Battery University

Charge speed is another disadvantage of electric cars. The standard charging time oscillates between 4 and 18 hours at 15 amps and decreases proportionally as current increases. A supercharger can charge a Tesla Model S up to 80% in 30 minutes. Against the average fuelling time of regular combustion engine cars, which takes from 5 to 10 minutes, this constitutes a considerable drawback. Electric car users would welcome ultra-fast charging and the technology necessary for it is already available. The problem is that fast charging significantly deteriorates the battery and reduces its lifespan. In general, any charging that takes less than 90 minutes should be avoided unless strictly necessary. Some electric cars keep evidence of battery usage and charging, and records of too frequent charging can result in the warranty being canceled in the event of a battery problem.

The price of the battery also represents a substantial part of the price of an electric car. There are different conversions, but the most generally used is the price-per-kilowatt hour ratio. Research and larger production numbers result in lower costs and more affordable final prices. In 2017, prices fell to an average of about

$350/kWh. For example, Tesla was able to reduce their price to 250 USD/kWh at that time by using the already mentioned Panasonic 18650 batteries, which have been manufactured in large quantities for a long time and have, therefore, the advantage of costing less. By the end of 2017, Bloomberg said the average price of an electric car battery had reached $209 / kWh. Experts predict that the kilowatt hour price could fall to $100 by 2025, which could bring the prices of electric cars to the level of the prices of conventional combustion engine cars.

3.5. Infrastructure

Infrastructure for electric cars is mainly related to the availability of charging stations. Domestic charging stations are particularly important. Most surveys on infrastructure development estimate that the main charging station of almost every electric car is at the owner's home. Many countries have set ambitious targets to build publicly available charging points and their numbers have, in fact, risen steadily over the past decade.

The infrastructure for different vehicle types has different characteristics and is divided into several categories. Infrastructure issues are influenced by a number of factors such as availability, charging station specifications, charging methods, electric car user’s habits when charging, etc.

The availability of petrol stations for the different types of engine is constantly compared. Infrastructure for classic combustion engine cars is still the leading one, not only for being the most densely available, but also because refuelling takes the shortest time. As for pumping speed, regular cars are matched by vehicles powered by hydrogen, natural gas, propane butane, or electric cars whose discharged battery can be replaced by a charged one. The latter, however, are just in experimentation phase and only some models and makes allow this. The following table compares the ways energy is topped up, the time this takes and the infrastructure available in Europe.

Table no. 10 Refuelling Station Types and Availability in Europe

Energy Source	Petrol/Diesel	Hydrogen	Battery	Battery	Battery
Charging method	Gas station	Tanking	Cable	Change of battery	Inductive charging
Description	Regular tanking	Like at a gas station	Cable and socket	Change battery for a charged	Cable free - inductive charging
Charging/Tanking Time	5 min	5 min	4-8 hours 20-30 min fast-charging	5 min	2-8 hours
Suitale for	ICE, HEV, PhEV, REEV	FCEV, REE	BEV, PHEV	Special model	Pilot model
Infrastructure in Europe	130 000 stations	Restricted to 100 stations	Over 100 000 charging posts	Restricted 50 stations approx.	Just some pilot ones

Source: Mc Kinsey and European Alternative Fuels Observatory

A variety of charging or refuelling models are breaking into the market to different extents.

Battery Replacement is currently being used in pilot and small scale projects only. This concept lost ground when Better Place, a company that installed more than 50 battery exchange stations in Denmark and Israel in 2013, went bankrupt. In fact, the batteries of none of the new BEV models can be replaced. One of the few exceptions being Tesla Model S, whose battery can be replaced quickly. In addition, the company has announced it will build pilot exchange battery stations at its US Supercharger stations.

Induction or wireless charging has been pilot tested at several locations but has not yet become commercially successful or economically efficient. This technology makes use of an electromagnetic field that is generated beneath the vehicle.

Wire or plug charging is the most common energy top-up method for electric cars. It represents the fastest growing charging point network in Europe and the world. There are several types divided according to different technical parameters or by the power that is pumped into the car.

The charging infrastructure as well as the charging itself have several technical specifications that need to be taken into account when building it so that the created infrastructure be suitable for the widest possible range of electric car types. These specifications refer to the level and type of power, as well as the plug and battery type. All of these characteristics determine where the electric vehicle can be charged and how long it will take.

The power level of the charging source is given in kilowatts (kW), is defined by current and voltage, and determines how fast the battery can be charged. The range of the charger power level is relatively wide, namely between 3.3kW (slow) and 50kW (fast).

Low power chargers are mostly used as home stations that take several hours to fully charge a battery. Chargers between 3.3 and 7 kW charge a lower middle class car in 4-8 hours. In order for higher power chargers to be used as home stations, it would be necessary to change the parameters of the electric installation and circuit breakers of the house in question. Higher performance is used at public charging points and Superchargers.

The ***electric current*** provided by distribution networks is usually AC. However, as batteries are able to store direct current only, the electricity supplied by the network needs to be converted. Cars that are able to draw power from the network must be equipped with a converter. Fast-chargers are usually equipped with a converter and supply direct current.

The plugs currently used for charging are different types. The standard 2-pin "Menkes" plug is the most commonly used for slow charging in Europe. There are several types available for fast charging: Japanese CHAdeMO, European-American CCS "Combo" and Tesla Supercharger.

The *size of the battery* usually determines the amount of energy it can store and is defined in kilowatt-hours. PHEVs typically have small batteries and can charge up to 3.7 kW. Purely electric cars have more powerful batteries, so they can be charged at around 7kW AC or 50kW DC. In this case, the stronger the battery, the higher the charging power it can take.

Common Charging Habits

Most electric car owners do not drive more than 100 to 150 kilometres a day, which corresponds to the current range of conventional lower class electric vehicles. Their charging behaviour and charging frequency reflect this situation. Surveys show that over 95% of them have a home charger in their own garage or share it in residential complexes.

Secondary charging sources are available at work or near their workplaces. These are becoming more and more available, especially in larger companies and administrative business complexes.

Public charging points, for example, in shopping centres or built by public authorities are the third most common choice for electric car owners. This type of charging points has systematically expanded in recent years especially in developed countries. As electric vehicles become more popular, this type of charger is expected to be used predominantly in cities. While, for example, in Germany nearly two-thirds of households have their own garage or parking space, in London two-thirds of them lack these facilities. Thus, cities and countries with similar situations to that in the capital of England, public institutions will need to support and help build charging infrastructure if they want electro-mobility to thrive. McKinsey estimates that while the current share of domestic chargers is 90%, when electric cars become more popular and common the ratio of public and corporate chargers will need to grow to 40%.

Business Models for Infrastructure

Building a charging station network is imperative is electro-mobility is to develop any further. On the other hand, the cost of building it to the extent specified by some countries or, for example, the European Union is a challenge for the governments of the different countries. Nevertheless, it is already clear that they will not be able to bear these costs without contributions and the involvement of the private sector.

There are two factors that can nurture the growth of infrastructure. One of them is a significant drop in the costs of hardware and the installation of stations. For example, according to Mc Kinsey, in the Netherlands they dropped by almost 48% between 2011 and 2013. The second factor is the engagement of new entities interested in a new kind of business such as the construction and operation of charging stations. The US company Charge Point, which operates 70% of the charging stations in the country and has developed an economically efficient model for this kind of business, is a good example.

In general, selling energy for electric cars is not a sufficient source of revenue to cover investments in infrastructure. Therefore, some European and US companies apply a different approach. They provide not only the necessary equipment and its installation, but also the so-called “back office services”, i.e. billing and payment management for clients interested in having charging stations installed at their premises, such as businesses, municipalities, business and administrative centres, etc. They use different electronic systems including cards or RFID to facilitate the management and access of electric car drivers to their charging stations. Public institutions and companies pay for the equipment and its installation. As a result, the network of charging stations is expanding thanks to the fact that their costs are being covered from different sources and their owners determine their pricing policy and whether they are going to be public or private. Some stores, for example, offer free charging for two hours but charge high fees for any extra time. Some companies, on the other hand, provide free charging to their employees. Providers of charging services generate revenue from delivering and installing equipment, drivers' fees, and operation services for owners.

