MSc Program
Renewable Energy in Central and Eastern Europe

Studying the Possibility of Switching to Electric Taxis in Vienna for a Small Taxi Company with Five Cars from Technological, Economic and Environmental Points of View

A Master Thesis submitted for the degree of
Master of Science

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Affidavit

I, **Atanas Atanassov**, hereby declare

1. That I am the sole author of the present Master Thesis, " Studying the Possibility of Switching to Electric Taxis in Vienna for a Small Taxi Company with Five Cars from Technological, Economic and Environmental Points of View",
   93 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 Thesis as an examination paper in any form in Austria or abroad.

Vienna, _______________ ___________________________

Date Signature

Abstract

My job as a taxi driver in Vienna is the main motivation for choosing this topic for the master thesis. Working for a small taxi company with 5 taxis made me curious to study the possibility of switching to electric cars from technological, economic and environmental point of view.

In the last few years the number of hybrid taxis in Vienna has significantly increased and they are quite well accepted by the customers. Today with the new improved technologies and batteries the electric cars used as taxis in the cities are more and more in discussion. There are a lot of projects regarding the use of electric vehicles in the taxi industry. Vienna is not an exception either. Some electric taxis already run on the streets of Vienna.

The core objective of this work is to analyze the possibility of switching to electric taxis for a small taxi company in Vienna with 5 cars. The analyzes will include technological overview, ecological evaluation – lifecycle assessment, economic calculations and also taxi drivers interviews for their readiness to switch to electric cars and information about their driving behavior.

This work should show the possibility to switch to electric vehicles and the advantages for all the parties – taxi companies, drivers, customers and not least environment.

As transport is one of the major air pollutants, switching to electric taxis could contribute to CO_2-emissions reduction and meeting the EU targets regarding GHG emissions.

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List of Abbreviations

GHG	Greenhouse Gasses
ICE	Internal Combustion Engine
O&M	Operation and Maintenance
EV	Electric Vehicles
LCA	Lifecycle Assessment
WTT	Well-to-Tank
TTW	Tank-to-Wheel
WTW	Well-to-Wheel
CO_2	Carbon Dioxide

1 INTRODUCTION

The transport sector is one of the main pollutants of the environment. According to the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management from 1990 to 2012 the CO_2 emissions in transport sector increased from 13.2 million tones to 21.5 million tones.[1] The share of GHG emissions by transport in 2010 is 26.1%.[2]

In order to decrease the GHG emissions in the transport new, nature friendly, technologies should be used. Electric vehicles are an example of this technology. They are particularly suitable for urban areas with short distances driven and possibility for recharging the batteries. Public transport, delivery services, taxi industry and car sharing are very appropriate for electric vehicles.

The entire Viennese taxi fleet consists of 4,300 licensed vehicles. About 2,500 are radio taxis, connected to dispatch companies, and additional 1,800 taxis without radio.[3] The potential for reducing the CO_2 emissions by switching to electric taxis is significant. Switching of 50% of the total of 2,500 Viennese radio taxis results in a CO_2-Saving potential of approximately 10,000 tones of CO_2eq per year.[4] Of course these savings could be realized only by using energy from renewable energy sources.

In addition to reducing the GHG, switching to electric taxis in Vienna will also contribute to promoting sustainable transport, both in business and private sector. Vienna can become an example of green city with sustainable transport and thus attract more tourists.

[1] BMLFUW (2012): Startseite, Daten und Zahlen, Umwelt, CO2-Emissionen nach Sektoren 1990 – 2012, http://duz.bmlfuw.gv.at/Umwelt/CO2_Emissionen.html.

[2] European Environment Agency (2010): GHG trends and projections in Austria, Share of GHG emissions (excluding international bunkers) by main source and by gas in 2010.

[3] Gawlik, W., Litzlbauer, M., Schuster, A., et al. (2013): ZENEM - Zukünftige Energienetze mit Elektromobilität, FFG-Forschungsprojekt, NE2020, 4. AS, Projektnummer: 829953, Endbericht, p.13, Wien 2013.

[4] Gawlik, W., Litzlbauer, M., Schuster, A., et al. (2013): ZENEM - Zukünftige Energienetze mit Elektromobilität, FFG-Forschungsprojekt, NE2020, 4. AS, Projektnummer: 829953, Endbericht, p.55, Wien 2013.

1.1 Motivation

On one hand my job as a taxi driver in a small taxi company in Vienna with 5 vehicles and on the other my interest in electric vehicles and sustainable transport motivated me to choose this topic. With this work I would like to show the possibility of switching to electric taxis in Vienna for small companies and promote the sustainable transportation in the taxi industry.

The most of the 4,300 taxis in Vienna use ICE vehicles and especially diesel vehicles. In the last years this changed with the penetration of the hybrid technology, but still the majority of the taxi fleet consists of diesel ICE. The number of electric vehicles in Viennese taxi industry is negligible – less than 10 vehicles. The reason for the still small number of electric taxis is the high purchase price, lack of infrastructure and adequate strategy for the integration of electric taxis in the taxi industry.

There are some projects researching the possibility of switching to electric taxis in Vienna but they are primarily focused on radio taxi fleets. In this work the focus will be on taxis without connection to any dispatch company, taxis responding on hails and waiting on taxi stands.

The benefits from the transition to electric taxis are another reason for choosing this topic. This could be a win-win situation for all parties involved:

Municipality

- Improving the city's image
- Improving the quality of life in Vienna
- Promoting sustainable transportation
- Encourage adoption of EVs by more private automobile owners
- Electric taxis would support the Energy goals of GHG reduction
- New investments – new jobs

Customers

- Better air quality in Vienna
- Noise emission reduction

- Environmental impact mitigation

Taxi companies

- Less fuel costs compared with conventional vehicles
- Less service, operation and maintenance costs
- Eco-friendly service
- Electricity prices are much less volatile
- Subsidies for EVs
- Higher residual value than ICE vehicles

1.2 Core objectives

A small existing taxi company with 5 taxis wants to invest in a new more nature friendly and sustainable technology. They decide to invest in a zero emissions technology – electric vehicles.

The company studied in this work is not connected to a dispatch company and their taxis respond only to hails and do not provide a call-ahead service. These taxis normally drive around or wait on taxi stands for their customers. They represent almost the half of the taxis in Vienna.

All the vehicles will operate in single shifts. Which means every driver receives his own vehicle. The existing charging stations infrastructure and the possibility of charging during breaks will be analyzed in order to find the nearest charging station to drivers home. There are a lot of park houses in Vienna with charging stations. This could be an opportunity to charge the batteries in normal conditions without shortening their lives. Also fast charging stations will be considered in order to charge during short breaks. The possibility of the company building its own charging station will also be taken into account.

The core objective of this master thesis is to investigate the possibility to switch to electric vehicles from technological, economic and environmental point of view.

Some proposals supporting and promoting the introduction of electric taxis will be addressed.

The main questions addressed in this work are:

- Is it economically viable for a small taxi company to invest in 5 electric taxis,
- Is it possible to operate 5 electric vehicles with the existing charging infrastructure,
- Is it economically viable to invest in own charging station,
- Which of the existing electric vehicle on the Austrian market are most appropriate for the taxi industry,
- Are there and what are the advantages for the environment – lifecycle assessment,
- What infrastructure changes could support the introduction of electric taxis,
- What legal changes could support the introduction of electric taxis.

1.3 Citation of main literature

Different studies and specialized literature will be used to answer the questions mentioned above. Also some figures, tables and information from the „ZENEM PROJECT"[5] will be used in order to achieve better and more accurate results. All the taxi drivers in the company will be interviewed in order to get more realistic figures regarding kilometer driven per shift, waiting time, driving behavior, number and duration of breaks during the shift and readiness to switch to electric vehicles. Figures, tables, charts and graphs from the "Renewable Energy in Central and Eastern Europe" lectures will also be used in the master thesis.

1.4 Structure of the work

This master thesis consists of eight main chapters. Each chapter addresses a particular aspect of the topic set in the thesis. Examination of the topic from different

[5] Gawlik, W., Litzlbauer, M., Schuster, A., et al (2013): ZENEM - Zukünftige Energienetze mit Elektromobilität, FFG-Forschungsprojekt, NE2020, 4. AS, Projektnummer: 829953, Endbericht, Wien 2013

points of view – economical, ecological, technological and legal will give a clear idea of the possibility to switch to electric taxis in the company concerned.

The first chapter - introduction presents the main reasons for selecting this topic and related issues to which it must respond. Also the basic literature and sources that the author intends to use and quote will be mentioned, as well as the structure of the work itself.

Chapter two provides information about taxi industry and major structures. The current taxi market is discussed and some operational models are mentioned. Information about number of taxis, kilometers travelled, vehicles used for taxi services, taxi stands, tariffs, dispatch companies and so on are also considered.

Chapter 3 examines the methods of approach used to answer the core questions raised in this master thesis. These questions are divided into three main groups - issues related to the environment, technological issues and economic issues. In the next 4th, 5th and 6th chapters these questions are examined in detail and relevant calculations are made. Results regarding the opportunity of transition to electric taxis in a small company with 5 taxis from economic, environmental and technological point of view are presented. Information on existing electric cars and their technical characteristics is presented in order to choose the most appropriate vehicle for taxi purposes. Existing infrastructure is considered in order to assess whether it is possible for drivers to recharge their EVs batteries near their homes. Also the possibility for fast charging is checked to determine if there is a need to invest in own fast charging station. CO_2 emissions from the selected EV are calculated and compared with 3 other ICE vehicles – Diesel, Hybrid and Natural Gas in order to determine the most environmentally friendly technology and the CO_2 savings by switching to electric vehicles within the inspected company. From economic point of view the selected EV annual investment costs are compared with the mentioned above 3 vehicles in order to establish the sustainability of investment in electric cars.

In Chapter 7 the results of the research for the possibilities of switching to electric taxis in Vienna for a small taxi company consisting of five taxis are presented. The results are presented again from technological, ecological and economic point of view.

Last Chapter 8 concludes the possibility of switching to electric taxis and measures that would contribute to this transition to electric taxis.

2 BACKGROUND INFORMATION

2.1 Taxi market

The taxi market is managed and regulated by the government of Vienna. There are about 4,300 taxis registered and 9,671 concession documents issued[6]. The most of them are vehicles with internal combustion engines. The number of hybrid vehicles in Vienna's taxi fleet increased significantly in the last years, however the number of electric taxi vehicles today in Vienna is still less than 10 cars. The demand for electric taxi cars is growing steadily.

The government of Vienna sets the taxi fares and they apply to all the taxis in the city. The last change of taxi fares was on 1.12.2012. All the taxi drivers should use a taximeter. By trips outside the city limits the price can be negotiated usually including an additional charge for the trip back to the city border. The day fare begins from 6.00 a.m. to 11.00 p.m. and starts at 3.80€, the night from 11.00 p.m. to 6.00 a.m. and starts at 4.30€. Additionally charged are each kilometer driven and each minute stay.

In all the 23 districts in Vienna there are a number of taxi stands. The customer is free to choose any car, not necessarily the first one. Taxis also respond to hails and most of them use call-ahead services. There are two dispatch companies in Vienna, where customers can order taxi by phone or Internet. 2.80€ are charged additionally for the order.

2.2 Taxi operational models

The taxi companies need concessions for each car registered as a taxi. There are companies with one and more vehicles. According to Austrian Commerce Chamber statistics 95.9% of the companies in the association of transport industry with passenger cars (Fachverband Beförderungsgewerbe mit Personenkraftwagen) have less than 10 employees, 3.7% from 10 to 49 and only 0.4% from 50 to 250

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[6] WKO (2015): Beförderungsgewerbe mit Personenkraftwagen, Fachgruppe, Daten & Fakten Zahlen, Wien 2014, p. 5.
https://www.wko.at/Content.Node/branchen/w/TransportVerkehr/BefoerderungPKW/Zahlen--Daten---Fakten/StatistikV6-2013_2.pdf.

employees. In some cases the driver is the owner of the company and he operates with his own vehicle.

Most drivers do not own their taxis, they just rent them from a company with more vehicles. Depending on the personal working time there are different models of renting a taxi:

- Fixed rental for week – single shifted,
- Fixed rental for week – double shifted,
- Day rental - percentage from the turnover.

The most of the taxis in Vienna are double shifted and usually the day shift starts at 6.00 a.m. to 6.00 p.m. and night from 6.00 p.m. to 6.00 a.m. Depending on the company requirements the shift change could be done at the garage of the company or at the home addresses of the drivers. Some companies allow drivers of single-shifted vehicles to park the vehicles near their homes.

2.3 Distances travelled

The taxis in Vienna usually drive about 50,000 km per year. It is very hard to determine the distance driven per taxi per day. In my experience the distance per shift may vary from 100 to 250 kilometers. Day shift distances are shorter than night shift distances, because of the traffic. During the day people usually take a taxi from a taxi stand or order by phone while at night the chance of being hailed is much higher. Taxis without connection to a dispatch company, relying heavily on hails, drive more kilometers than radio taxis, because of driving around and looking for customers. The most kilometers are travelled on Fridays, Saturdays and the days before holidays, especially at night.

3 METHOD OF APPROACH

In order to evaluate the possibility and the feasibility a small taxi company with 5 vehicles to switch to electric vehicles 3 main aspects will be considered: technological, environmental and economic.

3.1 Technological approach

The transition to electric vehicles in the taxi industry is mainly determined by the technological status quo in the electric vehicle branch in the country and generally in the world. Analyzing the Austrian EV's market will give us information about the current situation and some technical details about the vehicles sold in the country. Distance driven with one charge, reliability of the battery, battery life, charging time, operation and maintenance, comfort of the vehicle and compatibility with the existing charging infrastructure are the main parameters which should be considered when selecting the appropriate car for taxi services.

For the taxi industry, the government of Vienna sets specifications for vehicles, which include measurements, maximum vehicle age, and equipment standards. All these requirements should be met by the selection.

After choosing the most suitable EV for taxi services in Vienna, the existing charging infrastructure will be analyzed in order to estimate the possibility of operating the company without building their own charging station. The single-shifted operation of the taxis gives drivers the opportunity to charge their vehicle batteries in normal conditions after finishing the shift. Finding a charging station close to every drivers home is a prerequisite for smooth operation of the company's EV‘s. The availability of the selected charging stations will also be analyzed in order to provide seamless operation of the taxi fleet. As the range of the most EV's available on the market is between 100 and 150 km and the distances driven per shift 100 to 250 km the existing fast charging infrastructure will also be taken into account.

Analysis of the above mentioned technological and infrastructural issues will give us an idea of the feasibility of transition to EV's for the existing small taxi company with 5 vehicles.

3.2 Environmental approach

Switching to electric taxis would make sense only if environmental impact mitigation is a fact. A detailed ecological appraisal can be given only through the lifecycle assessment considering the whole lifecycle for the production and operation of the vehicle.

As EV's have no tailpipe emissions to be included in the calculation of CO_2 emissions, the electricity mix used by the existing charging infrastructure will be investigated. In order to achieve best results, information about all charging stations used by the taxi drivers will be gathered. Also official data from utilities and charging stations operators will be adopted.

Information and data from car companies regarding CO_2 emissions per kilometer and CO_2 emissions for the car production will be considered in the calculations.

The received GHG emissions from the 5 EV's taxis will be compared with the hybrid technology and ICE vehicles on natural gas and diesel in order to estimate the GHG savings by switching to electric taxis.

3.3 Economic approach

The economic appraisal of switching to EV's within a small taxi company with 5 vehicles will be done through analyzing of specific investment costs, operation and maintenance costs, funding, fuel cost, resale value and finally compared with hybrid and conventional ICE vehicles. Comparison with other technologies will give information about the profitability of investing in EV's and the most suitable technology for taxi industry from economic point of view.

Information about investment costs will be collected directly from manufacturer's web-sites. Literature research will deliver data about O&M costs and resale value. Exploration of government incentives for plug-in electric vehicles will also be conducted. Interviews with drivers and company owners will give information about fuel consumption, kilometer driven and O&M costs. The actual price of fuel and electricity will be used in the calculations.

The total driving costs C_{drive} per year will be calculated using the following formula:[7]

$$C_{drive} = IC\ \alpha + P_f FI\ skm + C_{O\&M} \qquad [€/car/year]$$

IC……investment costs [€/car]

α……..capital recovery factor

skm…..specific km driven per car per year [km/(car.yr)]

Pf……..fuel price incl. taxes [€/liter]

$C_{O\&M}$…operating and maintenance costs

FI……..fuel intensity [liter/100 km]

The costs per km driven C_{km} will be calculated as:[7]

$$C_{km} = \frac{IC \cdot \alpha}{skm} + P_f \cdot FI + \frac{C_{O\&M}}{skm} \qquad [€/100\ km\ driven]$$

Using these formulas the economic performance of the 3 technologies – EV's, hybrid and ICE will be analyzed.

A 5 years depreciation period will be selected.

[7] Ajanovic, A. (2013): Driving costs, Comparison of technical, economic, and ecological aspects, International Survey on Transport, MSc Program – Module 1, *Renewable Energy in Central and eastern Europe*, Lecture note: p. 68.

4 TECHNOLOGY AND INFRASTRUCTURE PERSPECTIVE

4.1 Austrian electric vehicle market

The first EV's worldwide appeared in the middle of 19th century. Despite the dominance of ICE ever since, the electric powered vehicles have earned their place in the public transportation sector like trains, trams and trolley buses. After the introduction of the first electric vehicles in the 19th century there have been several attempts to return EV's to the market, like in 1990's, but they failed. In the last years EV's are gaining more popularity.

As shown on the graph below the number of registered EV's in Austria significantly increased from 2010 to 2014. At the end of 2014 there were 3.386 EV's licensed, this corresponds to a share of 0.07% of the total stock.[8] This market share is still meager compared with countries like Norway with 5.75% in 2013.[9]

[8] Statistik Austria (2014), cited by Austria Tech (2015): Monitoringbericht AustriaTech 2014, *Bundesministerium für Verkehr, Innovation und Technologie*. Retrieved 23.06.15 from: https://www.bmvit.gv.at/verkehr/elektromobilitaet/downloads/emobil_monitoring_2014.pdf.

[9] Zachary Shahan (07.03.2013): Electric vehicle market share in 19 countries, *ABB Conversations*. Retrieved 24.06.2015 from: http://www.abb-conversations.com/2014/03/electric-vehicle-market-share-in-19-countries/.