4. Economic Aspects of BEV Ownership in Slovakia

This chapter makes use of data concerning batteries for electric cars, namely their capacity and price, taken from the previous chapter. It also takes into account the average annual mileage, which at the present is between 15 and 20 thousand kilometres. According to Artur Dolittle's study "Battery Electric Vehicle vs. Internal Combustion Vehicle", in 2016 electric car drivers drove on average 27% less than owners of combustion engine vehicles. This is the result of the range of electric vehicles and of the fact that they are used for other purposes than regular cars. It can be assumed that households with two cars use the electric car for daily journeys and shorter distances, and the combustion engine car for longer journeys. Electric vehicle owners are also very likely to use other alternative modes of transport as well. It is precisely the range of electric cars and their weaker infrastructure that gives reason to believe that at the beginning electric cars will account for a smaller share of the total mileage than other vehicles. The time it will take for the share of electric cars and those with combustion engines to be level is estimated to be at least 10 years, mainly due to lower range and insufficient infrastructure, the two major obstacles at the first development phase of electro-mobility. This work does not take into account lower mileage estimates and only refers to lower average annual mileage figures for its calculations.

The price of fuel is another key factor when comparing the advantages of electric and combustion engine cars. The energy consumption per kilometre or 100 kilometres, a standard technical indicator, is a factor every car driver takes into account when considering buying a vehicle. As this paper tries to forecast the development of electro-mobility in Slovakia, fuel and electricity prices in the Slovak Republic have been taken into account. For this purpose average 2017 fuel and electricity prices have been used in order to make calculations simpler. Using timelines over several years does not make much sense as the price of electricity for households in Slovakia is relatively stable, just like the price of gasoline and diesel, which for several years has oscillated between 1 and 1.30 EUR. In fact, the aim of this chapter is not to examine in detail the effect fuel price has in the economy of a particular type of vehicle.

The composition of the final price of fossil fuels and electricity is not the same. While excise duty and value added tax account for over 50% of the price of diesel and gas in Slovakia - there is no excise in the price of electricity. For objectivity purposes, maybe it would be more accurate to use a mix of electricity prices for businesses and households. However, this conversion has not used as many studies, including the International Energy Agency's analyses, show that up to 90% of all charging stations will be located at the users' home. In the future, the use of fast chargers at business or public chargers will have a merely complementary character.

Another key factor that determines the cost and total procurement and operation expenses of an electric car is the price of the battery. As different sources offer different price figures and Original Equipment Manufacturers (OEMs) do not publish accurate data, this paper uses price figures published by the International Energy Agency in their latest 2018 Electro Vehicle Outlook. This work does not take into account the vehicle price at the end of the compared cycle. It goes without saying that electric cars have some value at the end of the compared cycle, just as those with a combustion engine. The price of a ten-year-old vehicle varies depending on its make, the use it was made of, and its condition. Electric cars also have a residual value, especially the batteries that still have some capacity. Most studies suggest that the battery needs to be replaced once their actual capacity drops below two-thirds of its initial capacity. A secondary market with used-batteries is expected to originate, which could be used as stationary batteries to store electricity produced by solar panels, for instance.

The total cost of ownership of an electric car is still higher than that of a combustion engine car. The 2018 Electro Vehicle Outlook published by IEA compares different parameters such as car size, battery price, fuel prices, and mileage per year. The outcome of this analysis is no surprise at all. As far as battery prices remain relatively high and account for a substantial part of the price of an electric vehicle, these become economically comparable to regular cars when fuel prices are higher and longer distances are covered.

This chapter compares some selected types of electric vehicles that have already been mentioned in the previous chapter with cars of the same make and similar parameters. For this purpose, the average mileage in Europe and Slovakia was taken into account, which ranges between 15 and 20 thousand kilometres. In order for these estimates to be as close to reality as possible, the average fuel and electricity prices in Slovakia have been used, as published by the Slovak Statistical Office and energyportal.sk, respectively.

Firstly, a simple conversion of energy and fuel consumption over a twelve-month period is made followed by the operational costs of a BEV and of combustion engine cars driven by diesel and petrol.

Table no. 11 Fuel Costs Comparison for Different Types of Vehicles

Type of Vehicle	Distance Km/Year	Mean Consumption 100 km	Mean Price PHM/EUR	Total	% BEV 100
Diesel	15000	6	1,13	1019,7	226%
Petrol	15000	7	1,29	1351,35	300%
BEV	15000	19,5	0,15	450,45	100%

Source: Calculations Using Statistical Data

This comparison clearly shows that the distance covered by an electric car is much more economical than that of a combustion engine car. Driving a diesel-powered car costs over 120% and a gasoline engine car 200% of the cost of an electric one.

Even more surprising figures appear when comparing the savings of BEVs in financial terms for longer annual distances. The following table shows that when longer average annual distances are covered, namely 20,000 or more for a 10-year period, a BEV saves the equivalent to the value of a lower-middle class car. Despite this, however, electric cars are still more expensive than combustion engine ones. In fact, the above mentioned calculations have a purely theoretical character as electric car drivers cover in general about 30% shorter distances, electric cars still remain unsuitable for longer journeys, and the existing infrastructure is insufficient.

Table no. 12 Absolute Savings Of a BEV Against a Combustion Engine Car

Type of Vehicle	Distance Km/Year	Mean Consumption 100 km	Mean Price PHM/EUR	Total	Financial Variance To BEV	10 Year Variance
Diesel	15 000,00	6,00	1,13	1 019,70	569,25	5 692,50
Petrol	15 000,00	7,00	1,29	1 351,35	900,90	9 009,00
BEV	15 000,00	19,50	0,15	450,45	-	-
Diesel	20 000,00	6,00	1,13	1 359,60	759,00	7 590,00
Petrol	20 000,00	7,00	1,29	1 801,80	1 201,20	12 012,00
BEV	20 000,00	19,50	0,15	600,60	-	-
Diesel	25 000,00	6,00	1,13	1 699,50	948,75	9 487,50
Petrol	25 000,00	7,00	1,29	2 252,25	1 501,50	15 015,00
BEV	25 000,00	19,50	0,15	750,75	-	-

Source: Calculations Based on Statistical Data

The previous chapters deal with selected types of electric vehicles available on the EU and US market. Their operating costs are different, just as their range.

Table no. 13 13 Energy Consumption Cost By Electric Vehicle Type

Vehicle	Battery kWh	Range km	kWh/100km	Energy cost/kWh	Range per year, km	Annual total costs EUR
BMW i3	22,00	135,00	16,50	0,15	15000,00	371,25
GM Spark	21,00	120,00	17,50	0,15	15000,00	393,75
Fiat 500e	24,00	135,00	18,00	0,15	15000,00	405,00
Honda Fit	20,00	112,00	18,00	0,15	15000,00	405,00
Nissan Leaf	30,00	160,00	19,00	0,15	15000,00	427,50
Mitsubishi MiEV	16,00	85,00	19,00	0,15	15000,00	427,50
Ford Focus	23,00	110,00	20,00	0,15	15000,00	450,00
Smart ED	16,10	90,00	20,00	0,15	15000,00	450,00
Mercedes B	28,00	136,00	20,50	0,15	15000,00	461,25
Tesla S 60	60,00	275,00	22,00	0,15	15000,00	495,00
Tesla S 85	90,00	360,00	24,00	0,15	15000,00	540,00
Average	31,83	156,18	19,50	0,15	15000,00	438,75

Source: Battery University, Author's Calculations

These calculations gave out interesting results. Consumption does not always depend on the size of the car. This is specially visible when comparing BMW i3, Fiat 500e and GM Spark. It is clear that in the case of electric cars, just as with combustion engine ones, consumption depends on the degree of sophistication of the technology as well as on the setting of the overall vehicle parameters. For the purpose of these calculations data from batteryuniversity.com have been used. This server specialises in researching and evaluating different types of batteries used in different industries, including the car industry. The previous tables compare the cost of driving different types of vehicles based on the average consumption of these electric vehicles.

The compared vehicles are similar types of cars by the same manufacturers that offer vehicles with the same parameters as ICE electromobiles. The BMW 3 Series has been produced for a long time, so it is not a problem to find two models with a gasoline or diesel engine. Honda Fit is produced based on the Honda Jazz platform, GM Spark is the equivalent to Daewoo Matiz, while Mitsubishi MiEV is based on a platform called kei cars produced specifically for the Japanese market. Most non-European makes do not have a diesel version, so it was problematic to compare their consumption. Tesla models cannot be taken into account for this comparison as it offers pure electric cars and, in addition, for price categories very unlikely to flood the markets.

Table no. 14 Consumption of Comparable Diesel-powered Cars

Car type	Consumption l/100km	Fuel Price l/EUR	Range per Year	Total Annual Costs
BMW 3 d	6,7	1,13	15000	1135,65
GM Spark	0	1,13	15000	0
Fiat 500	4,5	1,13	15000	762,75
Honda Jazz	0	1,13	15000	0
Nissan Juke	5,9	1,13	15000	1000,05
Mitsubishi i	0	1,13	15000	0
Ford Focus	5,7	1,13	15000	966,15
Smart	5,3	1,13	15000	898,35
Mercedes B	5	1,13	15000	847,5

Source: Author’s research, OEM websites.

This comparison of consumption uses data concerning consumption in the city as electric vehicles are mostly intended to be used in urban and suburban areas, so the results are more objective. The following table confirms the well-known fact that the cost of running a gasoline vehicle is higher due to the consumption of this type of engines.

Table no. 15 Consumption of Comparable Petrol-powered Cars

Car type	Consumption l/100km	Fuel l/EUR	Range per Year	Total Annual Costs
BMW 3 benz	7,5	1,29	15000	1451,25
Daewoo Matiz	4,8	1,29	15000	928,8
Fiat 500	6,3	1,29	15000	1219,05
Honda Jazz	5,5	1,29	15000	1064,25
Nissan Juke	7	1,29	15000	1354,5
Mitsubishi i	5,8	1,29	15000	1122,3
Ford Focus	6,3	1,29	15000	1219,05
Smart ED	5,6	1,29	15000	1083,6
Mercedes B	6,5	1,29	15000	1257,75

Source: Author's research, OEM websites.

Comparing the consumption of an electric car and that of a combustion engine car of the same type clearly shows the advantage of electric cars. In the case of smaller cars, an electric car consumes about a third of what gasoline vehicles do, and a little under a half of the costs of a diesel one. In terms of net consumption, therefore, an electric car is clearly more advantageous than a combustion engine car.

Table no. 16 Consumption of Comparable Types of Vehicles with Different Propulsion (Eur)

Vehicle	BEV	Diesel	Gas	BEV/Diesel	BEV/Gas
BMW i3	371,25	1135,65	1451,25	33%	26%
GM Spark	393,75	0	928,8	NA	42%
Fiat 500e	405,00	762,75	1219,05	53%	33%
Honda Fit	405,00	0	1064,25	NA	38%
Nissan Leaf	427,50	1000,05	1354,5	43%	32%
Mitsubishi MiEV	427,50	0	1122,3	NA	38%
Ford Focus	450,00	966,15	1219,05	47%	37%
Smart ED	450,00	898,35	1083,6	50%	42%
Mercedes B	461,25	847,5	1257,75	54%	37%

Source: Author's research, OEM websites

For the sake of objectivity, fuel costs have been compared over a ten-year period as within these ten years every electric car is expected to need changing its battery at least once. Some studies include two battery replacements for this period and measure the residual value of the vehicle and the possible selling price. However, for the purpose of this paper these options have not been taken into account as the price of a ten-year old vehicle is difficult to determine and can vary significantly from case to case. The comparison aimed at here would require to determine the price of the battery and its costs. This type of data is unusual, though. OEM does not usually indicate battery price as electric cars are relatively new and battery box replacements are not standard and easily obtainable data. The predominantly theoretical character of this work, however, makes it possible to use data published by the IEA, the International Energy Agency, in its latest EV Outlook issue. The IEA uses data from small battery box manufacturers and Reuters.

Table no. 17 Cost of Battery Box Production, KWH / Load

	USD	USD/EUR	EUR
Small batt	274	0,86	235,64
Reuters	174	0,86	149,64
Average	224	0,86	192,64

Source: International Energy Agency, Exchange Rate as of June 28, 2018

The costs of purchasing a battery box were compared using the average price, because a price difference of $100 represents more than 50% of the cost of one specific type of battery. Moreover, the information available does not make it possible to assign a particular cost item to the relevant manufacturer. It is obvious, though, that those producers who manage to cut costs in the future will have and advantage over their competitors.

In this comparison, the gap between the cost of an electric car and that of a vehicle with a combustion engine gets smaller. In three cases, namely Fiat 500e, Nisan Leaf - which is compared to its closest equivalent Nissan Juke - and Mercedes B, the cost of a new battery makes the combustion engine model more favourable than their electric match.

Table no. 18 Fuel Costs Over A 10-year Period Including Battery Replacement

Vehicle	Battery kWh	Cost per kWh	New battery Eur	BEV energy Eur	BEV total Eur	Diesel Eur	Gas Eur	BEV/Diesel	BEV /Gas
BMW i3	22	193	4 238,1	3 712,5	7 950,6	11 356,5	14 512,5	70%	55%
GM Spark	21	193	4 045,4	3 937,5	7 982,9	0,0	9 288,0	NA	86%
Fiat 500e	24	193	4 623,4	4 050,0	8 673,4	7 627,5	12 190,5	114%	71%
Honda Fit	20	193	3 852,8	4 050,0	7 902,8	0,0	10 642,5	NA	74%
Nissan Leaf	30	193	5 779,2	4 275,0	10 054,2	10 000,5	13 545,0	101%	74%
Mitsubishi MiEV	16	193	3 082,2	4 275,0	7 357,2	0,0	11 223,0	NA	66%
Ford Focus	23	193	4 430,7	4 500,0	8 930,7	9 661,5	12 190,5	92%	73%
Smart ED	16.1	193	3 178,6	4 500,0	7 678,6	8 983,5	10 836,0	85%	71%
Mercedes B	28	193	5 393,9	4 612,5	10 006,4	8 475,0	12 577,5	118%	80%
Average	22,28	193	4 291,6	4 212,5	8 504,1	9 350,8	11 889,5	91%	72%

Source: Author's research, OEM websites

Another key factor when assessing the economic advantage of a vehicle is its acquisition cost. Here, the lowest prices of the different models in the official dealer lists in Slovakia, the Czech Republic or in one of the neighbouring markets have been considered. This calculation uses the prices of the basic version of the different cars, since the different additional pieces of equipment differ from owner to owner and there are no data on the most popular configurations for the different types. Indded, while some manufacturers allow individual customer configurations, others offer a relatively high standard in the different equipment packages. As it has already been said, some models do not have a diesel version. Likewise, the Mitsubishi MiEV could not be compared to any other model since it is produced exclusively for the Japanese and Asian markets.

Table no. 19 Overview of Similar BEV and ICE Vehicles

	BEV COSTS				Diesel costs			Gas costs		
Vehicle	**New battery**	**BEV consumption**	**BEV price**	**BEV total**	**Diesel fuel**	**Diesel car price**	**Diesel total**	**Gas fuel**	**Gas car price**	**Total Gas Car**
BMW i3	4 238	3 713	36 600	**44 551**	11 357	35 500	**46 857**	14 513	32 950	**47 463**
GM Spark	4 045	3 938	21 000	**28 983**	0	0	**0**	9 288	11 500	**20 788**
Fiat 500e	4 623	4 050	12 500	**21 173**	0	0	**0**	12 191	12 490	**24 681**
Honda Fit	3 853	4 050	31 000	**38 903**	0	0	**0**	10 643	14 000	**24 643**
Nissan Leaf	5 779	4 275	26 500	**36 554**	10 001	18 500	**28 501**	13 545	11 500	**25 045**
Mitsubishi MiEV	3 082	4 275	19 900	**27 257**	0	0	**0**	11 223	0	**11 223**
Ford Focus	4 431	4 500	34 900	**43 831**	9 662	17 800	**27 462**	12 191	13 800	**25 991**
Smart ED	3 179	4 500	22 000	**29 679**	0	0	**0**	10 836	11 000	**21 836**
Mercedes B	5 394	4 613	38 000	**48 006**	8 475	20 000	**28 475**	12 578	22 000	**34 578**
Average	4 292	4 213	26 933	**35 437**	6 582	22 950	**32 823**	11 890	14 360	**26 250**

Source: Author's research, OEM websites.

The table presents the data in different colours in order to clearly differentiate the figures concerning an electric, a diesel and a petrol engine vehicle. A simple glimpse reveals that most combustion engine models have a clear advantage against their electric match. The table below compares electric vehicles with their ICE versions using a percentage calculation.

Table no. 20 Cost of BEV, Diesel and GAS Vehicles in %

Vehicle	**BEV total**	**Diesel total**	**Gas Total**	**BEV/Diesel**	**BEV/GAS**
BMW i3	44 550,58	46 856,50	47 462,50	95%	94%
GM Spark	28 982,94	0,00	20 788,00	NA	139%
Fiat 500e	21 173,36	0,00	24 680,50	NA	86%
Honda Fit	38 902,80	0,00	24 642,50	NA	158%
Nissan Leaf	36 554,20	28 500,50	25 045,00	128%	146%
Mitsu.MiEV	27 257,24	0,00	11 223,00	NA	NA
Ford Focus	43 830,72	27 461,50	25 990,50	160%	169%
Smart ED	29 678,56	0,00	21 836,00	NA	136%
Mercedes B	48 006,42	28 475,00	34 577,50	169%	139%
Average	35 437,42	32 823,38	26 249,50	108%	135%

Source: Author's research, OEM websites.