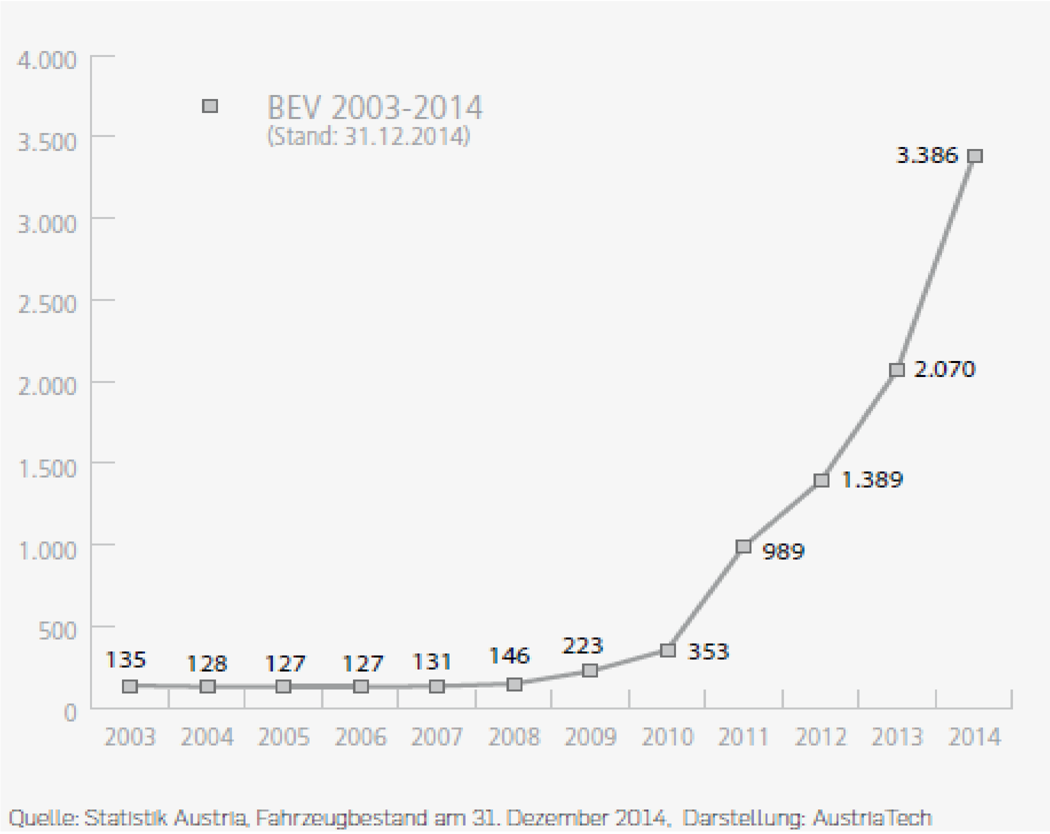

Figure 1: Registered pure electric vehicles in Austria 2003–2014[8]

Switching to electric taxis of the Viennese taxi fleet could influence the market share of pure EV's and be used as a tool for promoting sustainable transportation and particularly electric vehicles. Of course this could happen with adequate policy, political will and government subsidies.

Table 1 shows the battery electric vehicles sold on the Austrian market with their range, electricity consumption per 100 km and type of charging connector.[10]

[10] Austria Tech (2015): Monitoringbericht AustriaTech 2014, *Bundesministerium für Verkehr*, *Innovation und Technologie*. Retrieved 24.06.15 from: https://www.bmvit.gv.at/verkehr/elektromobilitaet/downloads/emobil_monitoring_2014.pdf.

Table 1: Available BEV on Austrian market[10]

BEV Marke - Typ	Elektrische Reichweite	Verbrauch	Stecker Typ
Bdoto - Fiat E-Ducato Kombi	200 km	-	Schuko, CHAdeMO
Bdoto - Fiat E-Scudo Kombi	130 km	-	Schuko, CHAdeMO
Bdoto - Renault E-Traffic Kombi	160 km	-	Schuko, CHAdeMO
BMW i3	190 km	14 - 17 kWh/100 km	Typ 2, CCS
Citroen C-Zero airbeam	150 km	12,6 kWh/100 km	Typ 1, CHAdeMO
Smart fortwo electric drive	145 km	15 kWh/100 km	Typ 2
Ford Focus electric	162 km	15,9 kWh/100 km	Typ 1
German E-Cars Stromos	120 km	15 - 20 kWh/100 km	Typ 2, CEE, Schuko
Kia Soul EV	212 km	14,7 kWh/100 km	Typ 1, CHAdeMO
Melex N.Car 366 Personenwagen	80 km	12 kWh/100 km	Schuko
Mercedes B-Klasse ED	200 km	16,6 kWh/100 km	Typ 2
Mitsubishi i-MiEV	150 km	13,5 kWh/100 km	Schuko, CHAdeMO
Nissan e-NV200 Evalia (PKW)	170 km	16,5 kWh/100 km	Typ 1, CHAdeMO
Nissan Leaf	199 km	15,0 kWh/100 km	Typ 1, CHAdeMO
Peugeot iOn	150 km	13,5 kWh/100 km	Typ 1, CHAdeMO
Renault Kangoo ZE (PKW)	170 km	15,5 kWh/100 km	Typ 2 (Schuko Optional)
Renault Twizy Urban 80	100 km	6,1 kWh/100 km	Schuko
Renault Zoe	210 km	14,6 kWh/100 km	Typ 2 (Schuko optional)
Tezzari Zero	140 km	-	Schuko
Tesla Model S 60	390 km	22 kWh/100 km	Typ 2, Supercharger
Tesla Model S 85	502 km	23,5 kWh/100 km	Typ 2, Supercharger
VW e-Golf	190 km	12,7 kWh/100 km	Typ 2, CCS
VW e-up!	160 km	11,7 kWh/100 km	Typ 2, CCS

There are some technical specifications set by the government of Vienna concerning the measurements of the vehicles suitable for taxi services:[11]

- External length (minimum length): 4,200 mm,
- External width (minimum width): 1,560 mm,
- External height (minimum height): 1,300 mm.

Considering this specifications the number of EV's meeting the requirements significantly reduces. Table 2 shows some important characteristics of the vehicles helping us to determine the most appropriate EV for taxi services in Vienna.

[11] Wirtschaftskammer Wien (20.11.2014): Betriebsordnung, *WKO.at*, Retrieved 24.06.15 from: https://www.wko.at/Content.Node/branchen/w/TransportVerkehr/BefoerderungPKW/Taxi-und-Mietwagen---die-Branche/Betriebsordnung.pdf.

Table 2: EV's specifications (own table)

Brand Model	Range (km)	Price ink. Battery (€)	Price excl. Battery (€)	Consumption (KWh/100km)	Charging time (h)	Fast DC charging 80% (h)
Ford Focus Electric	162[12]	39,900[12]		15,4[12]	6-7[13]	
Mercedes B Class	200[12]	39,600[12]		16.6[12]	9[14]	2-3[14]
Nissan e-NV200 EVALIA	170[15]	38,364[15]	32,460[15]	16.5[15]	4-7[15]	0.5[15]
Nissan Leaf	199[12]	29,290[12]	23,390[12]	15.0[12]	8[16]	0.5[16]
Renault Kangoo ZE	170[12]		24,360[12]	15.5[12]	6-9[12]	
Tesla Model S70D		80,200[12]				
Tesla Mod. S85	502[12]	81,740[12]		24[12]		
VW eGolf	190[12]	36,200[12]		12.7[12]	8[12]	0.5[12]

From the table above we can conclude that the most appropriate EV's for the taxi industry regarding range are the both tesla models, but taking into account the high investment costs the Mercedes B Class, Nissan Leaf and e-Golf look most attractive for the purpose. The Mercedes brand is generally very well accepted by both drivers and customers, but the long period for fast charging the battery – 3 hours, makes it unattractive. As Nissan Leaf is one of the most sold electric cars in the world and it has been almost 5 years on the market it will be chosen for our taxi company. The

[12] Autoreview (2015): Elektroautos: Übersicht aller Testberichte, technischen Daten & Preise, *autoreview.at*, Retrieved 27.07.15 from: http://autorevue.at/autowelt/alle-elektroautos-preise-testberichte-daten.

[13] Ford Motor Company (2015): Der Neue Focus Electric, Broschüre Ford Focus Electric, *ford.de* Retrieved 07.09.15 from: http://www.ford.de/Pkw-Modelle/FordFocus-Electric/BroschuereundPreisliste

[14] Daimler AG (2015): Neufahrzeuge, B-Klasse Sports Tourer B 250 e, Technische Daten, *mercedes-benz.de*, Retrieved 07.09.15 from: http://www.mercedes-benz.de/content/germany/mpc/mpc_germany_website/de/home_mpc/passengercars/home/new_cars/models/b-class/w242/facts/technicaldata/model.html.

[15] NISSAN CENTER EUROPE GMBH (2015): NISSAN e-NV200 EVALIA, Preise & Ausstattung, E-Broschüre, *nissan.at*, Retrieved 07.09.15 from: http://www.nissan.at/content/dam/services/AT/brochure/104795.pdf.

[16] NISSAN CENTER EUROPE GMBH (2015): NISSAN LEAF Preise & Ausstattung, E-Broschüre, *nissan.at*, Retrieved 07.09.15 from: http://www.nissan.at/content/dam/services/AT/brochure/104603.pdf.

other reason for choosing Nissan leaf is the *Wien E-Taxi* project funded by the Ministry of Transport, innovation and technology. According to this project both Nissan electric models – Nissan leaf and Nissan e-NV 200 will be funded for up to 8.000 Euro.[17]

4.2 Charging infrastructure

To be able to operate the 5 electro-taxis in the company a sufficient number of charging stations will be needed. As mentioned before all the taxis are single shifted which means they could be fully charged during the breaks between shifts and recharged at fast charging stations if necessary during short breaks. First the availability of charging stations near drivers homes will be checked out and then the fast charging opportunities.

Here are the driver's addresses:

Driver 1: Döblinger Hauptstraße 6, 1190 Vienna
Driver 2: Praterstraße 50, 1020 Vienna
Driver 3: Kriehubergaße 10, 1050 Vienna
Driver 4: Mollardgasse 80, 1060 Vienna
Driver 5: Pasettistrasse 25, 1200 Vienna

Through the portal www.ev-charging.com, owned by *KELAG-Kärntner Elektrizitäts-Aktiengesellschaft* the next E-Station near driver's homes area will be pointed. Using Google Maps the walking distance to the next charging station will be determined and then discussed with the drivers.

4.2.1 Charging between shifts

Next Figure 2 shows the nearest charging possibilities for Driver 1. There are 3 charging stations near driver's home address. Figure 3 shows the walking distance – 8 minutes to the nearest one calculated with Google maps. The walking distance to the other 2 charging stations is respectively 11 and 12 Minutes.

[17] Hartmann, M. (2015): „Strom kommt in Fahrt", *Taxi Aktuell.*

The nearest charging station is operated by *Wien Energie GmbH* and is 24 hours open. It offers 2 parking lots for E-Cars with Type 2 plugs, 11.1 kW and Type F plugs, 3.7 kW. The other 2 charging stations also works non-stop and each one offers 2 parking lots. The first one is operated by *SMATRICS GmbH & Co KG* and offers 2 Type 2 plugs with 22.2 kW each. The second one is operated again by *Wien Energie GmbH* and has 2 Type F plugs with 3.7 kW. All the plugs are compatible with the Nissan leaf.

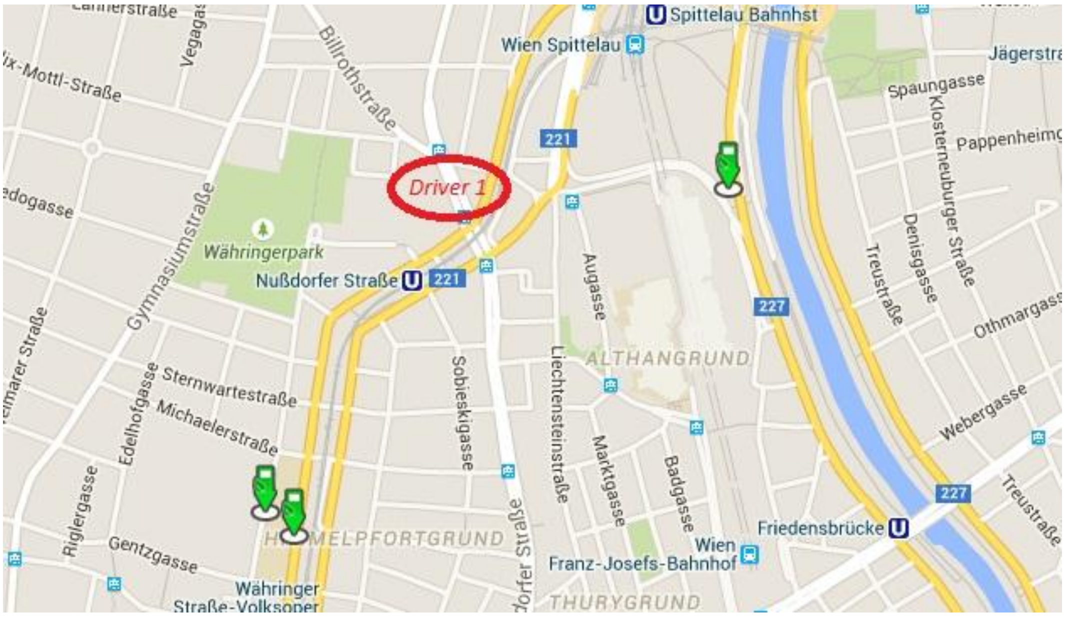

Figure 2: Driver 1 charging possibilities[18]

Driver 1 does not need to change his habits regarding walking to pick up the car. Currently he walks the same distance to his home after parking the taxi.

[18] KELAG-Kärntner Elektrizitäts-Aktiengesellschaft(2015): Charging stations in Vienna, *ev-charging.com*, Retrieved 28.07.15 from: https://ev-charging.com/at/en/elektrotankstellen.

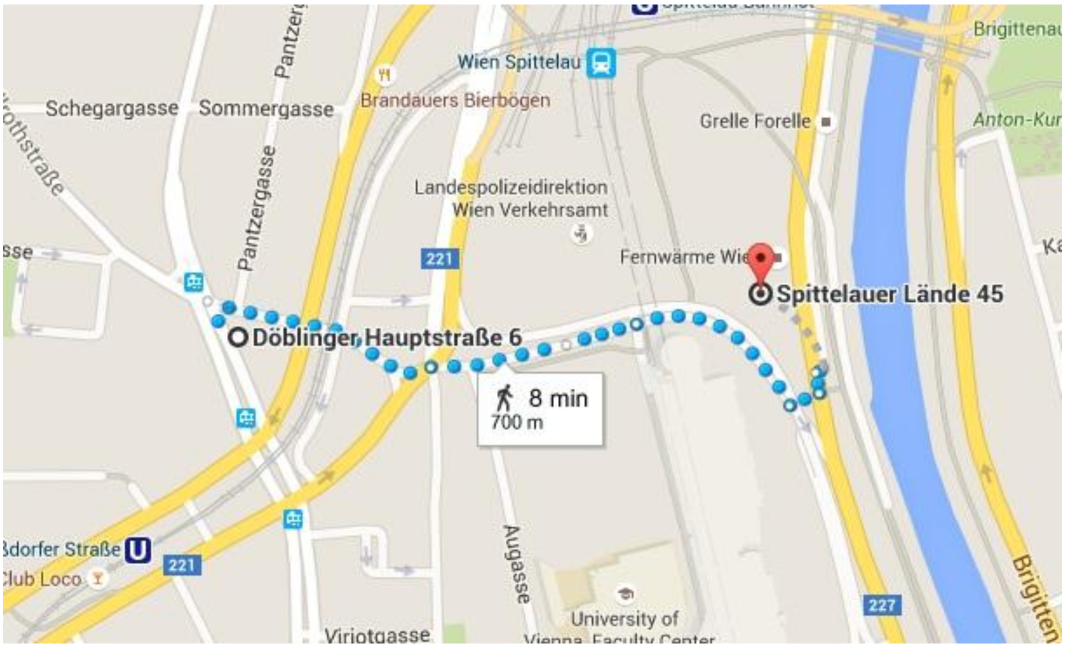

Figure 3: Driver 1 walking distance nearest charging station[19]

Figure 4 displays the charging options for Driver 2. The nearest charging station is operated by *Wien Energie GmbH*, offers 4 parking lots for E-Cars(2 Type 2 – 11.1 kW and 2 Type F – 3.7 kW), availability 24 hours and is located on the street the driver lives on. According to Google Maps calculations the walking distance is 650 m and it will take 8 minutes walking there.

For Driver 2 there are a lot of charging possibilities apart from the nearest one and there are 15-25 minutes walking distance from his home, taking into account that he currently parks in 22. Vienna district and rides by bicycle home, which takes about 20 minutes, switching to electro-taxi will shorten the time walking/cycling home.

[19] Google Maps(2015): Vienna, Austria, Walking route calculation,
Retrieved 28.07.15 from:
https://www.google.at/maps/dir/D%C3%B6blinger+Hauptstra%C3%9Fe+6,+1190+Wien/Spittelauer+L%C3%A4nde+45,+1090+Wien/@48.2330131,16.3569468,16z/data=!4m14!4m13!1m5!1m1!1s0x476d07ccd605869b:0xaad3a74f6ee73cce!2m2!1d16.3535888!2d48.2330578!1m5!1m1!1s0x476d0634dd556515:0x6ff16a455ad7a6db!2m2!1d16.360045!2d48.2334234!3e2?hl=en.

Figure 4: Driver 2 charging possibilities[20]

Figure 5: Driver 2 walking distance nearest charging station[21]

[20] KELAG-Kärntner Elektrizitäts-Aktiengesellschaft(2015): Charging stations in Vienna, ev-charging.com, Retrieved 28.07.15 from:
https://ev-charging.com/at/en/elektrotankstellen.

[21] Google Maps(2015): Vienna, Austria, Walking route calculation,
Retrieved 28.07.15 from:
https://www.google.at/maps/dir/Praterstra%C3%9Fe+50,+1020+Wien/Praterstra%C3%9Fe+1,+1020+.Wien/@48.2131483,16.3839983,15.5z/data=!4m14!4m13!1m5!1m1!1s0x476d070900f8edb9:0x21472d7efdf7d1c8!2m2!1d16.386669!2d48.2156425!1m5!1m1!1s0x476d07a0bdfad597:0x1699ce7d0c37be3f!2m2!1d16.3799884!2d48.2130008!3e2?hl=en

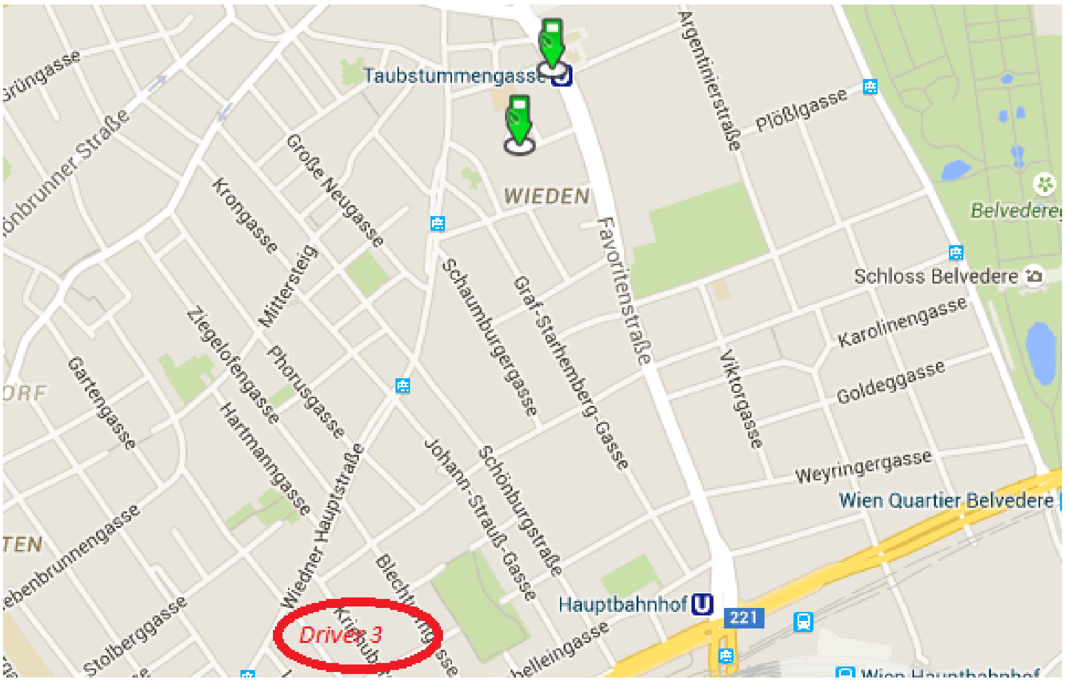

Figure 6: Driver 3 charging possibilities[22]

Figure 6 shows the nearest charging stations for Driver 3. The nearest one is operated again by *Wien Energie GmbH* and offers 2 parking lots with Type 2 plugs each 11.1 kW. It is 24 hours open and is at 17 minutes walking distance.[23]

Driver 3 also has a garage, very close to his home, where he usually parks. If a wall box charging station is mounted in the garage there is no need to change driver's habits.