The table above clearly shows that the cost of an electric car is higher than its diesel and petrol versions. There are only two exceptions. The first one is the BMWi3, whose relatively high price puts them in disadvantage against its comparable electric versions, which enjoy relatively low energy and battery replacement costs. However, it should be borne in mind that BMW produces premium vehicles and the difference in absolute figures for all models against all other manufacturers accounts for the price of a lower-middle class car. As for Fiat 500e, its advantage results from its favourable price. Indeed, Fiat broke into the market with this model for a price comparable to that of its combustion engine match, which is one of the conditions mentioned in all available studies and analyses focusing on the development of electro-mobility. Now, let us have a look at what the possibilities of the different types of vehicles would look like if the purchase price of the electric model were the same as the price of their combustion engine matches.

Table no. 21 Theoretical Comparison of Same Car Types at Same Purchase Cost

Vehicle	**BEV total**	**Diesel total**	**Total Gas Car**	**BEV/Diesel**	**BEV/Gas**
BMW i3	40 900,58	46 856,50	47 462,50	87%	86%
GM Spark	19 482,94	0,00	20 788,00	NA	94%
Fiat 500e	21 163,36	0,00	24 680,50	NA	86%
Honda Fit	21 902,80	0,00	24 642,50	NA	89%
Nissan Leaf	21 554,20	28 500,50	25 045,00	76%	86%
Mitsubishi MiEV	7 357,24	0,00	11 223,00	NA	66%
Ford Focus	22 730,72	27 461,50	25 990,50	83%	87%
Smart ED	18 678,56	0,00	21 836,00	NA	86%
Mercedes B	32 006,42	28 475,00	34 577,50	112%	93%
Average	22 864,09	32 823,38	26 249,50	70%	87%

Source: Calculations made using available statistical data

The table above clearly shows that if the purchasing cost of an electric car were the same as that of a conventional one, the electric vehicle would be more economical even when including the price of its battery change within a 10-year period. If the production cost of an electric car goes down, it can be assumed that the production cost of the battery box would fall as well. Therefore, the costs connected with replacing it would be lower, making the electric car more advantageous.

Table no 22 Average passenger vehicle price in the years 2022 -2017

Year	Average Price of cars EUR	New cars	Cars Total	New cars % of total	GDP (mil. E)	Costs of new cars (mil. E)	Cars % of GDP	Number of e-mobiles if 30% of new
2002	16 478	79 099	1 879 854	4%	39 299,9	1 303,4	3%	23 730
2004	21 583	81 185	1 945 809	4%	43 581,7	1 752,2	4%	24 356
2017	25 736	126 629	3 117 964	4%	81 725	3 258,9	4%	37 989

Source: Jan Lešinský, Ministry of Interior, Slovak Statistical Office, National Bank of Slovakia, own calculations

Looking closer to the previous table, one can find that average prices of new cars between 2002 and 2017 have increased in Slovakia by over 30%, which is a relatively high growth. Despite the rise in prices, the number of new cars rose by about 4% on average with occasional variations of one percent. The average cost of all new cars to GDP is approximately 4%. Year-on-year, the number of cars increases by about one percent.

The ration of electric cars to new cars is currently not one percent. The Ministry of Economy of the Slovak Republic estimates that in the year 2030 there will be about 35,000 electric vehicles in Slovakia, which is 1.1 percent in comparison with the total number of cars in 2017. Compared to an estimations of the International Energy Agency, which predicts a 30% share of electric vehicles in 2030, it is a very cautious estimate that is closer to reality.The penultimate column of the table, which calculates the estimated 30% ratio of the total number of electric vehicles, is purely hypothetical. If that were the case, by 2017 nearly 38,000 electric vehicles would have been purchased in Slovakia. This is the number that the Ministry of Economy did not even want to estimate in 2030 as the total number of electric cars.

Table no.23 Average labour costs vs. Electromobile price

Country/year	2013 Eur	Hourly labour costs 2017 Eur	Average e-mobile price, Eur 2017	Hours/car	Days
Denmark	39.9	42,50	29 794	701,04	87,63
Belgium	38.7	39,60	29 794	752,37	94,05
France	34.5[p]	36,00	29 794	827,61	103,45
Netherlands	33.2	34,80	29 794	856,15	107,02
Germany	30.9	34,10	29 794	873,72	109,22
Austria	30.6	34,10	29 794	873,72	109,22
(28 countries)	24.8	26,80	29 794	1 111,72	138,96
United Kingdom	24.1	25,70	29 794	1 159,30	144,91
Spain	21.2	21,20	29 794	1 405,38	175,67
Slovenia	15.3	17,00	29 794	1 752,59	219,07
Czech Republic	9.7	11,30	29 794	2 636,64	329,58
Slovakia	9.2	11,10	29 794	2 684,14	335,52
Poland	8.1	9,40	29 794	3 169,57	396,20
Hungary	7.7[e]	9,10	29 794	3 274,07	409,26
Lithuania	6.2	8,00	29 794	3 724,25	465,53
Romania	4.4	6,30	29 794	4 729,21	591,15
Bulgaria	3.6	4,90	29 794	6 080,41	760,05

Source: Eurostat, J. Lešinsky, own calculations

The potential or ability to buy electric cars can also be asessed by comparing the hourly labor cost in the European Union published by Eurostat. It is the so-called total cost of labor, ie wages plus social, health and tax payments. Slovakia has approximately one-quarter labor costs compared to the countries with the highest average labor cost, and roughly one-third of the EU average. The table shows that people from the richest countries would have worked for an electric car for two to three months, people in countries around the average just over four months, and people in Slovakia would have worked for almost a year. This is only a theoretical comparison because the total cost of work is not paid to employees because of the contributions to public funds . In Slovakia, the employee receives approximately 50% of the total labor cost. This means that, in reality, an electric car would have to work for two years while not spending on accommodation, food, holiday and other needs.

Table no.24 Monthy vage in Slovakia vs. Electromobile price

Year	average vage Eur	E-mobile price eur	Months to buy
2012	805	29794,00	37,01
2013	824	29794,00	36,16
2014	858	29794,00	34,72
2015	883	29794,00	33,74
2016	912	29794,00	32,67
2017	954	29794,00	31,23
2018	980	29794,00	30,40

Source: Slovak statistic office, J. Lešinsky, own calculations

The realistic potential for buying a car will be obtained by comparing the average wage in Slovakia, which in 2018 according to the data of the Slovak Statistical Office is around the threshold of thousands of Euros. The last column of the table shows that the average Slovak would work on the purchase of an electric car for almost three years without the other costs mentioned above. In fact, he would have worked for a year longer, as he also deducts from the gross wage about 30 percent depending on what deductible items from the income tax he can apply.

Based on the above calculations and arguments, the Slovak average customer will be very sensitive to the price of the vehicle to be invested in. If the purchase price of electric cars is two to three times higher than the price of a classical car in the same class, the assumptions of the International Energy Agency for a 30% share of electric cars in 2030 will not be relevant for Slovakia.

Electric vehicles could become more advantageous in the event of some other factors that, however, would be unfavourable for the owner of the vehicle. If fuel prices were to increase, regular cars would be less attractive than they are at current prices. Governments could also impose significant limitations and disadvantages for combustion engine cars, something that is partially happening already. For example, cities introduce restrictions to vehicles with higher emissions or create other obstacles. Higher tax on fuel or fuel-powered vehicles would represent an additional advantage for electric cars. However, this type of support is not motivating and could have negative effects on the automotive industry. Price sensitive customers can be expected to postpone purchasing a car or consider buying a used vehicle.

If electro-mobility in Slovakia and in most of the developed world were to reach the level governments would like to have, it is necessary to reduce the costs connected with owning an electric car to the same level or lower than the cost of owning a combustion engine automobile. This could compensate for the additional handicaps of electric vehicles, such as range, charging time, and infrastructure.

The calculations presented above as well as talks with SEVA (Slovak Association for Electro-mobility) representatives show that owing an electric car is not an optimal solution for price-sensitive owners at the cost these currently represent. More likely, it can be an option for fleets of company cars and for institutions with a bigger number of vehicles. Such vehicles, popularly known as pool cars, can be assumed to cover longer distances. Over a ten-year period with an average mileage of 25,000 kilometres per year, electric vehicles are already more economical in terms of saved fuel costs. Fleets of cars can be managed to optimise operation costs giving preference to electric vehicles for short and medium journeys in connection with their range.

5. Possible Impacts of Electro-mobility on Slovakia's Electricity Network

5.1. Possible Impacts on Energy Production

Between 2007 and 2012 the Slovak Republic was an electricity exporting country. Those years saw several new sources of electricity were opened in nuclear power plants and steam-gas cycle plants, which produced a surplus of electricity that could be exported. In 2014, however, some gas power plants were closed for economic reasons. Indeed, this type of power plants failed to produce energy at competitive prices. Moreover, coal-based energy production at the Nováky and Vojany power stations was limited for economic and environmental reasons. At the same time, new investments in industry and higher household consumption (e.g. increased use of air conditioning units) resulted in a significant increase of overall consumption. As a result, in recent years the country has a slight negative balance.

The report on the monitoring of the electricity supply security for 2016, which is worked out annually by the Slovak Ministry of Economy, counts with the commissioning of two units of the Mochovce Nuclear Power Plant, which are expected to make the balance of electricity production in Slovakia positive again. The following table shows the situation forecast in this report.

Table no.25 Estimated Electricity Production and Consumption in Slovakia

Year/ TWh	2017	2018	2019	2020	2021	2022
Power used	30,5	31	31,5	32,1	32,4	32,7
Power produced	27,7	28,2	31,6	34,5	34,9	35,7
Balance	-2,8	-2,8	0,1	2,4	2,5	3
Balance in %	-9,2%	-9,0%	0,3%	7,5%	7,7%	9,2%

Source: Report on Monitoring of Electricity Supply Security for 2016, Slovak Ministry of Economy

Slovakia's targets in electric car development are relatively modest compared to other countries. The 2015 electro-mobility development strategy of the Slovak Republic, worked out by the Ministry of Economy, foresees two development scenarios by 2020. The so-called Standard Scenario estimates the number of electric cars to be 10,000 while the more ambitious Technology Scenario foresees 25,000 electric vehicles. These figures represent significantly lower targets than those of Austria and Germany. In fact, Slovakia's ambitions in the introduction of electro-mobility appears really modest next to theirs. In absolute numbers this comparison is most critical as Slovakia's figure accounts for just over one percent of Germany's and about 4 percent of Austria's. In terms of GDP, population, or car market size the Slovak Republic would need to set up much higher ambitions to reach levels comparable to those two countries. The table below illustrates these parameters.

Table no.26 Possible Number of Electric Cars by Different Indicators

Country	Germany	Austria	Slovakia
2020 target	1 000 000	250 000	11 000
Share for Slovakia's population	66 000	160 000	25000
By GDP	27 000	67 000	11 000
Share for Slovak car market	23 000	52 000	25000

Source: Ministry of Economy Work Team, 2015 Electro-mobility Development Strategy

Such modest scenarios do not imply a significant impact on the production and consumption of electricity. The previous calculations on the average consumption of electric cars and the plans outlined in the Strategy have been used to calculate the impact on Slovakia's energy balance. The impact of the country's shy estimates and targets on the total electricity balance is less than one percent.

Table no.27 Total Consumption of Electric Cars According to the Electro-mobility Strategy of the Slovak Republic

	Number of electric cars	**Mean consumption kWh/100 km**	**Mileage km/year**	**Total consumption of electric car GWh/year**	**2016 Total consumption in SR GWh**	**Share of electric cars %**
Standard scenario	10 000	19,5	15 000	29,25	31 056	0,0942%
Technology scenario	25 000	19,5	15 000	73,13	31 056	0,2355%

Source: Calculations based on available statistics

The European Union and many other multinational groups and organisations, such as the Electro Vehicle Initiative, expect much larger shares of electric vehicles. EVI counts with a 30% share of electric cars in the total number of vehicles in 2030 in the developed world. These are figures the Slovak Republic can reach gradually despite its slower approach and shy ambitions. Let us have a look at the impact an increase in the number of electric cars would mean for the total energy consumption in Slovakia.

Table no.28 Estimated Electric Car Share in Slovakia and Its Impact on Power Use

Percentage of electric cars	Number of electric cars	Mean consumption kWh/100 km	Mileage km/year	Total consumption elektromobily kWh/year	Total 2016 consumpt. in Slovakai GWh	Share of electric cars %
5%	112746,3	19,5	15 000	329,78	31056,00	1,0619%
10%	225492,6	19,5	15 000	659,56	31056,00	2,1238%
15%	338238,9	19,5	15 000	989,34	31056,00	3,1857%
20%	450985,2	19,5	15 000	1319,13	31056,00	4,2476%
25%	563731,5	19,5	15 000	1648,91	31056,00	5,3095%
30%	676477,8	19,5	15 000	1978,69	31056,00	6,3714%

Source: Author's calculations

The ratio of electric cars was calculated based on the number of registered passenger vehicles in Slovakia in April 2018 according to the Ministry of the Interior of the Slovak Republic, which was 2 254 926. When comparing the different values and their impact on consumption, these figures can significantly affect the energy balance of Slovakia. This topic was discussed at the Energy Section of the Ministry of the Economy and according to the forecasts this department has at its disposal, the Slovak Republic should be able to cope with this eventual increase. As it has already been mentioned, new sources of electricity are expected to start operating in the near future, which will be able to cover increased consumption resulting from a higher share of electric vehicles in the country.

Table no.29 Estimated Electricity Production and Consumption in Slovakia

Year	2017	2018	2019	2020	2021	2022
Power use	30,5	31	31,5	32,1	32,4	32,7
Power production	27,7	28,2	31,6	34,5	34,9	35,7
Balance	-2,8	-2,8	0,1	2,4	2,5	3
Balance in %	-9,2%	-9,0%	0,3%	7,5%	7,7%	9,2%

Source: Report on Monitoring of Electricity Supply Security for 2016, Slovak Ministry of Economy

Taking into account the real number of electric vehicles, the scenarios drafted in the Electro-mobility Development Strategy, the theoretical scenarios worked out for this work, and the electricity production and consumption development, it is clear that electro-mobility in Slovakia is not expected to cause any problems in the energy balance of the country. As long as no other factors that could significantly affect the consumption or generation of electricity appear, the development of electro-mobility will not threaten the security of electricity supply. The fact that zero-emission sources account for 80% of Slovakia's energy mix - as this share is produced by nuclear and hydroelectric power plants - significantly contributes to making electro-mobility in Slovakia more attractive.

A 6% increase in the overall energy consumption in 2030 with a 30% electric car share is very similar to the International Energy Outlook forecast for 2017. Having regard to the existing strong and developed European energy system, which has sufficient capacity to generate increased volumes of electricity, dealing with increased annual energy consumption resulting from electro-mobility does not constitute an issue to worry about. The Slovak Republic has enough possibilities to buy energy at favourable prices abroad, which is exactly what it has been doing in recent years. A different situation that needs a different approach is coping with peaks in electricity consumption.

5.2. Covering Electric Car Charging at Peak Times

The electricity network is a separate issue regulated by relevant national and transnational documents. The report on monitoring the electricity supply security - worked out for Slovakia in conformity with EU Directives - highlights, in addition to the usual information on production and consumption, a section on supply security, power outages coverage and coverage of increased electricity consumption.

It can be assumed that a higher share of electric cars will come alongside a higher number of charging stations, some of which will have relatively high consumption volumes. Ultra-fast charging 350kW stations are being developed at the present, which can charge an electric vehicle in about 10 minutes. This fact, which is an advantage for customers, is a challenge for distribution networks. A charging station with just four ultra-fast charging devices represents 1.4 MW. This figures needs to be multiplied by the number of operating charging stations.

The International Energy Agency’s calculations assume that consumption at peak time can increase by as much as one-third if the share of electric vehicles is high, i.e. 30%. According to the Ministry of Economy, the installed capacity of all energy sources in the Slovak Republic in 2017 was 7,720 MW. This means that all power plants together can generate this volume at any moment operating at full power. Let us look at the energy production and consumption in the Slovak Republic in recent years.

Table no.30 Electricity Consumption and Production in Slovakia Over the Past Decade

YEAR	PRODUCTION [GWh]	TOTAL CONSUMPTION [GWh]	BALANCE* [GWh]	MEAN LOAD ** [MW]	MAXIMUM LOAD [MW]
2005	31 294	28 572	2 722	3 262	4 346
2006	31 227	29 624	1 603	3 382	4 423
2007	27 907	29 632	-1 725	3 383	4 418
2008	29 309	29 830	-521	3 396	4 342
2009	26 074	27 386	-1 312	3 126	4 131
2010	27 720	28 761	-1 041	3 283	4 342
2011	28 135	28 862	-727	3 295	4 279
2012	28 393	28 786	-393	3 277	4 395
2013	28 590	28 681	-91	3 274	4 175
2014	27 254	28 355	-1 101	3 237	4 120
2015	27 191	29 548	-2 357	3 377	4 146
2016	27 451	30 103	-2 651	3 427	4 382

Source: Report on Monitoring of Electricity Supply Security for 2016, Slovak Ministry of Economy

The table above shows that Slovakia's average consumption or network load is around 3300MW, with peaks around 4300MW. The table below compares the immediate capacity in Slovakia with possible increased consumption at peak times.