Driver 4 also has a garage where he parks the taxi between shifts. Installing a wall box charging station in the garage will maintain the status quo for the driver.

Figure 7 illustrates the charging possibilities for Driver 4. The nearest charging station is operated by *SMATRICS GmbH & Co KG* and offers CHAdeMO fast charging with 49.8 kW.

[22] KELAG-Kärntner Elektrizitäts-Aktiengesellschaft(2015): Charging stations in Vienna, ev-charging.com, Retrieved 28.07.15 from: https://ev-charging.com/at/en/elektrotankstellen.

[23] Google Maps(2015): Vienna, Austria, Walking route calculation, Retrieved 28.07.15 from: https://www.google.at/maps/dir/Kriehubergasse+10,+1050+Wien/Brahmsplatz+3,+1040+Wien/@48.1902637,16.3659916,15z/data=!4m15!4m14!1m5!1m1!1s0x476da9d34332ea45:0x4e25725f4c0aa17f!2m2!1d16.3662453!2d48.1849604!1m5!1m1!1s0x476d0781cfd5e311:0x3e14a9f27e8a534e!2m2!1d16.3688094!2d48.1933838!3e2!5i2?hl=en.

Figure 7: Driver 4 charging possibilities[24]

Figure 8 shows the nearest charging stations for Driver 5. The nearest charging station is about 5 minute walk from drivers home.[25] It is operated by *Wien Energie GmbH* and has 10 parking lots (5 Type 2 with 11.1 kW and 5 Type F with 3.7 kW).

Driver 5 is the only one in the company who works at day time. For him there is no need to change his habits considering parking the taxi between shifts.

[24] KELAG-Kärntner Elektrizitäts-Aktiengesellschaft(2015): Charging stations in Vienna, ev-charging.com, Retrieved 28.07.15 from: https://ev-charging.com/at/en/elektrotankstellen.

[25] Google Maps(2015): Vienna, Austria, Walking route calculation. Retrieved 28.07.15 from: https://www.google.at/maps/dir/Millennium+Tower,+Handelskai,+Vienna/Pasettistra%C3%9Fe+50,+1200+Wien/@48.2390511,16.3818292,17z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1s0x476d065afc468387:0x188d49d5a4165da8!2m2!1d16.3868931!2d48.2404153!1m5!1m1!1s0x476d064fd8225d41:0x45c4212ece326832!2m2!1d16.3813787!2d48.2376798!3e2?hl=en.

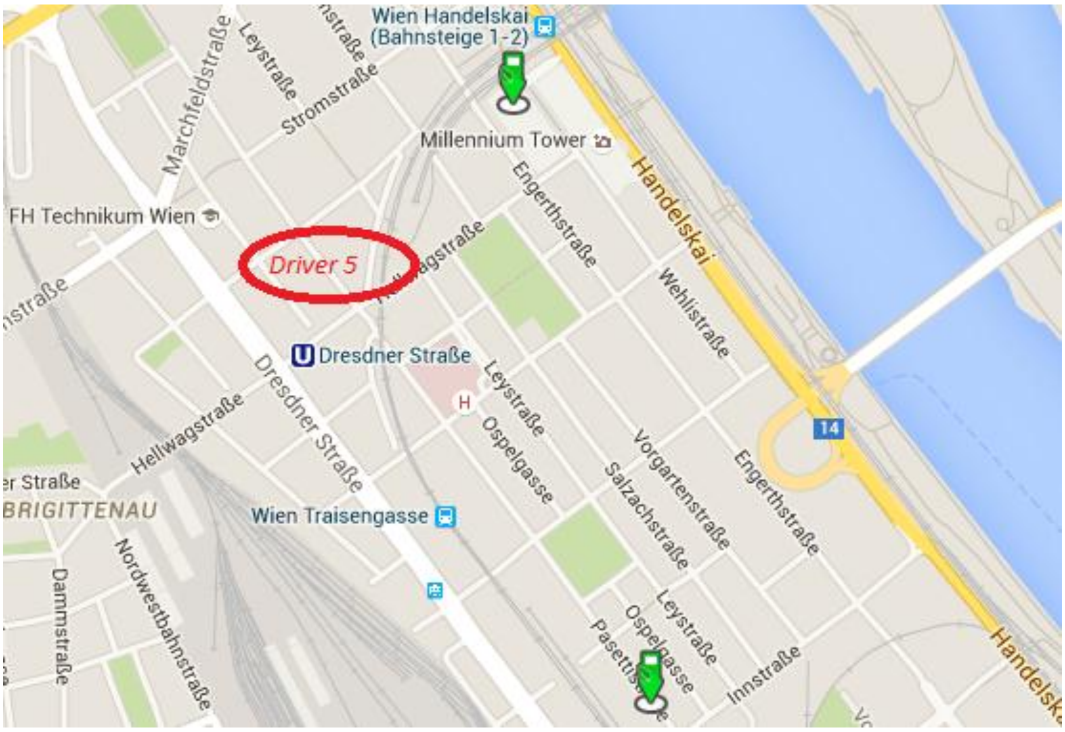

Figure 8: Driver 4 charging possibilities[26]

Generally we can conclude that switching to electric taxis for the company regarding parking (charging) between shifts does not require a big change in the habits of the drivers. With the existing infrastructure charging between shifts should not be a major obstacle.

4.2.2 Fast charging during the shift

The range of Nissan leaf can vary from 50 to 150 km depending on different circumstances like: outside temperature, driving style, traffic and weather conditions. As average distance driven by the taxis in the company is about 150 km, being able to deliver the taxi services requires quick charging stations.

As shown on Figure 9 there are only 5 CHAdeMO Type 2 fast charging locations in Vienna compatible with Nissan Leaf. Two of them are located in the city center, 2 in the south-west part and one in the north of the city. The 2 locations in the city center and the one in the south-west part are 24 hours open. The other two are with limited working hours.

[26] KELAG-Kärntner Elektrizitäts-Aktiengesellschaft(2015): Charging stations in Vienna, ev-charging.com, Retrieved 28.07.15 from:
https://ev-charging.com/at/en/elektrotankstellen.

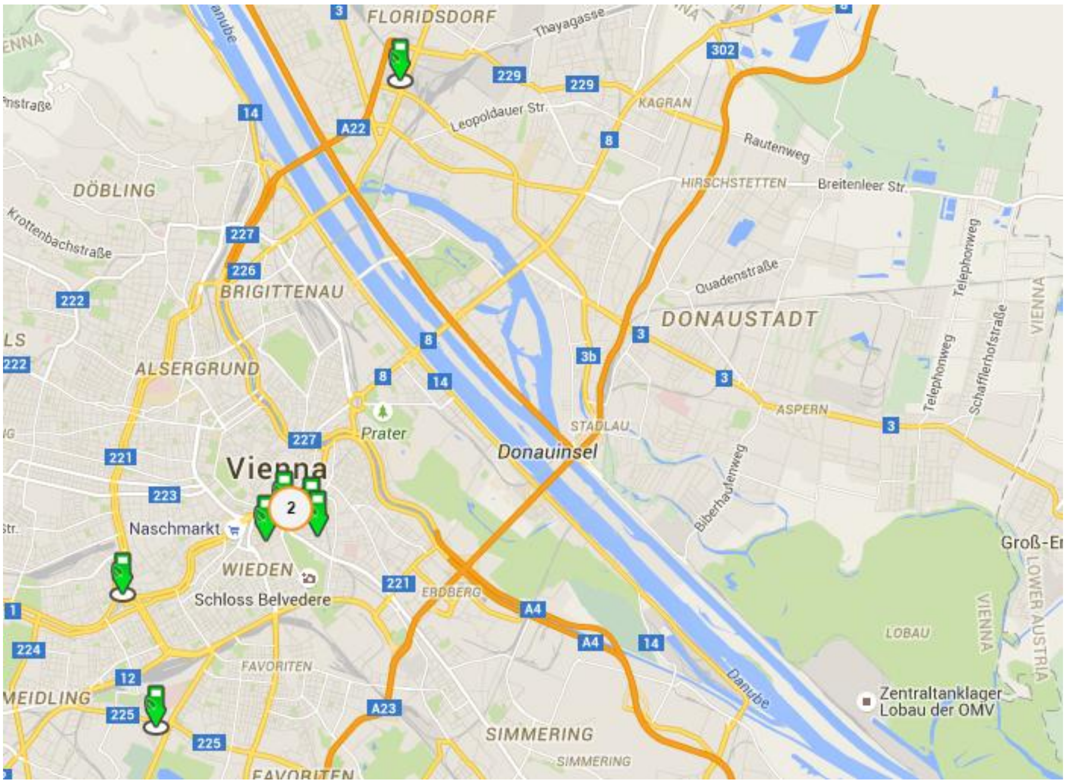

Figure 9: **CHAdeMO fast charging stations Vienna**[27]

To be able to operate the company and deliver the taxi services without significant change in drivers behavior the company should invest in a fast charging station, where the drivers will be able to charge their EV's.

According to the *Wien E-Taxi project*, which officially starts in summer, a fast charging infrastructure specially tuned to Vienna taxi companies will be built.[28] But since there is currently no such fast charging system we would have to include this investment in our calculations.

Three of the drivers work at night one is flexible (sometimes during the day, sometimes at night) and one at day time. After discussion with them regarding the charging schedule, we concluded that there will be no problem, as all start at

[27] KELAG-Kärntner Elektrizitäts-Aktiengesellschaft(2015): CHAdeMO charging stations in Vienna, *ev-charging.com*, Retrieved 28.07.15 from: https://ev-charging.com/at/en/elektrotankstellen.
[28] Hartmann, M. (2015): „Strom kommt in Fahrt", *Taxi Aktuell.*

different times and therefore the need of recharging the batteries will occur at different times. They will also be able to use the public fast charging stations.

From the information collected from all the drivers (See Addendum 5 to 10) for 10 days, we can determine the average mileage from all the drivers for each day and the average waiting time (Table 3). Knowing the average time taxi drivers spend at taxi stands waiting for the next customer and the average distance traveled per day we can determine whether this time is enough to recharge their batteries during the shift. This applies only if fast charging infrastructure at taxi stands exists. According to the information regarding the *Wien E-Taxi* project Nissan Leaf will have 100 km range in any weather and at any temperature.[29]

Table 3: Drivers average mileage and waiting time (own representation)

	driver1		driver2		driver3		driver4		driver5		average	
	mileage (km)	waiting time (min)	mileage (km)	waiting time (min)	mileage (km)	waiting time (min)	mileage (km)	waiting time (min)	mileage (km)	waiting time (min)	mileage (km)	waiting time (min)
day1	93	180	110	160	165	150	163	140	120	180	130,2	162
day2	122	140	106	180	116	180	155	150	126	170	125	164
day3	130	120	152	150	190	140	161	160	142	190	155	152
day4	150	130	208	120	208	120	216	140	143	180	185	138
day5	196	120	198	130	274	100	208	120	103	200	195,8	134
day6	86	160	116	160	225	130	127	140	100	200	130,8	158
day7	116	140	123	170	157	150	113	160	127	180	127,2	160
day8	120	140	144	140	163	140	129	160	140	160	139,2	148
day9	206	120	212	120	255	100	186	140	120	170	195,8	130
day10	162	120	201	110	204	110	179	120	116	190	172,4	130
										avrg.:	***155,64***	***147,6***

Taking into account the average mileage of about 155 kilometers, average time spent waiting for next customer about 2.5 hours and the 30 minutes needed for recharging the battery to 80% by fast charging we see that 2.5 hours is enough time to recharge the battery to 80% more than 4 times. Of course this could happen only if fast charging infrastructure at taxi stands exists.

[29] WKO (2015): Beförderungsgewerbe mit Personenkraftwagen, Fachgruppe, Wiener e-Taxi-Unternehmen gesucht, wko.at.
Retrieved 09.09.15 from:
https://www.wko.at/Content.Node/branchen/w/TransportVerkehr/BefoerderungPKW/Wiener-e-Taxi-Unternehmen-gesucht.html.

In the scenario where there is no fast charging infrastructure the taxi company will have to invest in their own fast charging station. This charging station will have two charging points. Again from the information provided by the taxi drivers (Addendum 5 to 10) we can see at what time each taxi driver reaches 100 kilometer mileage – assuming that at this time he should recharge his battery. Figure 10 represents the daytime at which each driver reaches 100 kilometer mileage. As shown on the graph for the 10 days considered, the maximum of the drivers who need to recharge at the same time is 2. As mentioned above, the company's fast charging station has 2 charging points which means they should be enough for the studied taxi company. Just in case when more than two electric taxis should be recharged at the same time they can use one of the five public charging locations in Vienna (Figure 9) or just wait 30 minutes. But as shown on the graph it will not happen often.

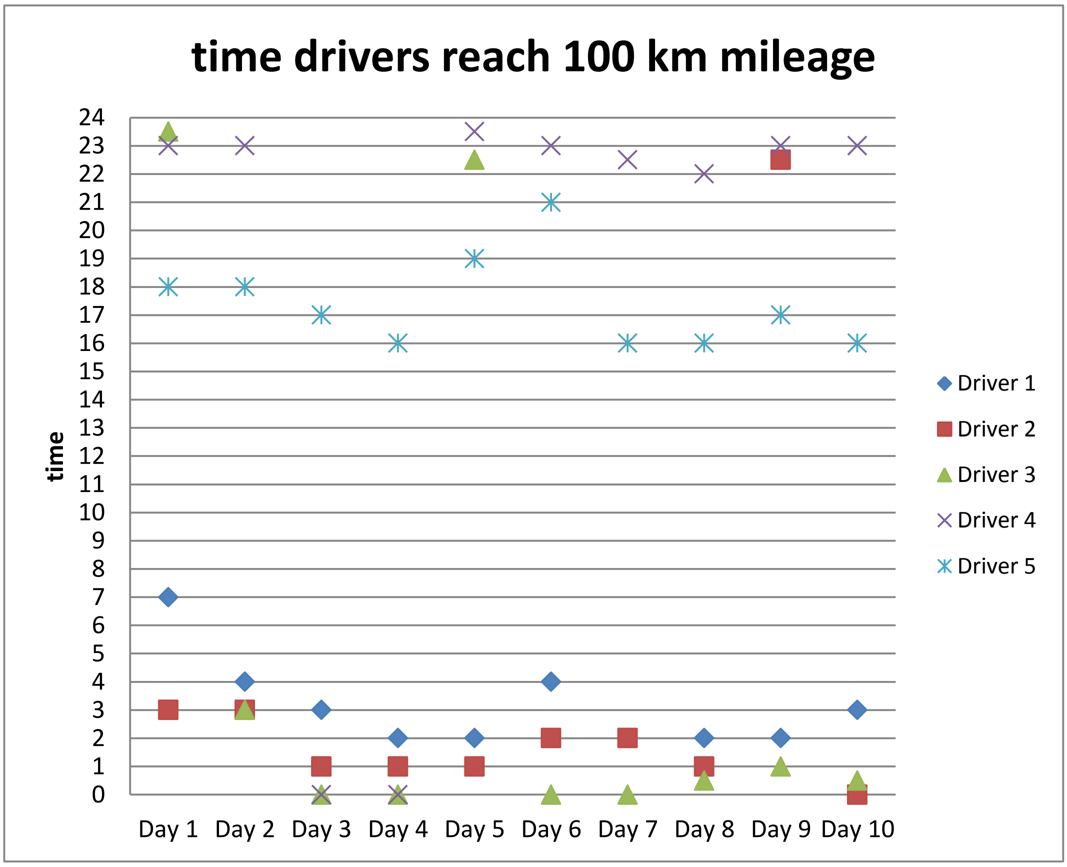

Figure 10: Day time at which drivers reach 100 km mileage (own representation)

5 ENVIRONMENTAL PERSPECTIVE

In order to estimate the environmental impact by switching to electric taxis for the small taxi company with 5 cars the whole lifecycle should be considered and compared to other technologies, like ICE and also hybrid. In transport sector the LCA is usually done by the well-to-wheel (WTW) analyses. This method includes the energy input and respectively the GHG for the fuel production and delivery (WTT) and the energy needed for the production and operation of the vehicles (TTW). In this work the WTW analysis will be used to determine the CO_2 emissions for the production of fuel and operation of the vehicle. After calculating the CO_2 emissions from EV's they will be compared to the emissions from ICE and Hybrid technologies and it will be estimated whether electric cars have a mitigating effect on the environment.

Considering the environmental impact by the BEV's, it is of great importance where the electricity comes from. When the electricity used for charging the batteries is generated from renewable energy sources then we should expect lower emissions than the ICE, but if it is generated from fossil fuels we cannot expect any positive effect on the environment.

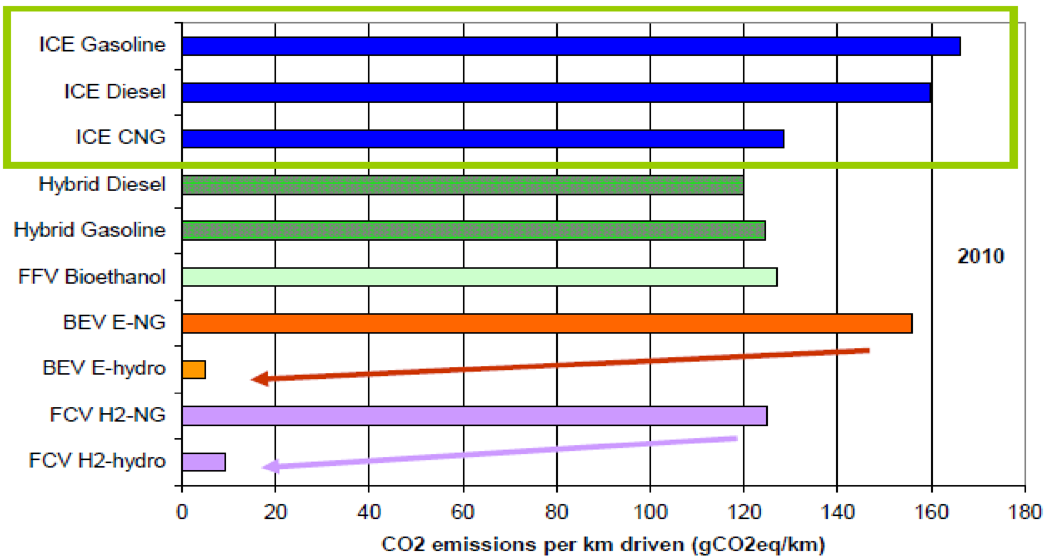

Figure 11: Comparison of specific CO_2 emissions of conventional vehicles[30]

As shown on Figure 11, the CO_2eq emissions per km by BEV significantly decrease from almost 160 g CO_2 eq/km to about 10 g CO_2 eq/km by using electricity from renewable energy sources (hydro) instead of electricity from natural gas sources.

5.1 Well-to-tank (WTT)

In order to achieve minimal impact on the environment, not only in local but also in global aspect, the installed fast charging station at the company should deliver electricity from renewable energy sources only. There are some companies in Vienna offering electricity generated from 100% hydro resources. Some of the drivers will also be able to recharge their batteries with electricity generated from renewable energy sources between the shifts. Figure 12 shows the *SMATRICS GmbH & Co KG* charging stations in Vienna using electricity exclusively from renewable energy sources.

[30] Ajanovic, A. (2013): Ecological assessment, Comparison of technical, economic, and ecological aspects, International Survey on Transport, MSc Program – Module 1, Renewable Energy in Central and eastern Europe, Lecture note: p. 72.

Figure 12: **Smatrics charging stations in Vienna**[31]

As it is difficult to predict how much of the electricity will be generated from renewable sources, for the calculations we will assume that half of it is generated from conventional sources and the other half from renewables. As hydro is the most common renewable energy source in Austria, CO_2eq per kWh produced energy from hydropower plants will be used for the calculation.