Table no.31 Immediate Power Consumption Capacity Test

	MW	**Installed Power MW**	**Gap MW**	**Reserve %**
Mean Network Load	3300	7720	4420	57%
Maximum Load	4300	7720	3420	44%
Average + 30%	4290	7720	3430	44%
Maximum + 30%	5590	7720	2130	28%

Source: Ministry of Economy, Author's calculations

The table above shows that the Slovak Energy System can be expected to cope with gush peak loads. Average consumption allows for a 57% margin, while maximum loads leave a 44% spare production capacity. Even if average consumption increased by one third, the margin would still be the same. In the case the maximum consumption increased, the system performance margin would still be 28%. These calculations concern a theoretical full exploitation of all available resources and maximum consumption. In practice, however, Not all resources can run at full power and there is always some performance reserve. Hydropower plants are used to cover gust loads at peak hours as these can increase performance relatively quickly. Nuclear power plants, fossil fuel power plants, and steam-gas cycles are not suited for covering gust loads because they need some time to achieve the desired output and are used to cover basic consumption. Renewable sources like solar and wind power plants are problematic to predict and plan due to the lack of very specific local weather forecasts. However, the Slovak Republic has a whole series of measures and instruments to cover increased consumption, generation drops or power outages such as purchasing support services, contractually agreed emergency reserves, changes in transmission system engagement and other crisis scenarios.

While energy production, average and peak consumption do not appear to be an issue for Slovakia as a whole, the problem may be local network failures, i.e. its grid load capacity as well as lack of investment to upgrade the network and increase capacity. In the future, a relatively large number of high-consumption charging stations might concentrate in one distribution node. This may not a theoretical scenario but a rather common situation. This is most likely to happen in industrial zones requiring relatively high consumptions, or in neighbourhoods at which the number of parking spaces make it possible - and in the future it might be mandatory - to install charging stations in line with European legislation. If the grid load capacity is not sufficient, network failures may occur resulting in total outages in larger areas or throughout the country.

For the purpose of this paper, grid load capacity at local level was discussed with transmission system specialists. In their opinion overall production is not a problem. Covering gust loads can be a lesser problem. Potentially the greatest risk, however, may be network insufficiencies at local level. These risks could not be assessed for lack of network quality data as distributors consider this to be confidential internal information.

There are several options how to tackle the adverse effects of unexpected consumption increases, namely economic, technical and the so-called smart solutions.

Economic measures can be used as incentives for car owners to charge their electric vehicles responsibly. In general, the largest volume of energy is consumed in the afternoons and evenings, when businesses are still using significant amounts of electricity and household consumption starts to rise. The lowest point is generally reached in the night hours. Private electric car owners should be motivated to charge at night time, thereby making use of surplus power system capacity. Conversely, higher tariffs could apply fro charging at peak hours in order to demote electric car owners to regularly use charging stations at these times. This kind of measures are simple, logical, and technically viable.

Technical solutions include monitoring, evaluating and regulating the network in order to avoid local overloads. This will require additional medium-term investment in hardware and software solutions. Especially industrial zones, as well as administrative and commercial centres will need to reassess their local network capacity to accommodate a sufficient number of charging stations. Likewise, distributors will need to adapt to the new conditions and strengthen their connections to such centres accordingly.

There are some smart solutions as well. One of them is, for example, to combine solar energy at households for charging electric vehicles. These solutions are technologically available but require additional investment in the installation of solar panels and stationary batteries. Solar energy, however, is available during the day, when most car owners are at work. Therefore, it is necessary to use stationary batteries to store the energy produced during the day so that the car or cars can be charged when necessary. This would help prevent overloading the network. On the other hand, however, this represents additional investments and, therefore, yet another disadvantage of electric cars in terms of economy. Another possible smart solution is to supply electricity from electric vehicles to the network. Many experts are of the opinion that an electric car is actually a large battery on wheels, which can be used to supply electricity to the network to cover gust loads. Theoretically, this is a possible solution. The owner of an electric car can determine how much stored energy they need to get home and supply the remaining amount to the network. At night, they can charge electricity at more affordable prices and sell their surplus at higher prices during the day hours. These smart solutions still need a lot of improvement, both in terms of technology and manner.

The addressed experts do not think Slovakia is or will in the near future be sufficiently prepared to implement the above mentioned smart solutions or technical measures as both require substantial investments by distribution companies and the private sector. The fastest applicable tool seems to be tariff measures increasing the price of electricity during peak times. This solution will especially affect electric vehicle owners.

6. Possible Scenarios for Charging Station Networks

Available charging infrastructure in households, workplaces and public spaces is a prerequisite for electric vehicles to be made increased use of. All analyses focusing on the electric car market show that the availability of charging stations is one of the key factors for the development of electro-mobility. Scenarios and development strategies are now more concerned with the infrastructure for passenger cars and small utility vehicles. To support the development of electro-mobility in public and freight transport, it will be necessary to implement further specific measures stimulating the installation of charging stations for buses and trucks. These will most likely have larger batteries and consume more electricity, thus increasing electricity consumption during the day and throughout the year. The International Energy Agency indicates in its 2017 Global EV Outlook that between 2010 and 2016 the ratio between publicly available charging stations and the number of cars in the world was 6:1. This ratio is not likely to remain unchanged and 90% of the charging will take place using residential charging stations. This figure is not available for Slovakia as charging stations operators and owners are not required to report to any institution. Only now, a new amendment is being introduced making it compulsory to report this information. The only data available concern the network of motorways and express roads. Out of 43 petrol stations, 7 are equipped with charging stations, which were built mainly by private companies. Most of the remaining charging stations are located in urban areas in the southwest of the country, where their density is higher, and in the north and east, where their density is lower.

The strategy for the development of electro-mobility in the Slovak Republic deals with building infrastructure in a rather descriptive manner, defining the types of charging stations as well as their potential owners and investors. In principle, it distinguishes residential, public and corporate charging stations and attempts at outlining what types of charging stations will suit what owners. The strategy highlights the need to build a charging infrastructure on a general level, highlighting the role of the relevant public institutions. At the same time, however, it notes that building infrastructure is an investment-intensive task, which, of course, regional and local authorities are not in a condition to finance. The strategy counts with a national network of charging centres, but no funding is mentioned. The strategy prioritises non-state initiatives, i.e. building private charging stations. A strategy is a general document often issued by Slovak public institutions when intentions are not supported by funds. Building infrastructure is one of the issues the 2016 National Policy Framework for the Development of Alternative Fuels Market deals with in line with EU Directive 2014/94 / EU on the Deployment of Alternative Fuels Infrastructure. The table below presents the estimated construction of charging stations.

Table no.32 Estimated Number of Stations for Medium and Fast Charging

Year	Plan		
	Medium Charging	Fast Charging	Total
2016	50	30	80
2017	100	40	140
2018	200	80	280
2019	400	120	520
2020	600	150	750
2025	1200	300	1500

Source: National Policy Framework for the Development of the Alternative Fuels Market, Ministry of Economy SR 2016

The Slovak Ministry of Transport (MDR SR) implements more specific objectives which are also supported by funds. This ministry is currently in charge of developing the charging infrastructure by means of the European Connecting Europe Facility (CEF). Through CEF, fast-charging stations are being installed in Slovakia along TEN-T corridors (Core Network and Core Network Corridors), to which the program is restricted. At the same time, the program is designed for transnational programs and partnerships and is, therefore, unreachable at national level for smaller and independent applicants.

The European Commission, through the CEF, provides approximately 62.6 million EUR for the construction of charging alternative fuels infrastructure in the territory of the Slovak Republic through various projects whose implementation by the private sector will bring to the territory of Slovakia a total of about 90 charging stations for electric vehicles.

The Ministry of Transport is considering creating a separate financial instrument, for example reallocating unspent funds from the Ministry of Transport to finance charging infrastructure projects. However, creating such a tool requires reevaluating several documents and projects, identifying remaining resources and creating the necessary project implementation conditions. However, this is a slow administrative process whose starting point has not been defined and whose projects are to be finished by 2023. Taking into account the present effectiveness of drawing EU Structural Funds in Slovakia, this is an unlikely and risky intention.