[31] SMATRICS GmbH & Co KG (2015): Charging stations in Vienna, *smatrics.com* Retrieved 29.07.15 from: http://smatrics.com/wo-wir-sind/.

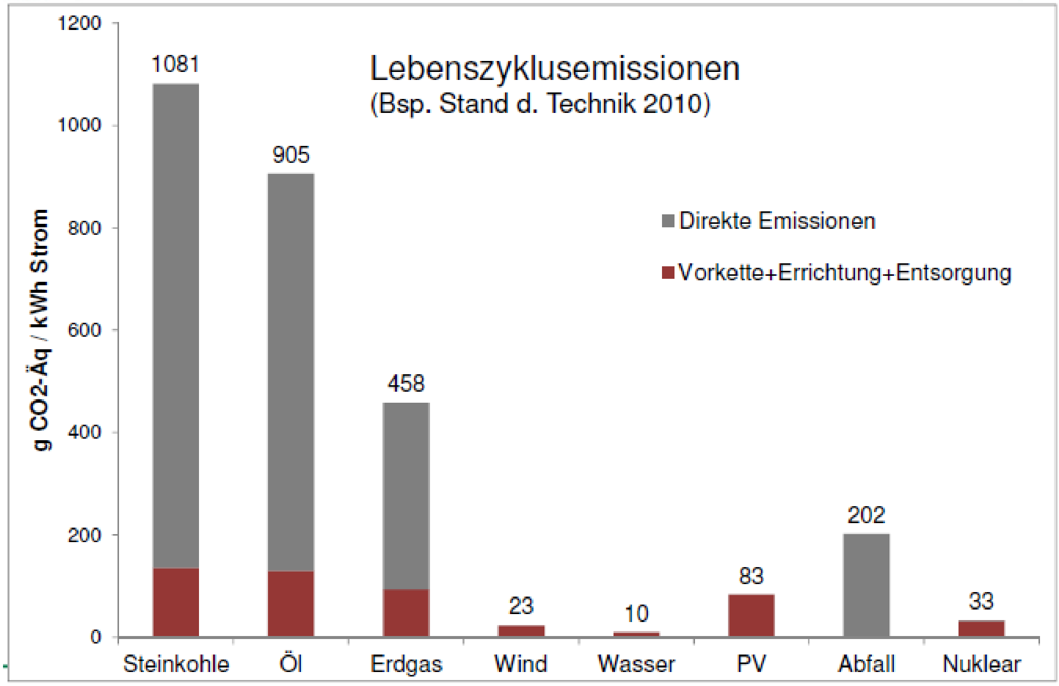

Figure 13: CO_2eq-emissions by electricity generation in Austria[32]

Figure 13 shows CO_2 emissions in Austria per kWh produced electricity from different power plants. Depending on the source these values for hydropower plants vary, but for our calculations the figure of 10 g CO_2 eq/kWh will be assumed. As long as different studies differ from each other, we have to see individual studies only as a rough guide.

Figure 14 below shows the CO_2 emissions in gram per kWh by electricity production for different European countries. For Austrian electricity mix this value is 157 gCO2eq/kWh. This low value is due to the high content of renewable energy sources in the Austrian electricity mix and in particular water power plants. According to Figure 14, this value of 129 gCO_2eq/kWh is much lower. In our calculations we will use the higher value, i.e. 157gCO2eq/kWh.

[32] Beermann, M., Canella, L., Jungmeier, G. (2012): „Treibhausgasemissionen der Stromerzeugung und Transportdienstleistung von E-Fahrzeugen in Österreich“, *JOANNEUM RESEARCH Forschungsgesellschaft.*

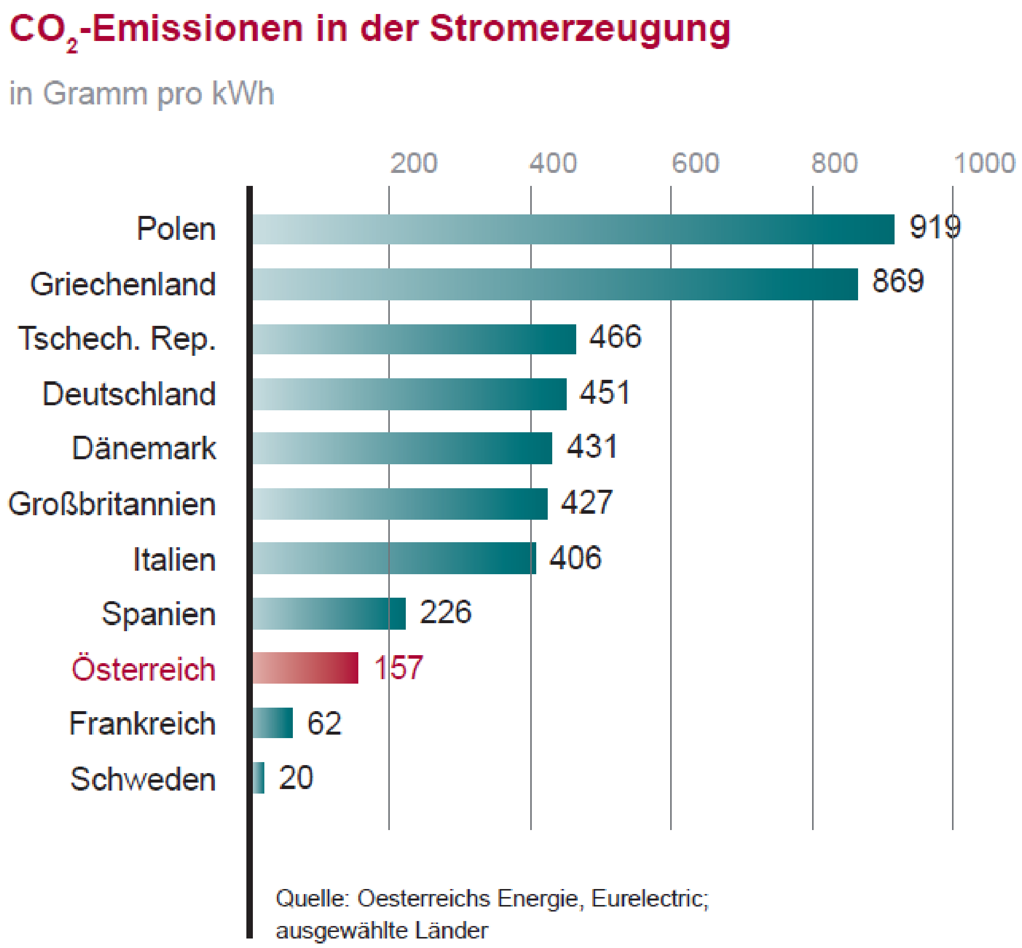

Figure 14: CO_2 emission comparison g/kWh by electricity production[33]

In 2012, the energy delivered to Austrian consumers on average has been a mix of 74.53% known renewable energy sources(green), 17.91% known fossil fuels(orange), as well as 0.31% other known energy sources (violet) and 7.25% electricity of unknown origin (grey) (ENTSO-E) (Fig.15). These are approximate values that resulted from the review of the electricity labeling in 2013.[29]

[33] Oesterreichs Energie (2013): „Strom: Der flexible Erzeugungsmix in Österreich“, Oesterreichs Energie, Daten & Fakten, Statistik und Marktforschung, Erzeugung, *oesterreichsenergie.at* Retrieved 29.07.15 from: http://oesterreichsenergie.at/daten-fakten/statistik/stromerzeugung.html.

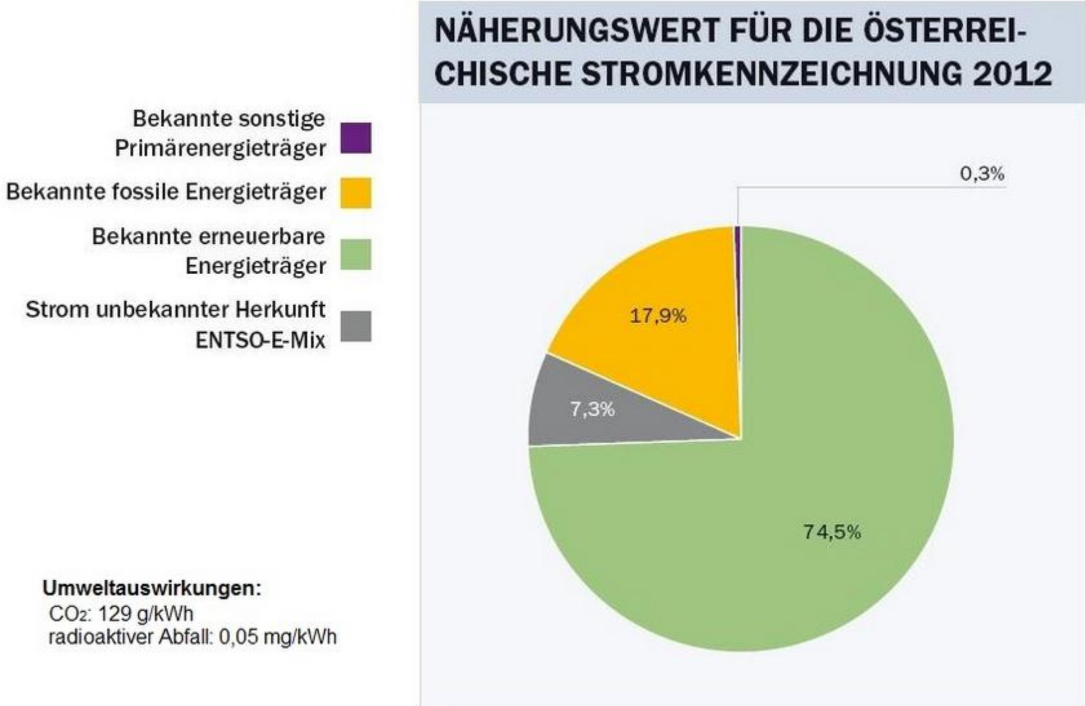

Figure 15: Approximation of the Austrian electricity labeling 2012[34]

5.2 Tank-to-wheel (TTW)

In order to calculate the electricity needed for the operation of the selected taxi company with 5 vehicles and the CO_2 emissions discharged for the production of this electricity, respectively, the kilometers driven by all the vehicles for one year and the consumption of the Nissan leaf should be determined.

According to the information derived from all the drivers regarding the kilometers driven for the period of one week, the average distance is 150 km per shift. After a discussion held with the owner of the company, the average shifts per taxi for one year turns to be about 200, which means 200 shifts multiplied by 150 km each equals to 30,000 km/taxi/year. For all the vehicles in the company this is calculated to 150,000 km/year. According to the *Nissan* official website, the consumption of Nissan leaf is 15 kWh/100 km.[35]

[34] E-control (2013): „Die österreichische Stromkennzeichnung für das Jahr 2012“, *e-control.at* Retrieved 30.07.15 from: http://www.e-control.at/industrie/oeko-energie/stromkennzeichnung.
[35] NISSAN CENTER EUROPE GMBH (2015): Nissan Leaf Entdecken, *nissan.at*, Retrieved 30.07.15 from: http://cq5.prod.nissan.eu/AT/de/vehicle/electric-vehicles/leaf/discover/life-with-ev.html.

The average power consumption of the Nissan Leaf is determined by the *ADAC EcoTest* at 19.9 kWh per 100 km (including charging losses).[31] According to *ADAC Autotest,* the city consumption of the electric Nissan is 17.6 kWh per 100 km, on the country road it is 18 kWh per 100 km, and on the highway 24.8 kWh per 100km.[31] ADAC EcoTest is "Well-to-Wheel" basis comparison based.[31] This means that not only the used driving power is determined, but also the energy needed to charge the vehicle battery.[31] The charging involves the battery losses through temperature control, so that more load energy is necessary than the nominal capacity of the battery.[36]

As most of the kilometers travelled in the taxi industry in Vienna are in the city area, the city consumption figures (17.6 kWh/100km) of Nissan Leaf will be used for the calculation purposes.

Table 4 shows the figures after calculating the CO_2 emissions per km from Nissan Leaf with the Austrian electricity mix and electricity from hydropower plants.

Table 4: Nissan Leaf gCO2eq per km (own table)

Austrian Electricity Mix[37]	Electricity from Hydropower plants[38]
27.6 gCO2eq/km	1.76 gCO2eq/km

As mentioned above, half of the electricity used for recharging the vehicle batteries in the taxi company will be generated from hydropower plants and the other half from the Austrian electricity mix, therefore the average value of 14.7 gCO2eq/km will be used.

To be able to truly identify the data, the CO_2 emissions per kilometer will be compared between a hybrid, a diesel car and a vehicle on natural gas. For the purposes of this comparison a Toyota Prius – Hybrid, a Ford Focus – Diesel and a

[36] Silvestro, D. (2014): Nissan Leaf Tekna, Auto Test, *Adac.de*, Retrieved 30.07.15 from: https://www.adac.de/_ext/itr/tests/Autotest/AT5077_Nissan_Leaf_tekna/Nissan_Leaf_tekna.pdf.

[37] Oesterreichs Energie (2013): “Strom: Der flexible Erzeugungsmix in Österreich“, Oesterreichs Energie, Daten & Fakten, Statistik und Marktforschung, Erzeugung, oesterreichsenergie.at, Retrieved 30.07.15 from: http://oesterreichsenergie.at/daten-fakten/statistik/stromerzeugung.html.

[38] Beermann, M., Canella, L., Jungmeier, G. (2012): “Treibhausgasemissionen der Stromerzeugung und Transportdienstleistung von E-Fahrzeugen in Österreich“, JOANNEUM RESEARCH Forschungsgesellschaft.

Mercedes B Class were chosen. All of them are of the same class as the Nissan Leaf.

The city consumption of Toyota Prius, according to the *ADAC Autotest,* is 2.6 liters per 100 km.[39] During the discussions held with colleagues driving Toyota Prius taxis, all of them shared that their fuel consumption varies between 5 and 6 liters per 100 km. For the calculation purposes, the figures from the ADAC Autotest will be adopted. One liter of petrol burns to 2.33 kg $CO_{2,}$ one liter of diesel burns to 2.64 kg CO_2 and one kilogram of natural gas burns to 2.79 kg CO_2.[40] The CO_2 emissions per km from Toyota Prius amount to 60.6 gCO2eq/km.

In this sense, Ford Focus 2.0 TDCI and Mercedes B Class on natural gas have a comparable city fuel consumption of 5.8 liters per 100 kilometer[41] and 5.7 kg/100 km[42], respectively; thus, the figures of 153.1 gCO2eq/km for Ford, and 159 gCO2eq/km for Mercedes are obtained. The calculated values refer to city fuel consumption and therefore, they differ from the official figures.

Figure 17 represents the CO_2 emissions per kilometer for Nissan Leaf, Toyota Prius – Hybrid, Ford Focus – Diesel and Mercedes B Class NG, without taking into account the CO_2 emissions discharged during car manufacture and also for the extraction and delivery of fuel. With a value of 14.7 gCO2eq/km, the Nissan Leaf could considerably contribute to decreasing the GHG. Even compared to Toyota Prius – Hybrid, it has 4 times less CO_2 emissions per kilometer.

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[39] Poloczek, M. (2012): Toyota Prius 1.8 Hybrid, Auto Test, *Adac.de,*
Retrieved 30.07.15 from:
https://www.adac.de/_ext/itr/tests/Autotest/AT4790_Toyota_Prius_1_8_Hybrid/Toyota_Prius_1_8_Hybrid.pdf.

[40] Fisch und Fischl GmbH (2015): Berechnung des CO2-Ausstoßes, *spritmonitor.de*,
Retrieved 30.07.15 from:
http://www.spritmonitor.de/de/berechnung_co2_ausstoss.html.

[41] Ruhdorfer, M. (2011): Ford Focus 2.0 TDCi Titanium (DPF), Auto Test, *Adac.de,*
Retrieved 31.07.15 from:
https://www.adac.de/_ext/itr/tests/Autotest/AT4557_Ford_Focus_2_0_TDCi_Titanium_DPF/Ford_Focus_2_0_TDCi_Titanium_DPF.pdf.

[42] Brand, M. (2014): Mercedes B 200 Natural Gas Drive, Auto Test, *Adac.de,*
Retrieved 31.07.15 from:
https://www.adac.de/_ext/itr/tests/Autotest/AT5128_Mercedes_B_200_Natural_Gas_Drive_Erdgasbetrieb/Mercedes_B_200_Natural_Gas_Drive_Erdgasbetrieb.pdf.

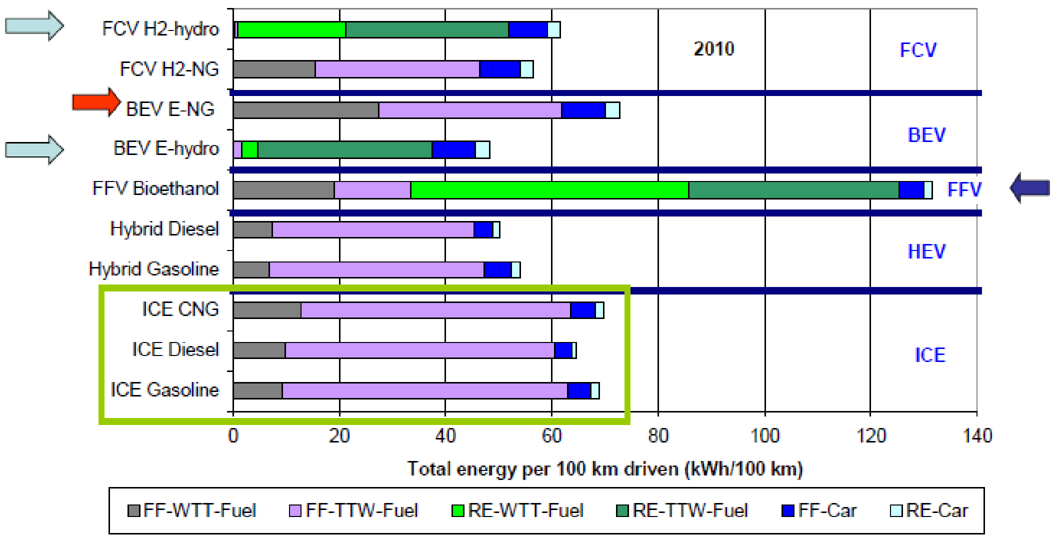

Figure 16: Total energy per 100 km driven (kWh/100 km)[43]

Figure 16 illustrates the total energy input for 100 driven kilometers for different technologies. From Figure 16 we can conclude that the energy input for the production of cars for all the technologies is almost the same, with small advantage for ICE and Hybrid technologies, and it represents a small share from the total energy consumption. We will, therefore, ignore it when comparing different technologies.

The greatest amount of energy is needed for the operation of the vehicles. Therefore, major CO_2 pollution of the environment occurs during the exploitation of the vehicle.

There is also a big difference within the BEV technology regarding the origin of the energy. The WTT energy input for BEV using renewable energy sources is much less than for those using fossil fuels. Therefore, the main factor determining GHG emissions by electric cars is the source of energy used for the production of electricity.

[43] Ajanovic, A. (2013): Ecological assessment, Comparison of technical, economic, and ecological aspects, International Survey on Transport, MSc Program – Module 1, Renewable Energy in Central and eastern Europe, Lecture note: p. 70.