By means of an amendment to the Act on Subsidies, the Slovak Ministry of Economy will introduce a subsidy mechanism for purchasing charging stations. The eligible applicants will be municipalities and self-governing regions. The expected start date is Q4 / 2018. No more detailed information about its preparation was available by the end of this work.

Much more realistic than public administration activities are concrete steps carried out by private companies. The most significant activities in Slovakia are carried out by Greenway, which has built 28 stations in Slovakia and 60 in Poland. By the end of 2018 their number is expected to be around 100. Other activities in this direction are being developed by the distribution company ZSE as well as Inogy. In the near future, Ionity charging stations are expected to appear along the major highways and roadways. Its founders are OEMs - Mercedes, Ford, Volkswagen (Audi, Porsche) and BMW. This company, which has a strong background, plans to build 400 charging stations throughout Europe, each of them having between 4 and 6 350kW stations capable of charging an electric vehicle in 10 minutes. This time is comparable to that of the standard tanking time of a combustion engine car.

Residential chargers constitute a special chapter in the development of electro-mobility. As has already been mentioned, it is believed that 90% of the charging will be at private charging stations, mostly at people's homes. The cost of a residential charging station is now between 500 and 3000 Euros. Although such an investment slightly increases the cost of purchasing an electric car, it does not represent a substantial item of the total cost and owners can choose between lower and higher price options. A major problem may be the discrepancy between the desire to buy an electric vehicle and the possibility to charge it in older residential areas with almost no garage houses, and the limited parking space is intended for combustion engine cars. In such areas, this will be a major problem. Taking into account that electric vehicles are considered to be urban and suburban vehicles due to their shorter range, lack of infrastructure and means to build it up can be a problem that can significantly hamper the development of electro-mobility in Slovak cities. Building infrastructure requires co-financing by local authorities and distribution companies. Lack of funds is a chronic problem for all local authorities in Slovakia which does not allow them to carry out their most basic tasks, and any development projects are mostly implemented to a very limited extent if at all. State support programs funded by the state budget or EU structural funds often only make it possible to implement some pilot projects, and do not really represent a systemic measure. Although the new EU directive implemented at national level makes it mandatory to create the conditions necessary for the development of electro-mobility infrastructure, i.e. to install cabling when constructing new or reconstructing older buildings and car parks, this is expected to create problems at local and public administration level. Parking lots in Slovakia are being built and rebuilt to a very limited extent because of insufficient financing, so any additional costs just make things worse. Infrastructure costs in older residential areas can be expected to be transferred to the distribution companies. These, however, are likely to behave economically and defer their construction until there are enough customers. Thus, the problem can be cycled and delay the development of electro-mobility.

Table no.33 Costs of Different Types of Charging Stations

Charging Station Type	**Costs in EUR**	**Note**
Up to 3kW	500-3000	Intended for residential charging
23 – 50 kW	30000 and more	Public Charging Stations - Middle
Up to 350 kW	300 000	Ultra-fast charging intended for Highways and main corridors

Source: Author’s findings

The table above shows the costs to be borne mostly by private persons and companies. The state and public authorities are likely to contribute to this development only in the form of legislation and facilitating their construction, tax and fee exemptions, or maybe by providing direct support to pilot projects. Thus, it can be assumed that most of the cost of developing electro-mobility infrastructure will be shouldered by the citizens and the private sector. In fact, this is most likely to happen despite the government’s declared effort to support clean, i.e. almost zero-emission transportation.

Table no.34 Estimated Cost According to Slovakia's Electro-mobility Strategies

Charging Station Type	**Estimated number**	**Cost per unit Eur**	**Total costs Eur**
Residential - Standard Scenario	10 000	1 500	15 000 000
Residential - Technical Scenario	25 000	1 500	37 500 000
Middle-size	1 200	30 000	36 000 000
Fast, High Capacity Charging	300	300 000	90 000 000
Total	26 500		163 500 000*

Source: Strategies and Author's calculations. * The total includes the technical scenario

The cost of charging stations ranging between 145 and 163 million is very likely to be carried by the private sector.

7. The Issue of Excise Duty on Mineral Oils

Fuels (mineral oils) are levied two indirect taxes in Slovakia, namely value added tax and excise tax on mineral oils. VAT is directly dependent on fuel (mineral oil) prices. Mineral oil excise tax is calculated on the volume (€ / 1000 l) of the mineral oil, so any increase or decrease in their price does not affect the amount of tax collected. Therefore, tax revenue depends on the volume of consumed mineral oil and the tax rate.

The rate at which mineral oils are levied reflects in the prices of most products and services, as fuels constitute an inevitable input due to our economic dependence on petroleum. Consequently, it can be stated that from the national economy point of view the taxation of mineral oils is far more wide-ranging and far-reaching than the fuel market (mineral oils). In general terms, choosing an optimal rate of taxation is not only important for the state in order to maximise the volume of effectively excised taxes, but also for the population itself as these taxes reflect in the vast majority of consumer products and services. Excise taxes represent an important, stable and relatively easily estimated income to the state budget of the Slovak Republic. From a fiscal point of view, they are among the most important revenues to the state budgets not only in Slovakia, but also in all EU countries.

The state uses mineral oil taxes to secure stable government revenues. Should any fallouts be predicted, they can raise excise taxes knowing that mineral oils (fuels) are so important for the industry and the common life of citizens that an increase in their rate will not result in significant consumption reductions. The past decades have witnessed several significant waves of excise duty increases without any negative consequences in terms of the collected amount. For example, the unit rate of unleaded petrol, the most popular one, increased from around € 255.57 / 1000 l in 1998 to around € 382.11 / 1000 l in 2000, which represents a 50% increase over the course of two years in terms of tax burden. Tax rates for leaded petrol and diesel fuel virtually copy this trend. The growth in tax rates matches the increase in tax revenues from mineral oils tax. This, however, also reflects the overall positive development of the economy as well as the growth of GDP in the economy of the Slovak Republic.

Mineral oils are currently levied at the following rates.

Motor gasoline depending on the type and content of the biogenic substance:

- amounting 554,00 EUR/ 1 000 l,
- amounting 514,00 EUR/ 1 000 l,
- amounting 597,49 EUR/ 1 000 l,,

Gas oil (diesel) depending on the type and content of the biogenic substance

- amounting 394,00 EUR/ 1 000 l,
- amounting 368,00 EUR/ 1 000 l,

Take the average price of oil in 2017, which was EUR 1.13 per litre. The share of excise tax was over 34% of the price of this commodity. In the case of petrol, excise duty is even higher. Indeed, at an average price of EUR 1.29 per litre, it was almost 45%. Together with VAT, tax constitutes about 50% to 60% of the commodity price. Mineral oils are, thus, the most tax-burdened commodity alongside tobacco products.

Excise taxes represent a steady revenue to the state budget and their share in the long run makes out between 10 and 15 percent depending on GDP growth and the total consumption of mineral oils (fuels). Excise duty on fuel accounts for about half of all excise duty revenues. For example, in 2017, from over EUR 2.2 billion collected on excise duty, excise tax on fuels was 1.2 billion or about 8% of the total revenue. Let us have a look at possible tax fallouts resulting from an increased share of electric vehicles in Slovakia.

The table no. 35 clearly shows that a 30% share of electric cars in the total number of passenger cars would represent a 16% drop of excise tax revenue and almost 2.5% lower total budget revenues, corresponding to over EUR 350 million in absolute figures. Naturally, it will be necessary to compensate this gap somehow.

Table no.35 Estimated Excise Duty Fallout by Share of Electric Vehicles in Transport

Share of Electric Cars	Number of Electric Cars	Budget revenues from excise duty on oils -m EUR	Budget revenues from excise duty- mil. EUR	Fallout mil. EUR	Budget Revenues - mil. EUR	Budget Revenue Fallout %	Excise duty budget revenue fallout
5%	112746,3	1 213,31	2 255,41	60,67	15 390,20	0,39%	2,69%
10%	225492,6	1 213,31	2 255,41	121,33	15 390,20	0,79%	5,38%
15%	338238,9	1 213,31	2 255,41	182,00	15 390,20	1,18%	8,07%
20%	450985,2	1 213,31	2 255,41	242,66	15 390,20	1,58%	10,76%
25%	563731,5	1 213,31	2 255,41	303,33	15 390,20	1,97%	13,45%
30%	676477,8	1 213,31	2 255,41	363,99	15 390,20	2,37%	16,14%

Source: Slovak Finance Ministry, 2017 figures, Author's calculations

Increases can be expected in the rate of excise duty on mineral oils (fuels) or in the price of electricity. Both measures can be expected to happen simultaneously. The state can argue that by increasing excise duty, it is trying to restrict the use of combustion-engine vehicles, which generate harmful emissions. One of the two main reasons for introducing excise duties is also the attempt to reduce harmful habits. Therefore, tax on tobacco and tobacco products is intended to reduce smoking. The second main reason is to generate revenues to the state budget. This reason is likely to be used to justify the introduction of another electricity tariff item, such as the promotion of renewable energy sources, which is already part of this tariff.