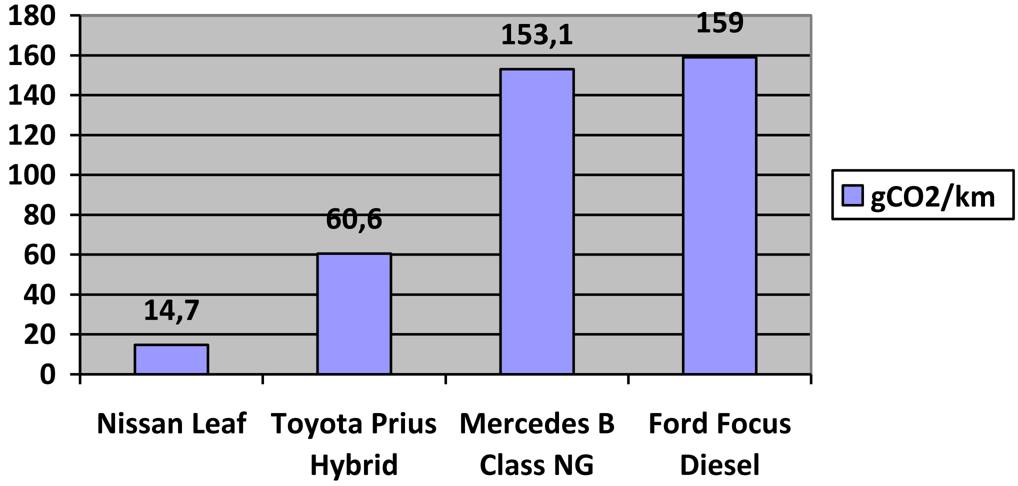

Figure 17: Comparison of CO_2 emissions per km (own representation)

If calculating the carbon footprint from all the 5 Nissan Leaf taxis in the company for one year (30,000 km each) and comparing them with the other technologies, the following figure is obtained:

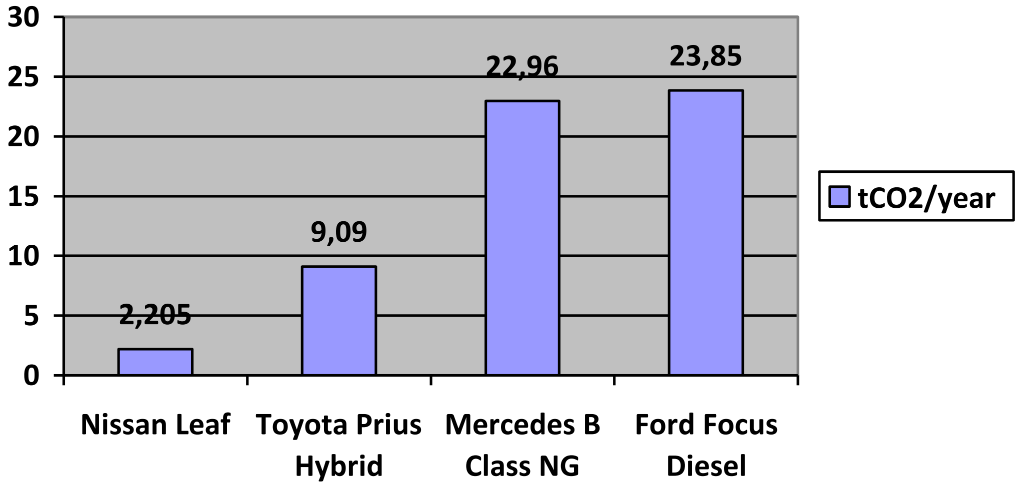

Figure 18: Comparison of CO_2 emissions per year (own representation)

By switching to Nissan Leaf electric taxis in our company with 5 cars and an average mileage for all the vehicles in the company of 150,000 km per year, the CO_2 savings will be: 21.6 tCO_2 for one year compared to Mercedes B Class running on natural gas; 20.7 tCO_2 compared to Ford Focus – Diesel; and 6.9 tCO_2 compared to Toyota Prius – Hybrid.

6 ECONOMIC PERSPECTIVE

The economic appraisal of switching to electric vehicles within the taxi company will be performed through a cost analysis of the existing and researched data. The cost per kilometer will be calculated by using the formula below and compared to the other technologies – ICE and Hybrid. Also the annuity of the investment costs for Nissan Leaf and the other technologies will be calculated in order to estimate the possibility of switching to electric vehicles.

$$C_{km} = \frac{IC \cdot \alpha}{skm} + P_f \cdot FI + \frac{C_{O\&M}}{skm} \qquad \text{[€/100 km driven]}$$

For the purposes of comparison, the technologies Toyota Prius – Hybrid, Ford Focus – Diesel and Mercedes B Class – Natural Gas were chosen. The period of investment which is selected is five years which is typical for the taxi industry.

6.1 Annual costs

Since electric vehicles are quite new on the market, it is difficult to determine the resale value. The German website *mobile.de* will be used as a starting point in order to determine the resale value. To be able to define the resale price as accurate as possible the mileage should be also taken into account. As mentioned above, the average distance driven per taxi per year is 30,000 km, therefore, the resale value should be compared between vehicles with more than 150,000 kilometers mileage. On *mobile.de,* the prices of Nissan Leaf (year of manufacture 2011) vary from 15,000 to 21,000 Euro, but all the vehicles sold have less than 100,000 kilometer mileage. For our calculations a 10,000 Euro resale value for the Nissan Leaf will be set as after 5 years exploitation they will have about 150,000 kilometer mileage. In this sense, 5,000 Euro for Toyota Prius, 3,000 Euro for Ford Focus and 5,000 Euro for Mercedes B Class were selected as resale values. These values are lower than the mean values published on the website since the cars are used as taxis and therefore the depreciation was added.

A crucial point by switching to electric vehicles, and especially electric taxis, is funding. As the initial investment in electric vehicles is higher than the investment in conventional transition to electric vehicles, this would be impossible without government funding programs. With the new BMVIT (Federal Ministry of Transport Innovation and Technology) funding program *Wien E-Taxi*, 8,000 Euros are granted for the purchase of Nissan Leaf or Nissan e-NV200 Evalia.[44]

One of the advantages of electric vehicles is the low operation and maintenance costs. Besides the standard service items, such as oil, air and oil filter, spark plugs and belts, there are a lot of other items that require service at certain mileage of a conventional car. An electric vehicle does not require any fuel injectors, pumps, fuel filter, radiator, thermostat, water pump, alternator, catalyst, clutch, power steering fluid, etc. Therefore, there isn't much to maintain in an electric car. According to some studies the maintenance of an electric car costs about one third of the maintenance of a conventional car. For our calculations we will assume 1,000 Euros operation and maintenance costs for Hybrid, Natural Gas and Conventional vehicles, and 400 Euros for the electric vehicle.

For the consumption, the figures from the *ADAC Autotest* mentioned in the Environmental Perspective chapter will be adopted. Since most of the kilometers travelled in the taxi industry are in the city, the city fuel consumption will be taken into account.

[44] BMVIT (2015): Presse, Projekt der Wiener Stadtwerke bringt bis 2018 hunderte zusätzliche eTaxis auf Wiens Straßen, *bmvit.gv.at*, Retrieved 25.08.15 from: https://www.bmvit.gv.at/presse/aktuell/nvm/2015/0819OTS0002.html.

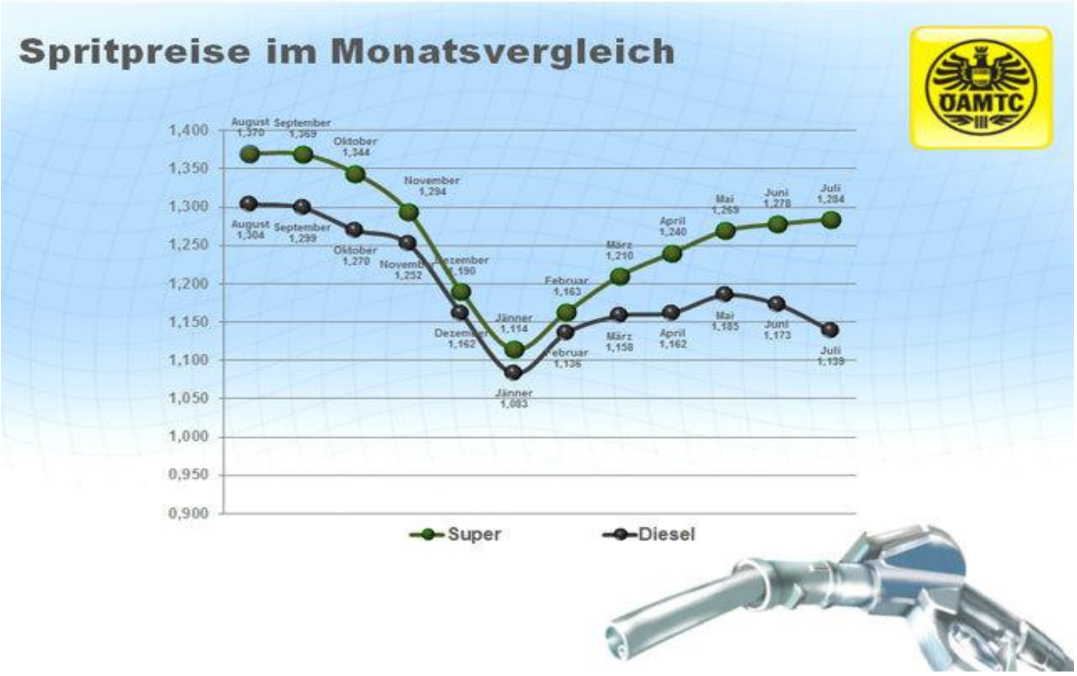

Figure 19: Gasoline and Diesel price development August 2014 – July 2015[45]

For the fuel price, the *ÖMTC* website will be used as a source. Figure 19 above shows the fluctuation of diesel and gasoline prices for the last year. The prices vary from 1 to 1.4 Euro per liter. For the calculations, an average price of 1.20 Euro for diesel and 1.30 Euro for gasoline will be adopted. For natural gas, the actual *ÖAMTC* average day price of approximately 1.1 Euro per kilogram will be used. For the electricity used for recharging generated from renewable energy sources, a price of 0.2 Euro per kilowatt hour will be suggested.

In chapter 3 it was concluded that the existing fast charging infrastructure in Vienna will not be enough for the operation of all 5 electric vehicles in the company, therefore, investing in fast charging station will be necessary. According to the calculations made in Project ZENEM, the investment costs for a loading station (connected load 100 kW, max. 50 kW per loading point) will vary from approximately 56,500 Euro to 126,500 Euro.[46] For the purpose of our calculations, we will assume investment costs of 80,000 Euro. The calculations will be made for both cases, with

[45] ÖAMTC (2015): Entwicklung der Kraftstoffpreise, Verkehr, Tanken, *oeamtc.at*, Retrieved 26.08.15 from: http://www.oeamtc.at/portal/tanken+2500++1004854.
[46] Gawlik, W., Litzlbauer, M., Schuster, A., et al. (2013): ZENEM - Zukünftige Energienetze mit Elektromobilität, FFG-Forschungsprojekt, NE2020, 4. AS, Projektnummer: 829953, Endbericht, p.47, Wien 2013.

and without investing in fast charging stations. Since the project *E-taxi* includes the construction of 10 new charging points, the necessity of investing in a private charging station may be unnecessary.

Table 5: Adopted costs for different vehicle technologies

	Nissan Leaf	Toyota Prius	Ford Focus	Mercedes B Class NG
Investment Horizon	5 years			
Discount rate	5%			
Investment cost (€)	€29,290[47]	€28,140[48]	€24,000[49]	€26,269[50]
Resale value (€)	€10,000	€5,000	€3,000	€5,000
Funding (€)	€8,000[51]	€500[52]	--------	€500[45]
O&M (€/y)	€400	€1,000	€1000	€1000
Consumption (l/100 km; kWh/100 km; kg/100)	17.6 kWh/100km	2.6 l/100 km	5.8 l/100 km	5.7 kg/100 km
Fuel, Electricity Price (€/L; (€/kWh; €/kg)	€0.2	€1.3	€1.2	€1.1
Fast charging station	€80,000			

47 Autoreview (2015): Elektroautos: Übersicht aller Testberichte, technischen Daten & Preise, autoreview.at, Retrieved 27.07.15 from: http://autorevue.at/autowelt/alle-elektroautos-preise-testberichte-daten.
48 Toyota Frey Austria GmbH (2015): Prius, *toyota.at*, Retrieved 24.08.15 from: https://www.toyota.at/new-cars/prius/index.json.
49 Ford Motor Company(Austria) GmbH (2015): Kataloge & Preislisten, Ford Focus, *ford.at*, Retrieved 24.08.15 from: http://www.ford.at/Pkw-Modelle/KatalogePreislistenPKW.
50 Daimler AG (2015): Neufahrzeuge, Alternative Antriebe, Natural Gas, *mercedes-benz.de* Retrieved 26.08.15 from: http://www.mercedes-benz.de/content/germany/mpc/mpc_germany_website/de/home_mpc/passengercars/home/new_cars/model_overview_alternative_drive_systems.flash.html#_int_passengercars:home:core-navi:model_overview_alternativ.
51 Hartmann, M. (2015): "Strom kommt in Fahrt", *Taxi Aktuell*, CC Taxi center GmbH.
52 Kommunalkredit Public Consulting GmbH (2015): Umweltförderung, Verkehr und Mobilität, Förderungsoffensive - Fahrzeuge mit alternativem Antrieb und Elektromobilität im öffentlichen Interesse, *umweltfoerderung.at* Retrieved 25.08.15 from: http://umweltfoerderung.at/uploads/ka_mobil_infoblatt_fahrzeuge_im_oeffentlichen_interesse.pdf.

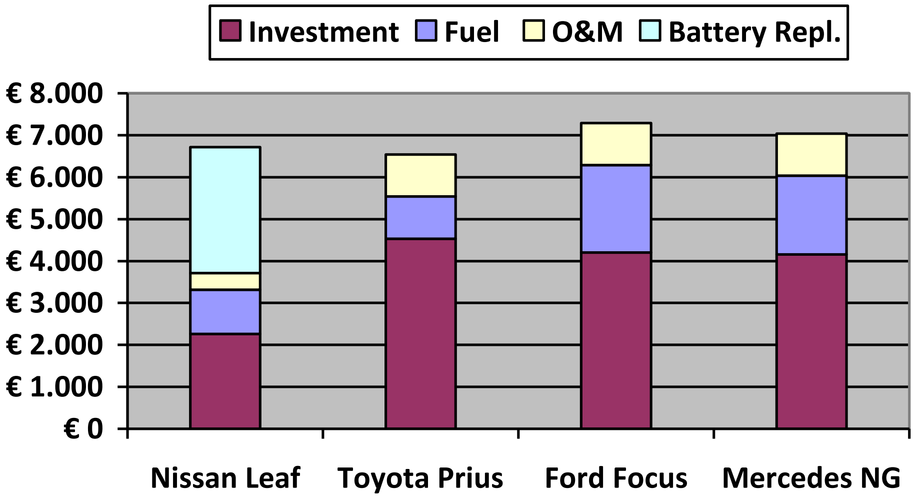

Figure 20: Annual costs for different technologies (own representation)

Figure 20 represents the annual costs for the different vehicle technologies considering investment costs, funding, O&M, fuel costs for the 30,000 km travelled per year, resale value and battery replacement costs by Nissan Leaf. If the battery lasts throughout the whole 5 year period of operation Nissan stands with minimum annual costs, about €3,714 per year. This is because of the high subsidy from the *E-Taxi* project (€8,000) and the high resale value assumed. For the battery replacement a cost of €15,000 was suggested. Even with the battery replacement costs (€6,714) Nissan is aligned with Toyota Prius in terms of annual costs. Ford Focus has the highest annual cost (approx. €7,288) followed by Mercedes B Class NG (€7,034). Nissan Leaf seems quite suitable for the taxi industry from an economical point of view if an appropriate fast charging infrastructure already exists. According to the preliminary information about *E-Taxi* project, the taxis involved will charge their batteries at the 10 newly built *Wien Energie* fast charging stations for free in the first year of operation.[53]

Figure 21 shows the annual costs considering the fast charging station investment. The total suggested investment of 80,000 Euro is divided into the number of cars in the company (5 cars) and distributed by years. In this case the annual cost is about

[53] BMVIT (2015): Presse, Projekt der Wiener Stadtwerke bringt bis 2018 hunderte zusätzliche eTaxis auf Wiens Straßen, bmvit.gv.at, Retrieved 27.08.15 from: https://www.bmvit.gv.at/presse/aktuell/nvm/2015/0819OTS0002.html.

9,914 Euro, including battery replacement. If battery replacement does not occur, Nissan Leaf is still in a good position compared to Toyota Prius – Hybrid.

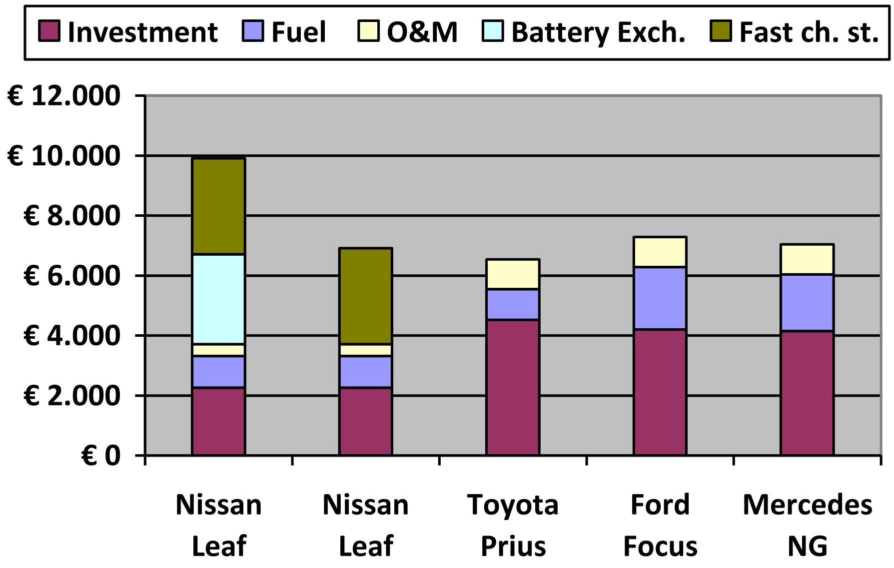

Figure 21: Annual costs for different technologies including fast charging station cost (own representation)

The calculations in Figure 20 and Figure 21 are just rough calculations without considering the discount rate of 5%. The next chart (Figure 22) represents the annuity of the investment taking into account the investment horizon of 5 years and the 5% discount rate. The data for the annuity calculation was taken from Table 4. Detailed calculations are presented in Addendum 1 to 5.

Nissan also offers battery rent for its Nissan Leaf model. As Nissan Leaf has been on the market for four years only and does not have enough experience with the batteries, we will also calculate the case in which batteries are rented. According to the official website *Nissan.at,* when a contract for more than 36 months is negotiated the monthly rent amounts to 122 Euros (Table 6). This price includes 25,000 kilometers per year, each additional kilometer will be charged at 0.05 Euro cents. As already assumed, the vehicles in our company drive 30,000 km per year each, which means that the remaining 5,000 kilometers will be charged at 0.05 Euro cents. The total annual cost for battery rental amounts to 1,714 Euros.

Table 6: Battery rent price Nissan Leaf[54]

	Kilometer/Jahr				
Vertragslaufzeit	bis zu 12.500 km	15.000 km	17.500 km	20.000 km	25.000 km
12 Monate	99 €	106 €	114 €	122 €	142 €
24 Monate	89 €	96 €	104 €	112 €	132 €
ab 36 Monate	79 €	86 €	94 €	102 €	122 €

NISSAN LEAF Batterie-Miete inklusive Versicherung
Jeder zusätzlich gefahrene Kilometer : 0,05 €
Minimale Kilometer pro Jahr : 12.500 km

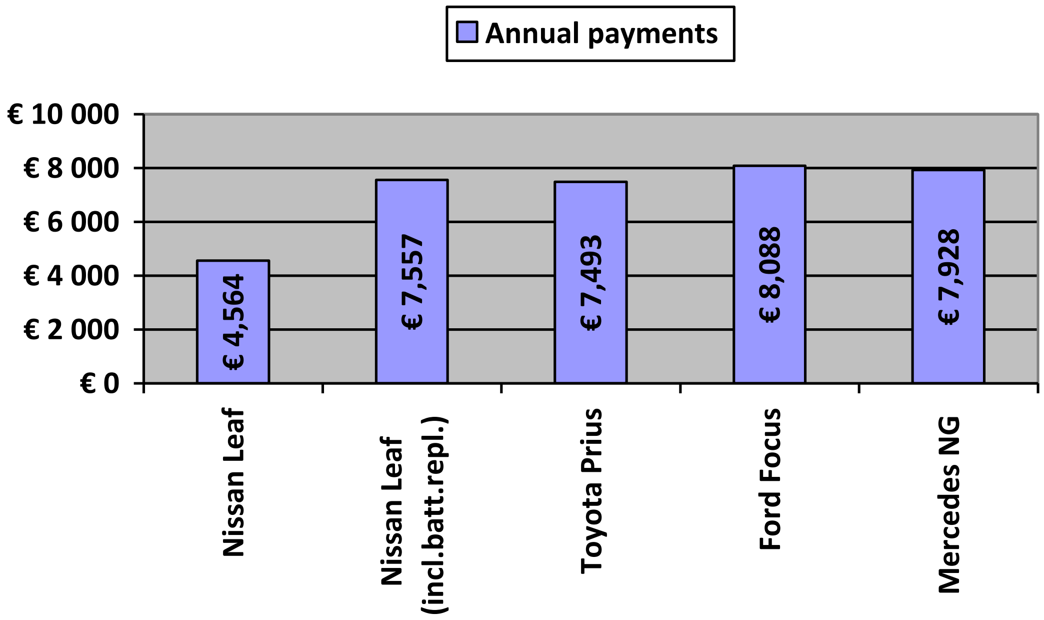

Figure 22: Annuity of investment for the different technologies (own representation)

The next chart (Figure 23) compares the annual costs for Nissan Leaf with battery purchase and battery leasing. With the option of battery purchase, a battery replacement in the third year of operation is suggested. The cost for the replacement is 15,000 Euros. The resale value in the case of battery rental is assumed to be 6,000 Euros after the fifth year of operation. The purchase price for Nissan Leaf without battery is 23,390 Euros (see Table 2).

[54] NISSAN CENTER EUROPE GMBH (2015): Angebote für den Nissan Leaf, Batteriemiete, *nissan.at*, Retrieved 28.08.15 from: http://www.nissan.at/AT/de/vehicle/electric-vehicles/leaf/prices-and-equipment/how-to-buy-my-leaf.html.

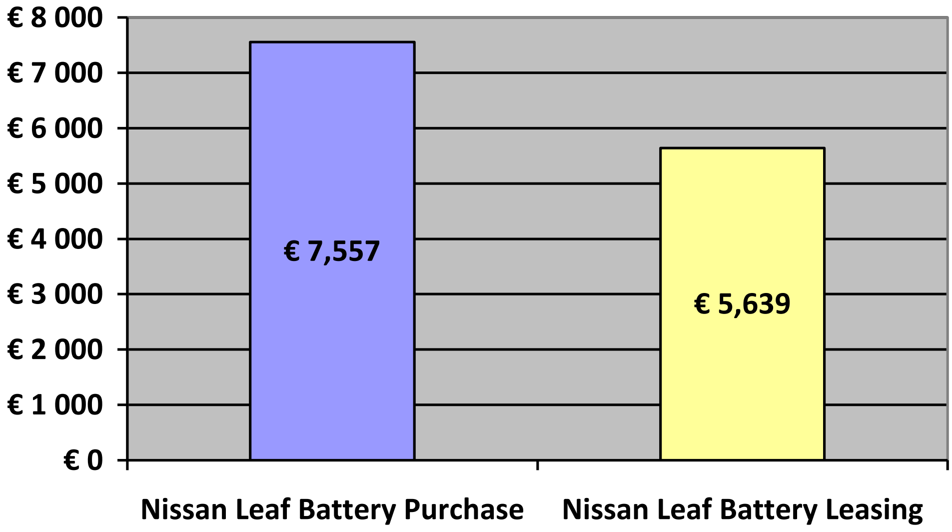

Figure 23: Annual costs by Nissan Leaf with battery purchase and battery leasing (own representation)

From the Figure 23 above we can conclude that, with the suggested figures, investing in a battery is not really necessary. If the price of the battery decreases to 10,000 Euros the annual cost will be about 6,559 Euros. As there is no information about the battery replacement cost on the Nissan official website, the battery leasing option seems to be more appropriate for the studied company.

In the Background Information chapter, two different operation models were mentioned. In the first model, the driver rents the car on a weekly basis and pays rental for it. In this case the fuel is at the driver's expense. The second model is renting a car and paying a percentage of the turnover to the company; in this model the fuel is paid by the company. All the annual cost calculations so far were made for the second operation model where fuel costs are borne by the company. If we want to calculate the annual investment costs for the first operation model we should not include the fuel costs. Figure 24 shows the annual costs for the different technologies without considering the fuel costs. The battery leasing option was chosen for Nissan Leaf. In this chart the initial investment, O&M costs, resale value and the 5% discount rate were taken into account for the calculations.

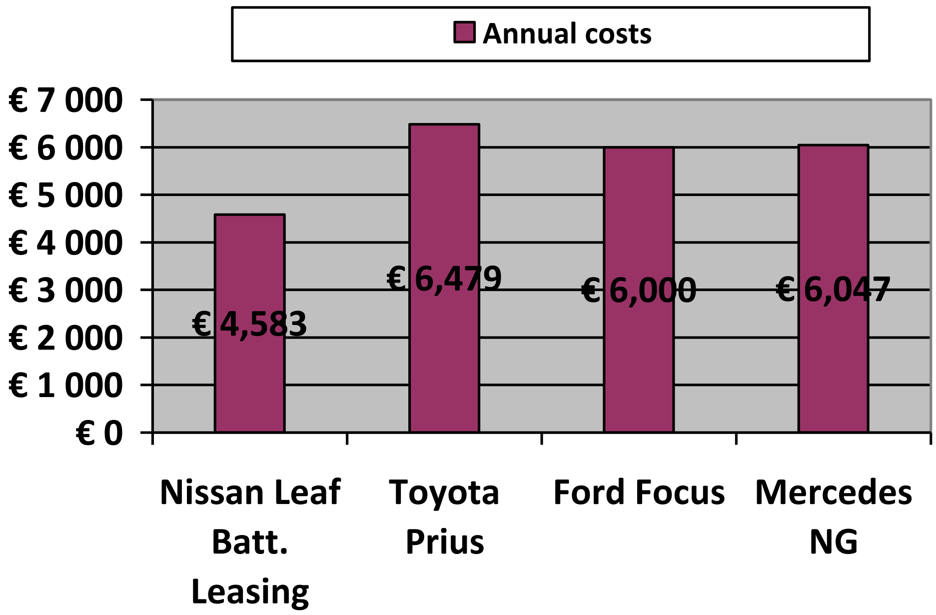

Figure 24: Annual investment costs without considering fuel costs (own representation)

When fuel costs are not considered, the annual costs by the different technologies do not differ much from one another. In this case Nissan Leaf is still a leader with the lowest annual costs.

Calculating the costs per kilometer with the formula mentioned in the beginning of this Chapter, the following results were obtained:

Nissan Leaf - 0.212 €/km

Toyota Prius - 0.280 €/km

Ford Focus - 0.288 €/km

Mercedes B Class - 0.294 €/km

Thanks to the high subsidy for Nissan Leaf, it has the lowest cost per kilometer. For the other three vehicles considered, the kilometer costs do not differ much from one another.

6.2 Sensitivity analyses

In order to observe the development of electric vehicles, a sensitive analysis of some possible scenarios will be performed. Government funding, interest rates, etc. would have an impact on the invasion of electric cars on the market depending on the price development of diesel and petrol, batteries, and in particular electric vehicles. With this sensitive analysis we will try to understand how these changes would affect the future development of electric cars. For example, if the price of electric vehicles falls down in the future and there are no more subsidies from the state, would it be still economically viable to invest in electric vehicles. There is a countless number of scenarios that could be considered and in our case we will focus only on the most important ones for the investigated taxi company.

For the second operation model, where the fuel costs are paid by the company, n would be appropriate to analyze the change in the price per kilometer taking into account the corresponding changes in diesel and petrol price. With the help of this analysis we will understand how some future changes in the price of fuel will reflect on switching to electric vehicles in the taxi industry. As diesel and hybrid technologies are most commonly used in the taxi industry, they will be used for the comparison with the electric vehicle.

As already calculated with the formula mentioned above, the price per kilometer, in terms of current electricity and petrol prices, is 0.212 €/km for Nissan Leaf and 0.280 €/km for Toyota Prius, respectively. Figure 25 below shows the sensitivity to petrol price for Toyota Prius. The range in which the price of gasoline changes is €1 to €2.30. Even with the price of gasoline of 1 €/L, the kilometer price for Toyota Prius (0.272 €/km) is much higher compared to Nissan Leaf (0.212 €/km). This, of course, is due to the subsidy of €8,000 for Nissan Leaf considered by the calculation. The increase in the price of gasoline to 2.3 €/L rises the price per kilometer for Toyota Prius to 0.306 €/km.

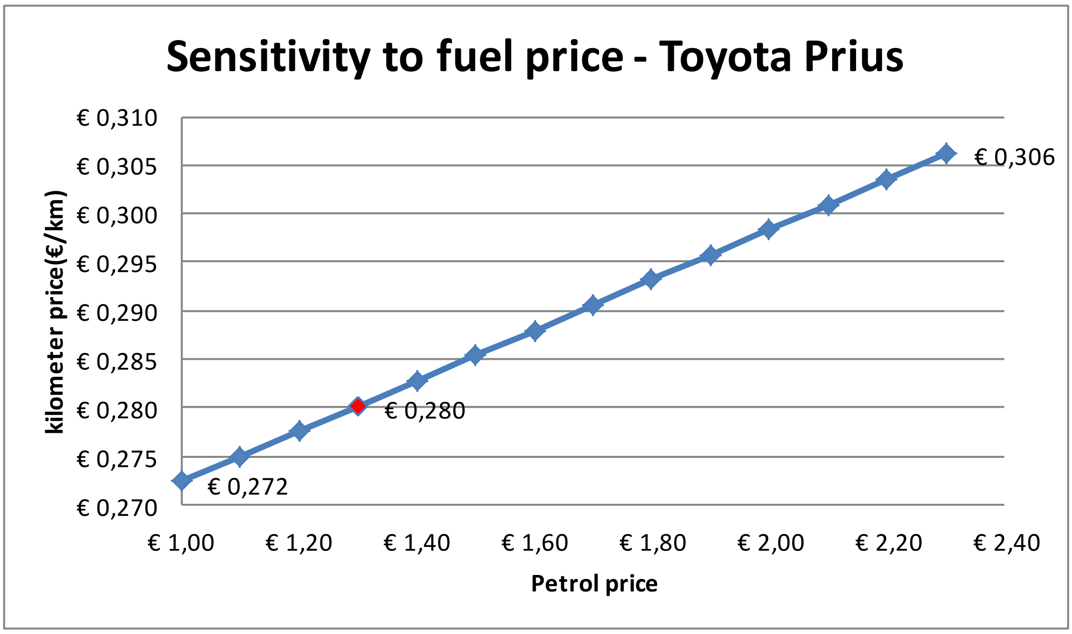

Figure 25: Sensitivity analysis to petrol price for Toyota Prius (own representation)

Figure 26 represents the sensitivity analysis for Ford Focus – Diesel. The kilometer costs for Ford Focus with the current diesel price of 1.2 €/L was calculated to 0.288 €/km. When calculated again with the lowest diesel price assumed (0.9 €/L), the kilometer price for Ford Focus is 0.271 €/km, i.e. higher compared to Nissan Leaf.

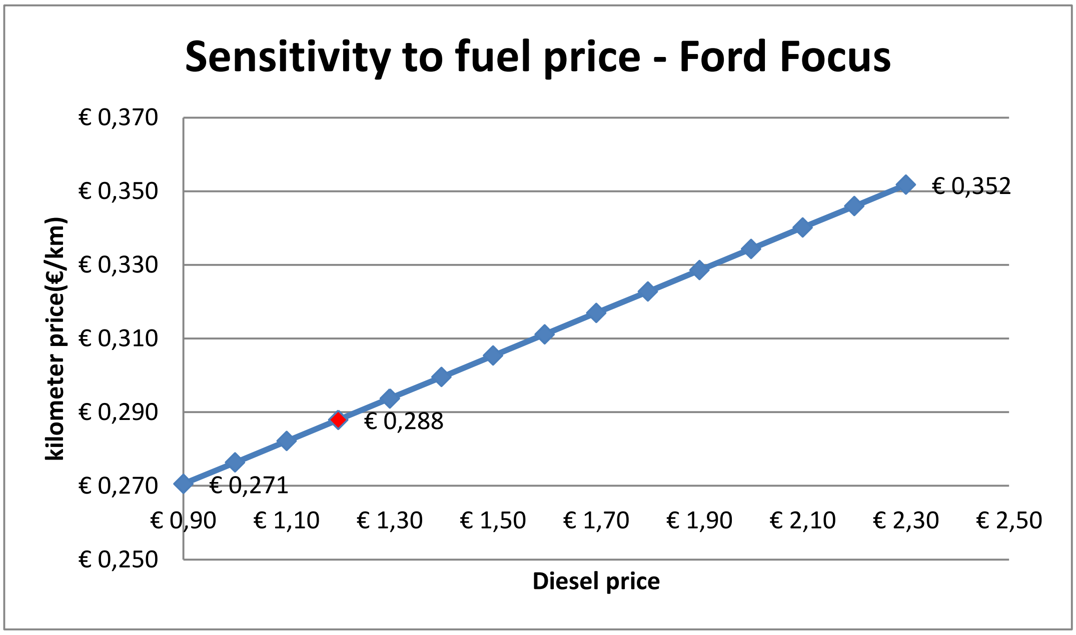

Figure 26: Sensitivity analysis to diesel price for Ford Focus (own representation)

Both sensitive analyses of the price of diesel and gasoline showed that even the drop in price to €1 for gasoline and €0.9 for diesel does not change the advantage of Nisan Leaf regarding price per kilometer.

The following sensitive analysis (Figure 27) represents the change in the price per kilometer in case the price of the electric car changes. In this case 7 different scenarios are included:

- Investment Nissan Leaf – €21,290 (current price including 8,000 € subsidy)
- Investment Nissan Leaf – €29,290 (current price; no subsidy is considered)
- Investment Nissan Leaf – €25,000
- Investment Nissan Leaf – €35,000
- Investment Nissan Leaf – €40,000
- Investment Nissan Leaf – €45,000
- Investment Nissan Leaf – €50,000

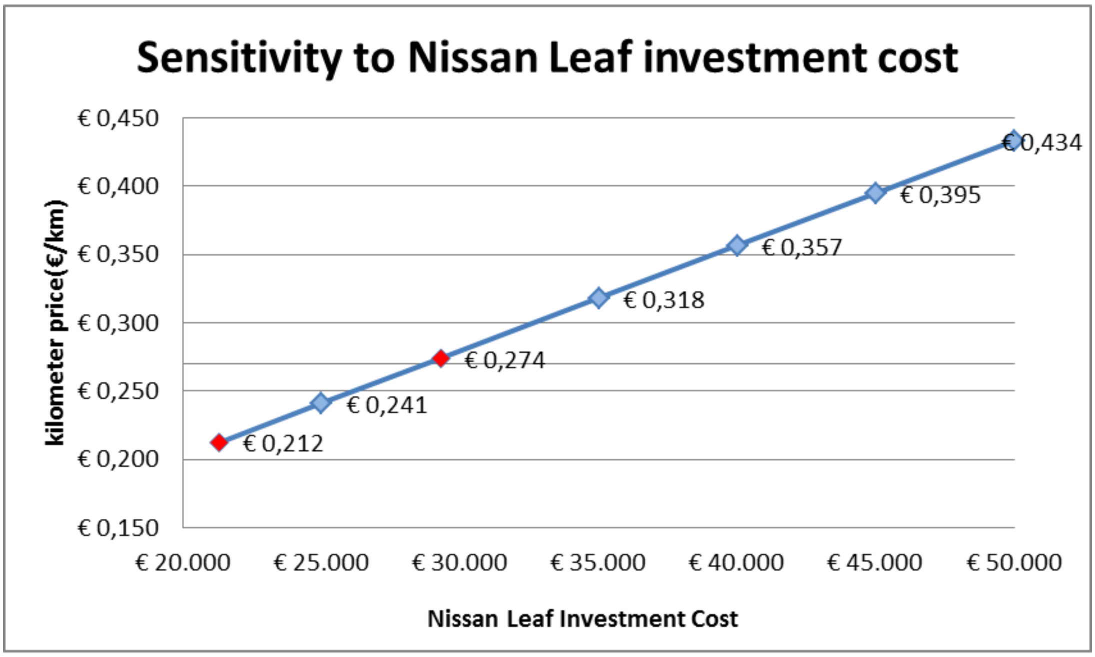

Figure 27: Sensitivity analysis to Nissan Leaf investment cost (own representation)

Two of the scenarios (red color) represent the current situation. First one includes a subsidy of €21,290 as an investment and the second one is without a subsidy of €29,290 as an investment. Even without a subsidy, the Nissan Leafs price per kilometer (0.274 €/km) is comparable to Ford Focus (0,288 €/km) and Toyota Prius (0.280 €/km). If the investment cost increases or other vehicles with higher investment costs are considered, then the situation will change. For example, if the investment amounts to €35,000, the kilometer cost will be 0.318 €/km which is already higher than the one considered Ford and Toyota, even at prices of diesel and petrol approaching 2 Euros.

So far we have examined cases in which the price of diesel and petrol changes. Figure 28 below represents the kilometer cost for Nissan Leaf by different electricity prices. The price range adopted was from 0.15 to 0.4 €/kWh. The price considered for the most of the calculations, 0.2 €/kWh, is shown in red color. In Figure 28 the Nissan Leaf price used for the calculation is €29,290 without considering the subsidy of 8,000 Euros. As shown on the diagram, increasing the electricity price to 0.25 Euro per kilowatt hour results in a kilometer price of 0.283 €/km for Nissan Leaf. In this case the price per kilometer falls exactly between Ford Focus with 0.288 €/km and Toyota Prius with 0.280 €/km, which means that it is still profitable to invest in an electric vehicle technology. The price increase to 30 and more Euro cents per kilowatt hour makes the investment unprofitable compared to ICE. All arguments provided do not include a subsidy, considering the subsidy investment is economically viable even at the price of 40 Euro cents per kilowatt hour.