The logic of generating revenue into public funds, including the state budget, gives reason to believe that the costs resulting from the introduction of electric cars in transport will be carried by every citizen of Slovakia, not just electric car owners or infrastructure investors. Everyone will have to contribute to progress and green transport in the form of increased costs.

8. Results and Discussion

The introduction to this paper defines hypotheses and questions related to electro-mobility in Slovakia. Electric vehicles are a hot topic in the present and near future. For the Slovak Republic, this question is not so immediate, but rather middle term. The results of this work confirm this assertion. Some aspects concerning the advantages and disadvantages of using electric vehicles have been reevaluated.

That a purely electric vehicle generates zero emissions is a claim considered to be almost indisputable. This work focuses on the real carbon footprint of electric vehicles. One of the results is that the emissions of a vehicle are as clean as the source of the electricity it uses. That means that if the country produces electricity from fossil fuels - coal, gas, petroleum products, or combustion of wood and municipal waste - the CO2 emissions of electric vehicles are just the same as those of combustion engine cars. The situation is much more favourable in countries that produce most of their electricity from non-emission sources such as water, air, or nuclear fuel. The use of electric cars in countries with a high-emission energy mix only means that emissions are transferred from places with a higher density of vehicles to the places where electricity is produced.

Range is another disadvantage of electric cars, although it keeps improving gradually and steadily. So far, most automakers use long established battery technologies, whose limitations are well known as well, such as long charging times, overheating or the possibility of explosion or ignition when overloaded. New technologies are just in their initial phase and still need some time before they start to be produced and used in the practice. Today's technology has limitations in terms of capacity. Consequently, manufacturers wanting to extend the range of their cars can either reduce the weight of the vehicle or produce bigger and heavier batteries. The problem is, however, that a larger battery increases the total weight of the vehicle, and larger batteries result in range reductions. Although electro-mobility is still at an early stage of development, more and more companies and research institutions are starting to deal with it, so their evolution can be expected to grow gradually faster. Eventually this disadvantage against combustion engine cars will disappear as well.

Charging time is seen as one of the easiest technical issues that can be solved in a relatively short time horizon. Currently, the average charging time on a low power residential charger up to 3kW is 5 to 8 hours. Fast charging stations with power between 23 and 50 kW can charge the battery at 80% within half an hour. Ultra-fast chargers with a power output of up to 350 kW can charge a car within 10 minutes, a figure comparable to the time it takes to tank fuel into a combustion engine car. The problem is that fast charging has been proved to degrade the battery and shorten its lifespan. Some experts interviewed for the purpose of this paper do not believe this to be a major restriction for the development of electro-mobility. They argue that fast charging is only a complementary charging method and since every electric car has its own battery management system that optimises its charging mode, even the super-fast charging can be made as harmless as possible. At the same time, however, battery management systems record the way batteries are used in a particular vehicle, and some incorrect procedures can lead to battery claims being denied. Only time will tell how fast-charging will affect the total cost of ownership of an electric car.

9. Hypothesis/Conclusions

The price of an electro-mobile or its affordability for an average user in Slovakia was one of the questions set out in this paper. This work compares several types of lower middle class cars with similar types of electric vehicles of different makes. The relevant calculations have been made using mostly average prices, but when price ranges are too high, such as in the case of the BMW 3 Series, lower price levels were preferred. The total cost of the vehicle over a ten-year period has also been compared based on the purchase price as well as the average prices of gasoline, diesel and electricity. If only electricity costs were taken into account, then electric cars would emerge as the most efficient means of personal transport. The cost of the electricity an electric car uses represents on average one third of the cost of the fossil fuel a combustion engine car needs. It is necessary to keep in mind that the battery or the whole battery box needs changing at least once in ten years. Therefore, this cost also needs to be included in the total cost of ownership of a vehicle. These comparisons were done based on information from the International Energy Agency. First, the average between the highest and the lowest price was established. When this value was taken into consideration, the electric car was still more economical than a combustion engine car. The last cost item included was the purchase price of a car and an electric car. Here, the difference in prices is more than half, i.e. electric cars are currently 50 to 70% more expensive than comparable types of combustion engine cars of the same make. This means that in Slovakia, where the average consumer is sensitive to the cost of procurement, electric cars will not become more popular before the price of electric cars becomes level to the price of a combustion engine vehicle.

The development of electro-mobility will result in increased electricity consumption. In Slovakia, some fossil fuel power plants - brown coal and mazut - have been dumped recently due to emission problems and low efficiency. Even new investments have been shut down, such as the Malzenice gas power plant built by Siemens, due to low competitiveness resulting from the fall of electricity prices in Europe and the impossibility to sell the generated power at production costs. At the same time, several large investments have caused Slovakia's electricity consumption to increase, so that more energy has been consumed in recent years than it has been produced. Therefore the country has passed from exporting electricity to importing it. The 2017 electricity consumption was, for example, 31,056 GWh while only 28,026 GWh was produced. This could be a problem in the future if the share of electric vehicles surpasses certain limits. However, Slovakia’s energy security reports as well as the opinions of experts from the Ministry of Economy of the Slovak Republic revealed that this is not likely to be a problem in the future. Since some new clean power sources alongside two other nuclear units in Mochovce are to go into production in the near future, no shortage of electricity is expected. Similarly, the European Energy Network is sufficiently built and counts with production costs that can cover increased consumption.

Another potential problem can be coping with peak electricity consumption in the event that a larger number of electric vehicles were to be charged at the same time. This could even cause network insufficiencies and blackouts. This happened, for example, in 2017 in Oslo, the city with the highest concentration of electric vehicles in the world. The installed capacity in Slovakia is 7 720 MW, with an average consumption of about 3 300 MW and a maximum of about 4300 MW. According to estimates by the International Energy Agency, charging electric cars at their peak may increase consumption by 30%. The calculations carried out for the purpose of this paper have shown that the Slovak electricity system can cope with such increases. However, experts fear problems with grid load capacity at local levels. If large-capacity chargers were to be used massively in low-power sites, they could cause the network to collapse at some places. This could cause problems at a higher level and even lead to overall black-outs. The different distribution companies either do not have estimates and scenarios for such an event, or were unwilling to provide them for this paper. Thus, the problem is not in production capacity or covering gush loads, as assumed in the research questions, but in the network's grid load capacity at the local level.

Sufficient available infrastructure is one of the basic prerequisites for electro-mobility to develop. Strategic documents drawn up by the Slovak central authorities anticipate its development, but do not define any specific measures to promote it. In general, it is believed that 90% of charging will be carried out in residential conditions using private chargers. However, publicly available charging stations constitute a tool that can reduce the drivers' concerns and discomfort resulting from the shorter range of electric vehicles. The Slovak Republic only engages in European Union activities implementing European directives into national legislation. There are no or very little initiatives using national sources. Slovakia, as in many other aspects, is likely to be among those countries that will lag behind, limit itself to watch and maybe only after some time imitate other countries' leading initiatives. Thus, most activities in this direction will be left for the private sector to develop infrastructure even though building and operating charging stations is not a profitable business model at the present.

Excise tax on mineral oils, i.e. gasoline and diesel, are a stable income to the state budget of the Slovak Republic. Excise duty is set for a flat quantity of one thousand litres, so that it is not affected by price fluctuations on the oil and petroleum derivates market. As it is also relatively easy to predict, it provides a convenient and easily defined source of public funds for the government. According to the Ministry of Finance of the Slovak Republic, their volume in the last couple of years has been around EUR 1.2 billion per year, which is about half of the excise tax revenue and about 8% of the total state budget revenues. If the share of electric vehicles were 30 percent, the loss of excise duty on fuel could be up to 2.5% or 350 million euros in absolute numbers. The state will need to compensate this drop and may opt to do this in the commodity that replaces fuel consumption, i.e. electricity. Therefore, a higher share of electric cars is likely to result in increased electricity prices, as it happened when renewable energy sources were introduced and promoted increasing consumer prices. Thus, it can be said that electro-mobility will be paid for by everyone, not just electric vehicle users.

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