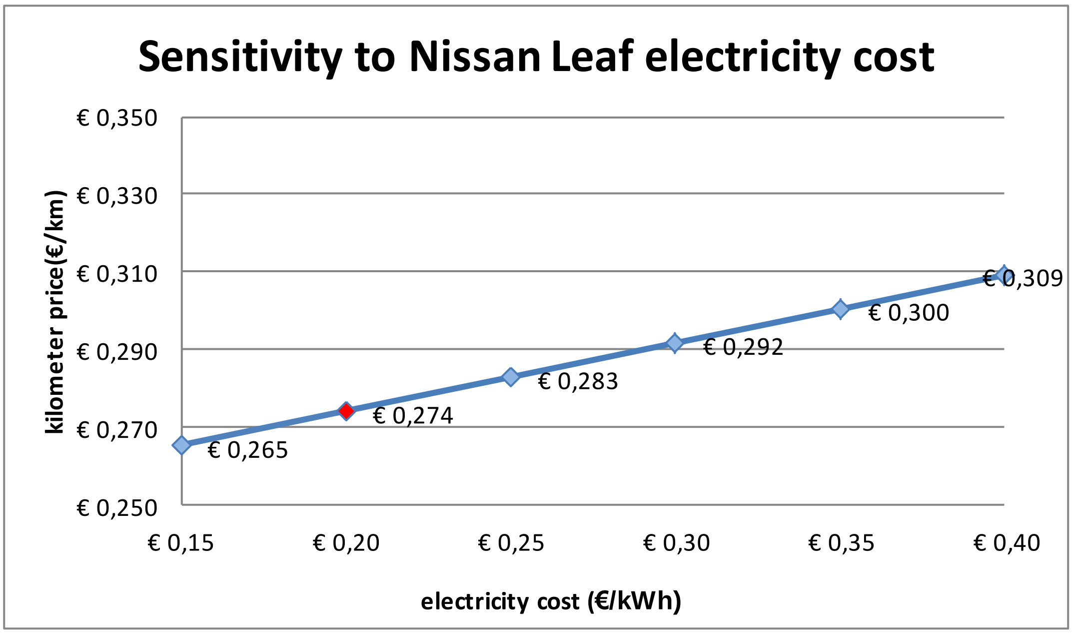

Figure 28: Sensitivity analysis to Nissan Leaf electricity cost (own representation)

It would also be interesting to investigate the cost per kilometer for Nissan Leaf for different discount rates. So far all the calculations have been made with a discount rate of 5%. Figure 29 represents the Nissan Leaf kilometer costs for discount rate range from 2 to 8%. The red colored value is for 5 %. The range in which the price per kilometer for Nissan Leaf varies by the assumed discount rates is 0.256 to 0.293 €/km. Again compared to the ICE technology, these values are quite acceptable. The price per kilometer by a discount rate of 7% is 0.287 €/km, standing again between Ford Focus with 0.288 €/km and Toyota Prius with 0.280 €/km. Assuming a discount rate of 8%, the price is 0.293 €/km, i.e. 5 Euro cent higher than Ford Focus.

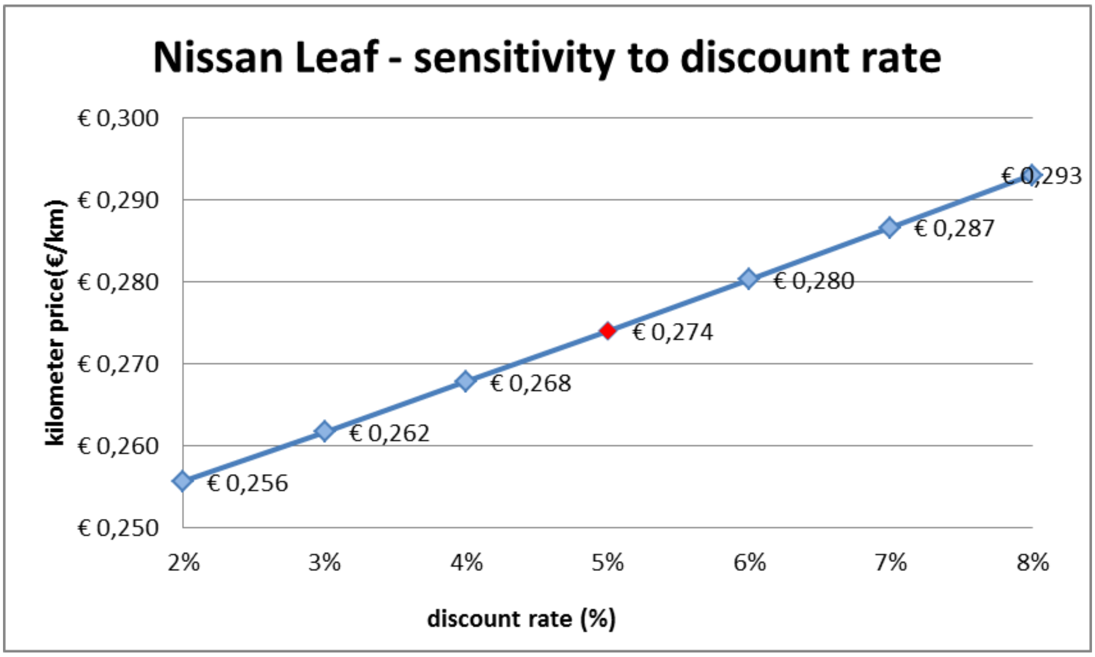

Figure 29: Nissan Leaf – sensitivity analysis to discount rate (own representation)

In general we can summarize that considering an investment cost of €29,290 adopted for Nissan Leaf and performed sensitive analyzes, investing in Nissan is profitable compared to Ford Focus – Diesel and Toyota Prius – Hybrid. Even without taking into account the subsidy of 8,000 Euro, investing in Nissan Leaf seems to be profitable considering the kilometer costs.

7 DESCRIPTION OF RESULTS

The core questions addressed in this master thesis were mentioned in chapter one. Here are once again the main issues discussed in this work divided by technological an infrastructural, ecological, economic and legal point of view:

Technological and infrastructural issues:

- Is it possible to operate the 5 electric vehicles with the existing charging infrastructure
- Which of the existing electric vehicles on the Austrian market are most appropriate for the taxi industry
- What infrastructure changes could support the entry of electric taxis

Ecological issues:

- Are there any advantages for the environment and what are they – lifecycle assessment

Economical and legal issues:

- Is it profitable for a small taxi company to invest in 5 electric taxis
- Is it profitable to invest in a private charging station
- What legal changes could support the entry of electric taxis

Answering these questions will deliver a clear picture of the current situation and the possibility to switch to electric cars within the company concerned.

7.1 Technological results

Switching to electric taxis would be possible if the existing technologies allow it and if the appropriate infrastructure is in place. In recent years the Topic of environmental protection and the use of renewable Energy Sources are becoming more and more popular. Switching to electric vehicles, using electricity from renewable energy sources, is also part of the environmental impact mitigation plan. All these led to significant investments in the development and research of electric vehicles technologies. Nowadays, almost every automobile manufacturing company has its own electric vehicle on the market. One of the pioneers in this electric vehicle segment was *Nissan Motor Company Ltd* with its model Nissan Leaf. They launched this model in 2010 which continues to present days. Investments in R&D contributed to the development of electric vehicle technology and reaching a competitive price compared with the conventional internal combustion engine technology. This on one hand, and on the other hand, the offered 8.000 Euro subsidies by the *Wien E-Taxi* project was the reason for choosing Nissan Leaf as an electric taxi vehicle in our company. The range of Nissan Leaf according to the official information should be 199 kilometers. Figure 30 below represents the *FleetCarma* study about Nissan Leaf range by different temperature.

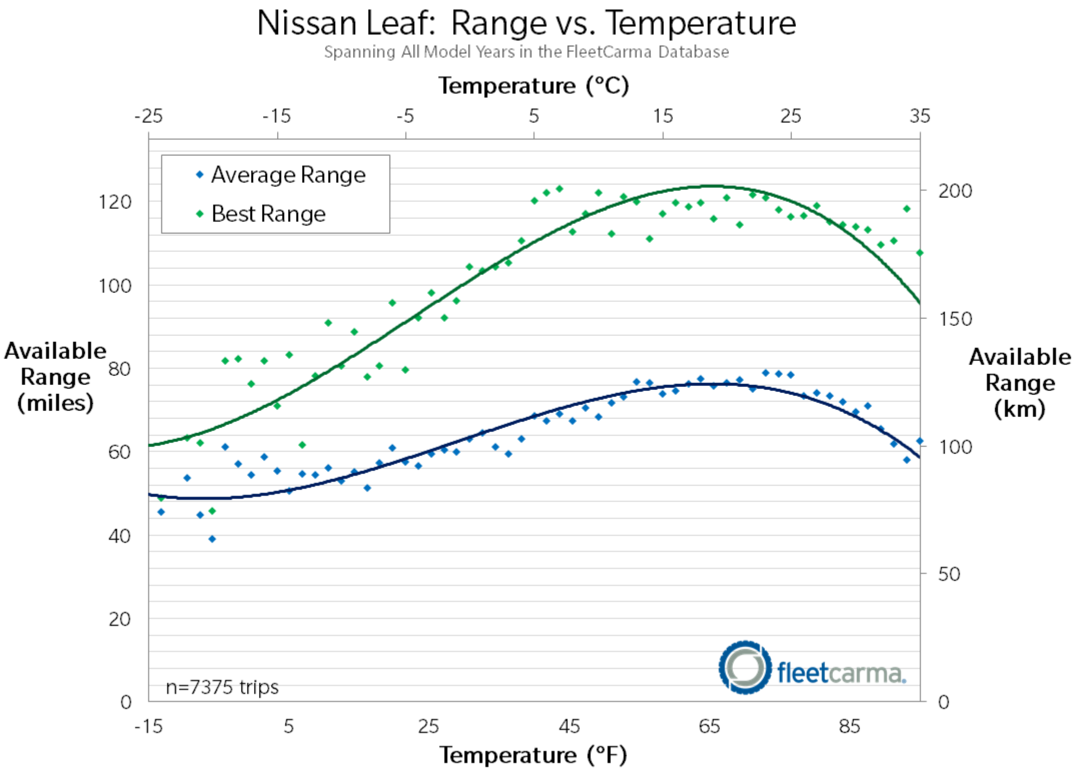

Figure 30: Nissan Leaf range by different outside temperature[55]

From Figure 30 we can assume that the average range for Nissan Leaf is about 100 kilometers. Of course, the range depends not only on the ambient temperature but

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[55] Fleet Carma (2015): Electric Range for the Nissan Leaf, *fleetcarma.com,* Retrieved 31.08.15 from: http://www.fleetcarma.com/nissan-leaf-chevrolet-volt-cold-weather-range-loss-electric-vehicle/.

also on the driving style, air conditioner usage, slope of the road, urban or suburban driving and so on. Assuming a 100-kilometer average distance travelled with full charged battery and 150 kilometers driven per taxi per shift, a fast charging infrastructure will be needed for the flawless performance of taxi services.

According to the *Wien E-Taxi* project, 10 new fast charging locations will be built in order to satisfy the needs of the growing electric taxis fleet. The project aims to increase the number of electric vehicles delivering taxi services to 250 by 2017. Partners of the project are Taxi 31300, Taxi 40100, Vienna Chamber of Commerce, TBW research GesmbH, Vienna University of Technology and the Austrian Institute of Technology (AIT). If a fast charging infrastructure exists investing in private charging stations would not be necessary. In both cases, with or without private fast charging station, the operation of the studied company and the performance of taxi services regarding fast charging seem to be quite feasible.

With an average daily distance of 150 kilometers travelled the drivers should recharge their batteries once per shift. The time spent for recharging a battery to 80% will be about 30 minutes. Of course, if the *Wien E-Taxi* project fast charging infrastructure would be built at taxi stands, drivers could charge batteries while waiting for the next customer, thus they will not waste time.

As all the drivers are single shifted, they could use the time between shifts for full recharging of the batteries under normal conditions. Recharging under normal conditions will spare the batteries and prolong their lives. In this case, battery replacement may not occur during the operation period and the annual investment cost will be significantly decreased. As studied in Chapter 4, the existing public charging infrastructure is enough for the operation of the 5 electric taxis in the company and the drivers do not need to change their behavior regarding walking distance to the park place. Two of the drivers also have the possibility to install wall boxes in the garages they use for parking the vehicles. The transition to electric taxis in the company regarding recharging between shifts seems possible without significant changes in the drivers' current behavior.

The discussions held with drivers show that they are all open to the idea of switching to electric taxis in Vienna. Regarding the recharging between shifts they also do not mind as they will not walk for more than 30 minutes. Some even consider the walk to home as relaxation after the long shift. The only thing that disturbs them is the fast charging. If fast charging infrastructure on taxi stands exists and they could recharge their batteries while waiting for clients they do not mind, but if they have to recharge their batteries at the company garage they have some concerns. Some believe that if you need to recharge the battery more than once, as might happen during the weekend, where more kilometers are travelled, returning to the garage would be annoying especially if the garage is not in the center. For example, when recharging the battery twice or more per night, more than an hour will be lost which is unacceptable for drivers.

In general, with the existing electric vehicle technology available on the Austrian market and current charging stations infrastructure in Vienna, the transition to electric taxis for the studied company with 5 cars is possible. The insufficient number of fast charging stations is currently the only obstacle but it seems to be surmounted with the *Wien E-Taxi* project which plans the construction of new fast charging stations. Investing in a private charging station situated near the city center could also be a solution.

7.2 Ecological results

One of the main aspects of the transition to electric cars is the environmental aspect. Switching to electric taxis without mitigating the environmental impact would not make any sense. To be able to assess more precisely the CO_2 emissions, the whole well-to-wheel cycle was divided in two stages, i.e. well-to-tank and tank-to-wheel, and the CO_2 emissions were calculated. As the Nissan Leaf and the electric vehicles in general release no emissions during operation, only the emissions produced by the electricity generation were considered. The CO_2 emissions discharged during the production of vehicles do not differ pretty much from one another, thus they were ignored. Also the emissions discharged during the extraction of oil and natural gas, WTT emissions, were ignored. To gain a clear idea after calculating the CO_2 emissions from the Nissan Leaf, it will be compared with three other vehicles: Toyota Prius – Hybrid, Ford Focus – Diesel and Mercedes B Class – Natural Gas. Comparing the results should result in the identification of the most nature friendly technology.

It is difficult to foresee how much of the electricity used for recharging the batteries will come from renewable energy sources; therefore, for the calculations we assumed that half of it comes from conventional sources and the other half from renewables. Due to the fact that the Austrian electricity comes mostly from water power plants, the CO_2 emissions are quite low - 157gCO2eq/kWh. As most of the electricity from renewable energy sources in Austria comes from water power plants, the value for hydropower plants was adopted for the calculations – 10gCO2eq/kWh. As assumed that one half of the electricity will come from renewable sources and the rest will be the Austrian mix, therefore, an average CO_2 emission of 83,5gCO2eq/kWh was obtained. Considering the 30.000 kilometers travelled by each taxi and the city consumption figure adopted from *ADAC Autotest* Nissan Leaf of 17,6 kWh per 100 kilometers, the CO_2 emissions for one Nissan Leaf Taxi for one year was obtained. The total CO_2 emissions for one year from all 5 electric vehicles in the company would be 2,205 t CO_2.

For the other 3 ICE vehicles, Toyota Prius, Ford Focus and Mercedes B Class, the city consumption figures from *ADAC Autotest* were adopted and the CO_2 emissions per 100 kilometers were calculated taking into account the CO_2 emissions discharged by the fuel combustion. Knowing the CO_2 emissions per kilometer and the total distance driven for one year for all the vehicles in the company – 150,000 kilometers, the total CO_2 emissions were obtained. Then the CO_2 emissions per year for all 5 vehicles in the company were calculated: for Toyota Prius – 9.07 t CO_2, for Ford Focus – 23.85 t CO_2, and for Mercedes B Class NG – 22.96 t CO_2.

Comparing the above figures, we can see that electric vehicles are the most nature friendly technology followed by Hybrid technology. The Ford Focus – Diesel and Mercedes B Class – Natural Gas emit 10 times more CO_2 per year than Nissan Leaf. All the figures were obtained without considering the CO_2 emissions discharged during the extraction and refining of oil and natural gas. Including them, the advantage of Nissan Leaf regarding CO_2 emission would be even greater.

7.3 Economical and legal results

In order to make the transition to electric taxis possible from an economic point of view, there should be adequate conditions for investment. As electric vehicles have still higher investment costs compared to conventional ICE vehicles, appropriate policies and programs by the state are needed for the integration of this technology. Each country has its own policy on the introduction of electric vehicles, whether in the private or business sector. Depending on subsidies and economic conditions in some countries, such as Norway, electric cars represent a significant share of the total number of vehicles in the country. Vienna *Wien E-Taxi* project creates enormous potential for the transition to electric taxis in the city. This could be a good example not only for the taxi business but also for the private sector and make a step towards a sustainable transport.

To evaluate the transition to electric taxis from an economic point of view, the annual investment costs for Nissan Leaf was calculated for the whole 5-year investment period. To make an objective assessment of the received annual costs they were compared with another three ICE vehicles, Toyota Prius – Hybrid, Ford Focus – Diesel and Mercedes B Class – Natural Gas, commonly used in the Viennese taxi industry. Calculating the annual costs, the investment costs, resale value, operation and maintenance costs, fuel costs, funding and 5% discount rate were considered. Some different scenarios were examined in order to evaluate the transition to electric taxis from economical aspect within the small company.

The first discussed scenario was where no investment in fast charging station was considered. In this scenario there were two cases represented, with and without battery replacement. The Nissan Leaf annual costs without considering battery replacement were €3,714 per year vs. €6,542 for Toyota Prius, €7,288 for Ford Focus and €7,034 for Mercedes B Class. Considering the battery replacement costs, the Nissan annual investment costs increased to €6,714, slightly more than Toyota.

The second scenario discussed was where the fast charging station investment was also taken into account. The total suggested investment of 80,000 Euros was divided into the number of cars in the company (5 cars) and distributed by years. In this case the total annual cost increased to €9,914 which is significantly higher compared to the other vehicles examined in the study. As battery replacement is unlikely due to its low mileage of 30,000 kilometers per year, if it does not happen Nissan Leaf will almost equal Toyota Prius again in terms of annual investment costs. The first two scenarios are only rough estimates without considering the 5% discount rate.

The third scenario compares again the annual investment costs of the four examined vehicles but this time considering the 5% discount rate. In this scenario investment in fast charging stations was not included. If battery replacement does not occur Nissan stands out again with the lowest annual payments – €4,564 vs. €7,493 Toyota Prius, €8,088 Ford Focus and €7,928 Mercedes B Class. If battery replacement by Nissan occurs during the 5 years of operation, the annual payments will amount to €7,557.

As *Nissan Center Europe GmbH* offers a lease option for the battery, both versions with the purchase and leasing of battery were compared. If battery is leased for more than 36 months the price will be €122 per month up to 25,000 kilometer per year, each additional kilometer will be charged at 0.05 Euro. As assumed, the taxis in the company drive in average 30,000 kilometers per year, making about 142.8 Euro per month battery rent. The annual costs of Nissan Leaf for battery purchase and battery replacement were calculated to €7,557 and for battery rent to €5,639. This calculation was not made considering the fast charging station investment. From the results obtained we can conclude that the option of leasing the battery is less expensive than purchasing the battery, but only if replacement during the 5-year period of operation occurs. If no replacement occurs, the battery purchase option remains the most profitable one, with annual costs of €4,564.

All scenarios considered so far include the cost of fuel. But as mentioned before, there are two different operation models. In the first model, the driver rents the car on a weekly basis and pays rental for it. In this case, the fuel is at the expense of the driver. The second model is renting the car and paying a percentage of the turnover to the company – in this model the fuel is paid by the company. Calculating again the annual investment costs without considering the fuel costs and investment in fast charging station, the following figures were obtained:

- Nissan Leaf (battery leasing) EV €4,583
- Toyota Prius – Hybrid €6,479
- Ford Focus – Diesel €6,000
- Mercedes B Class NG €6,047

Nissan Leaf has again the lowest annual payments. Considering the previously announced information from the *Wien E-Taxi* project according to which electric taxis involved in the project would have the possibility to recharge their batteries for free the first year at the newly built fast charging stations we will have a win-win situation for both sides – drivers and taxi company.

From the scenarios examined, it is clear that the transition to electric taxis in economic terms is possible. Only in the case where investing in fast charging stations was considered, the annual payments by Nissan Leaf were higher than the compared vehicles. Overall investments were almost identical or lower for Toyota Prius thanks to the subsidies provided under the *Wien E-Taxi* project.

8 SUGGESTIONS SUPPORTING THE TRANSITION TO ELECTRIC TAXIS

From a historical point of view the transition from one transport technology to another does not happen immediately and is a long process. Figure 31 below represents the replacement of technologies within vehicle fleets in the United Kingdom. As shown in the diagram below, the full transition or replacement of one vehicle with another is a process lasting more than 20 years. The overall shift from horse carriages and hackneys to automobiles continued from 1900 to 1940 and the transition from steam locomotives to diesel and electric continued from 1940 to 1980. The same happens with the electric cars, with that difference that electric cars will not displace other technologies but they will simply find their market share.

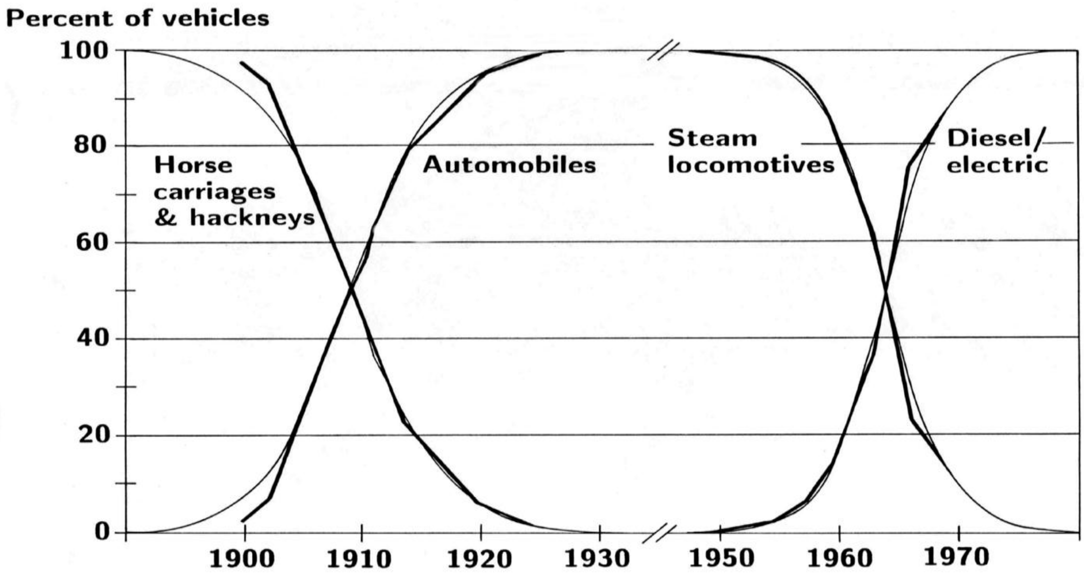

Figure 31: UK – Replacement of technologies within vehicle fleets[56]

Whereas the range of electric vehicles is still relatively small (approx. 150 km), electric vehicles are ideal for use in urban environments. They would be perfect for public transport services, company cars, taxi services, rental cars, couriers, ambulances, car sharing and so on. The taxi Industry in Vienna has a huge potential regarding switching to electric vehicles. The number of taxis in Vienna is

[56] Ajanovic, A. (2013): Historical developments, International Survey on Transport, MSc Program – Module 1, Renewable Energy in Central and eastern Europe, Lecture note: p. 19

approximately 4,800, and the number of concessions in 2013 is 9,671[57]. Switching to electric taxis is a huge challenge for the Viennese taxi industry.

With the *Wien E-Taxi* project, the first step towards electro mobility in the taxi industry seems to be accomplished. The main goal of the project is to increase the number of electric taxis to 120 by the end of 2015. The first project participants will be granted a subsidy of €8,000 to purchase a Nissan Leaf and free charging of their vehicles at the newly built fast charging infrastructure in the first year of operation.[58]

Except that first step to enable the majority of taxis to switch to electric cars, a range of other measures could be taken. The subsidy is a very important step in the transition period, especially considering the higher initial investment cost by electric cars. The creation of appropriate conditions for the development of this service is also essential. For example, the designation of taxi stands where only electric taxis are allowed to stay and wait would have a huge effect on the transition to eco-friendly taxi services. At those autonomous taxi stands drivers could charge their electric vehicles while waiting for the next customer, thus they will not waste extra time to recharge the batteries. Also, customers willing to use sustainable transport could benefit from these services. Since most of the work is concentrated in the center of Vienna, building several test taxi stands would be a good start. The construction of such EV taxi stands would encourage both the companies and drivers to invest in and switch to electric taxis. Drivers of electric taxis will benefit from the autonomous taxi stands where they will not wait for so long for the next customer, but even while waiting their time will not be lost because in the meantime they could recharge their batteries. Companies providing electric vehicles will become more popular among taxi drivers because of the advantages mentioned above. Of course, with the increasing demand for electric taxis by customers and by taxi drivers the number of taxi stands for electric taxis will also need to be increased. Thus, the sustainable transportation in both business and private sector could be

[57] WKO (2015): Beförderungsgewerbe mit Personenkraftwagen, Fachgruppe, Statistic für das Jahr 2013, Anzahl der Taxifahrzeuge 2010-2013, *wko.at,*
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[58] WKO (2015): Beförderungsgewerbe mit Personenkraftwagen, Fachgruppe, Wiener e-Taxi-Unternehmen gesucht, *wko.at,*
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https://www.wko.at/Content.Node/branchen/w/TransportVerkehr/BefoerderungPKW/Wiener-e-Taxi-Unternehmen-gesucht.html.

encouraged. This is an example in which creating favorable conditions will contribute to shift to electric taxis.

Another measure that would contribute to the transition to electric vehicles in the taxi industry is the identification of zones where only electric taxis are allowed to pass. In Vienna this could be the First District and also some shopping streets, e.g. Mariahilfer Strasse. These areas could be called “Green Zones” allowing passing of electric taxis only. Another option would be passing through such zones during the night to be allowed for electric taxis only. In this case the residents in these areas will be relieved due to less noise and CO_2 emissions. Such measures would stimulate the switch to electric taxis on one hand, and on the other hand, would create a win-win situation for all the parties involved. Residents of those areas will be able to sleep peacefully because of less noise and will also be able to open their windows during the night in the summer without having to breathe harmful emissions from ICE vehicles. Taxi drivers will enjoy less competition and therefore, less time spent waiting for the next customer. On the other hand, taxi companies will improve their image by offering sustainable transport. Moreover, the demand for such companies will increase because of the good conditions provided to electric taxi drivers, i.e. driving in areas intended especially for electric taxis. Also, Vienna will become a model environmental city providing sustainable transport services.

As mentioned above, the first step towards sustainable transport was already made with the *Wien E-Taxi* project. At a later stage, even if no subsidies for electric vehicles are available, the development of technology and economy of scale will contribute to the alignment of prices of electric vehicles with the conventional ones. Such alignment of prices, taking into account the low cost of fuel and low-maintenance investment in electric vehicles, may become more profitable than with the ICE vehicles.

Another step that could help the transition to electric taxis is the creation of an Internet platform where all customers supporting sustainable transportation could order their electric taxi. All registered members in this platform, i.e. customers, taxi companies, and taxi drivers, will have the opportunity to share ideas and exchange information related to sustainable transportation. With the help of specially developed smart phone applications each customer registered in the platform will be able to see the location of the nearest taxi, the status of its battery and then order it. Of course, customers not using smartphones will be able to order electro taxis by phone.

In general, we can conclude that the main steps to contribute to the transition to electric taxis are as follows:

- Subsidies for the initial investment, currently available through the *Wien E-Taxi* project
- Building a fast charging infrastructure at taxi stands
- Autonomous taxi stands for electric vehicles with fast charging possibilities
- Creating ‘Green Zones’ or ‘Green Districts’ – allowed for electric taxis only (for example First District or Mariahilfer Strasse)
- Organizing workshops where taxi drivers and taxi company owners learn the advantages and disadvantages of electric cars
- Developing an Internet platform where all customers supporting sustainable transportation could order an electric taxi, share ideas and exchange information regarding electro mobility.

It is acknowledged that mobility and environmental protection should accompany the development of vehicle technology, which will contribute to reducing the GHG from the transport sector and will address the challenges associated with the climate change. An important conclusion is the fact that improved air quality can only be achieved through a faster replacement of existing fleets, in addition to the introduction of vehicles producing lower emissions. In this respect the introduction of financial, infrastructural and legal measures plays an important role for encouraging companies to make their choice in favor of more environment-friendly vehicles.

9 SUMMARY AND CONCLUSIONS

As already mentioned in the beginning of the Master Thesis, the main purpose of this work is to establish whether it is possible for a small taxi company in Vienna possessing five automobiles to switch to electric taxis from technological, economic and environmental points of view. If the transition to electric taxis for the small investigated taxi company with 5 cars turns to be possible, this would be an important step towards sustainable transportation. Of course, the transition will not happen immediately. It will be a long process with many difficulties on the way but at the end by switching the majority of cabs to electric cars Vienna could become an example for a city providing sustainable and environment-friendly taxi services. Now, with the *Wien E-Taxi* project, when favorable conditions for the development of new and more sustainable taxi services occur, we should accept the challenge and, despite the difficulties, continue to improve the quality of our lives. All the benefits from switching to electric taxis, including lower CO_2 emissions, noise reduction, improving the city's reputation, lower fuel costs, reduced dependence on imported fuels, development of the national electricity system and evolution of new mobility, etc., will eventually reward our efforts. Switching to electric taxis will enable sustainable economic transition of the national economic and social status to a lifestyle and working routine based on sparing use of raw materials and energy and work driven by high intelligence.

If the three main aspects, economic, environmental and technological, enable switching to electric taxis in our company then there is no reason why this should not happen.

From a *technological point of view* the transition to electric taxis could happen only if the required technology exists and can be applied. For the investigated taxi company the required technology is an electric vehicle with satisfactory range and an existing charging infrastructure. After considering the Austrian market of electric vehicles and taking into account the subsidy granted under the *Wien E-Taxi* project, Nisan Leaf was the car selected for the taxi services. It is hard to determine the range of the Nissan Leaf as it depends on the driving style, weather conditions, outside temperature, slop, etc. According to the information regarding the *Wien E-Taxi* project, the Nissan Leaf will have 100 km range in any weather and at any temperature.[59] Considering the mileage that the five taxi drivers in the company travel, an average distance of 150 km per shift was adopted. In order to be able to travel this distance in all weather conditions an appropriate fast charging infrastructure should be in place. As it was investigated the existing infrastructure seems to be enough to charge the electric taxis between the shifts but not enough to fast recharge them during a shift. The five existing fast charging stations are not sufficient for the investigated company to recharge the batteries of its electric vehicles. One of the possibilities considered in this case is investing in a private fast charging station at the company's garage or waiting for the construction of the fast charging stations under the *Wien E-Taxi* project. In the event of investing in a private charging station it would be a good idea to locate the company's garage in a central area to allow drivers not to waste too much time travelling to the charging station. In any case, from both an economic and a technological point of view, the use of a fast charging infrastructure, especially built for taxi drivers, will be the best option. A fast charging infrastructure built at the taxi stands would significantly facilitate the transition to electric taxis. After the performed research and investigation of the existing company we can conclude that, from a technological point of view, the transition to electric taxis with the current technological status quo is feasible. Perhaps in the beginning it will not be easy in terms of distribution of fast charging stations and the schedule for recharging batteries. Here it would make sense to build a properly designed smart charging grid where at any time the battery status of each car to be known and priority to be given to cars with low batteries.

Also from an *environmental point of view* switching to electro taxis should also make sense for small companies, such as the company investigated, and also for the whole taxi fleet. If switching to electric taxis in Vienna has a positive effect on the environment we cannot make the general conclusion that this will be the case for any other place in the world. This applies on a local level since electric cars do not exhaust any gases, but globally the situation will be different. If considering the whole lifecycle during their operation the electric vehicles do not actually discharge any carbon emissions but in fact this happens during the process of their manufacture and the generation of electricity required for the propulsion. Therefore,

[59] WKO (2015): Beförderungsgewerbe mit Personenkraftwagen, Fachgruppe, Wiener e-Taxi-Unternehmen gesucht, wko.at,
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https://www.wko.at/Content.Node/branchen/w/TransportVerkehr/BefoerderungPKW/Wiener-e-Taxi-Unternehmen-gesucht.html.

a comprehensive lifecycle assessment needs to be done in order to determine whether the transition to electric vehicles would lead to the reduction of CO_2 emissions. It is important to consider the following: the CO_2 emissions produced during the vehicle manufacture, the CO_2 emissions during operation, the CO_2 emissions associated with the production of the fuel (electricity), and the emissions discharged during the vehicle recycling. Since the CO_2 emissions produced by the manufacture and recycling of electric cars and ICE vehicles do not differ much they were disregarded in our calculations. In order to get a clearer picture of the CO_2 emissions discharged from electric taxis they were compared with other technologies, such as hybrid, diesel and natural gas ICE vehicles. For the comparison the following automobiles were used: Toyota Prius – Hybrid, Ford Focus – Diesel and Mercedes B Class – Natural Gas. They are all very common in the Vienna taxi industry. The CO_2 emissions were calculated for all these vehicles for 1-year period of operation and compared to Nissan Leaf. An average of 30,000 travelled kilometers per taxi of was adopted. The CO_2 emissions per year for all different five vehicles in the company were calculated: for 5 Nissan Leaf cars - 2,205t CO_2, for 5 Toyota Prius cars – 9,07t CO_2, for 5 Ford Focus cars – 23,85t CO_2, and for 5 Mercedes B Class NG cars – 22,96t CO_2. It can be noted here that Nissan Leaf stands out with significantly lower CO_2 emissions compared to all other technologies. These values refer to Austria only and were calculated with the Austrian electricity mix. For our calculations we assumed that half of the electricity used for recharging the batteries comes from renewable energy sources – hydropower plants and the other half is Austrian electricity mix. The CO_2 emissions by Nissan Leaf were so low due to the fact that Austria has a significant share of renewable energy sources, mainly water power plants. Generally, it can be concluded that switching to electric taxis, both for the company concerned with five own taxis and in large scale, would have a greater effect on reducing the CO_2 emissions.

Switching to electric taxis from *economic point of view* would make sense only if the investment could be compared with other ICE vehicles commonly used in the Viennese taxi industry. Since the initial investment in electric vehicles is still higher than that in the conventional cars, switching to electric cars without receiving any subsidies would be very difficult. Moreover, the absence of infrastructure and experience in this area makes taxi companies uncertain and unprepared for such an investment. A granted subsidy would play a huge role in overcoming this barrier. Now, the *Wien E-Taxi* project provides taxi companies a chance to launch a new model of sustainable taxi services. One of the reasons why we chose Nissan Leaf for our study is because of the subsidy of €8,000 granted to the company under the *Wien E-Taxi* project. So we could explore as accurately as possible the option of switching to electric taxis from an economic point of view and several scenarios were considered. Initially the annual investment cost was calculated with and without a subsidy, also with and without battery replacement considering the 5-year period of investment, 5% discount rate, operation and maintenance costs and resale value after 5 years of operation. Then the results were compared with other ICE vehicles commonly used in the taxi industry: Toyota Prius – Hybrid, Ford Focus – Diesel and Mercedes B Class – Natural Gas. In case of a granted subsidy but no battery replacement Nissan Leaf has the lowest annual cost. In case of a subsidy and no need of battery replacement, the Nissan Leaf has the lowest annual cost. When battery replacement is required, the cost of Nisan Leaf aligns with that of Toyota Prius. If battery replacement and investment in a private charging station are taken into account but no subsidy is considered, the Nissan Leaf has the highest annual cost. Then the annual costs by battery purchase and battery leasing were calculated. From an economic point of view, assuming a mileage of the taxis investigated of 30,000 kilometer per year, it would be more profitable to lease the battery than to purchase it. If we make our calculations with the most realistic scenario where the battery is leased, a subsidy of €8,000 is considered and no investment in a private charging station is required, then the Nissan Leaf seems to be the most profitable investment compared to the other ICE technologies. When calculating the price per kilometer for all the vehicles considered in this study and making some sensitivity analyses regarding investment costs, discount rate, diesel and gasoline costs, Nissan Leaf managed to maintain the lowest cost per kilometer in most of the scenarios. Since in the majority of the considered scenarios the annual costs and the costs per kilometer for Nissan Leaf were lower or comparable to those of the other ICE vehicles considered, we can conclude that from an economic point of view for the studied company switching to electric taxis is feasible.

Finally, we can summarize that currently the transition to electric taxis is for the investigated taxi company with five cars in Vienna quite possible if an appropriate fast charging infrastructure is built or the company invests in its own fast charging infrastructure. With the *Wien E-Taxi* project and the planned construction of an appropriate fast charging infrastructure for the taxis, it seems that the obstacle will be surmounted. This project also supports the transition to electric taxis in economic terms. The difficult way towards sustainable taxi services is worth walking just because of the favorable impact on the environment by such transition to electric taxis.

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Addendums

Addendum 1: Nissan Leaf annuity calculation - battery purchase scenario

Nissan Leaf - battery purchase annuity calculation

investment(€)	29290
discount rate	5%
o&m(€/y)	400
fuel €/y	1056
resale value (€)	10000
funding (€)	8000
fast charging station (€)	
battery replacement (€)	
battery leasing (€/y)	
fuel price (€)	0,2
consumption (kWh/100km)	17,6
milleage/year (km)	30000

year	disc cf	nom cf	o&m	fuel	resale	bat. Leasing	battery
0	-21290						
1	-1386,667	-1456	-400	-1056		0	
2	-1320,635	-1456	-400	-1056		0	
3	-1257,748	-1456	-400	-1056		0	0
4	-1197,855	-1456	-400	-1056		0	
5	6694,448	8544	-400	-1056	10000	0	
npv	-19758,46						
annuity	*-4563,71*						

Addendum 2: Nissan Leaf annuity calculation - battery purchase and battery replacement scenario

Nissan Leaf - battery purchase and battery replacement annuity calculation

investment(€)	29290
discount rate	5%
o&m(€/y)	400
fuel €/y	1056
resale value (€)	10000
funding (€)	8000
fast charging station (€)	
battery replacement (€)	15000
battery leasing (€/y)	
fuel price (€)	0,2
consumption (kWh/100km)	17,6
milleage/year (km)	30000

year	disc cf	nom cf	o&m	fuel	resale	bat. Leasing	battery
0	-21290						
1	-1386,667	-1456	-400	-1056		0	
2	-1320,635	-1456	-400	-1056		0	
3	-14215,31	-16456	-400	-1056		0	-15000
4	-1197,855	-1456	-400	-1056		0	
5	6694,448	8544	-400	-1056	10000	0	
npv	-32716,02						
annuity	*-7556,58*						

Addendum 3: **Toyota Prius annuity calculation**

Toyota Prius annuity calculation

investment(€)	28140
discount rate (%)	5
o&m(€/y)	1000
fuel (€/y)	1014
resale value (€)	5000
funding (€)	500
fast ch. St. (€)	
fuel price (€)	1,3
consumption (l/100km)	2,6
milleage/year (km)	30000

year	disc cf	nom cf	o&m	fuel	resale
0	-27640				
1	-1918,1	-2014	-1000	-1014	
2	-1826,76	-2014	-1000	-1014	
3	-1739,77	-2014	-1000	-1014	
4	-1656,92	-2014	-1000	-1014	
5	2339,609	2986	-1000	-1014	5000
npv	*-32441,9*				
annuity	***-7493,27***				

Addendum 4: **Ford Focus annuity calculation**

Ford Focus
annuity calculation

investment(€)	24000
discount rate (%)	5
o&m(€/y)	1000
fuel (€/y)	2088
resale value (€)	3000
funding (€)	
fast ch. St. (€)	
fuel price (€)	1,2
consumption (l/100km)	5,8
milleage/year (km)	30000

year	disc cf	nom cf	o&m	fuel	resale
0	-24000				
1	-2940,95	-3088	-1000	-2088	
2	-2800,91	-3088	-1000	-2088	
3	-2667,53	-3088	-1000	-2088	
4	-2540,51	-3088	-1000	-2088	
5	-68,9503	-88	-1000	-2088	3000
npv	*-35018,8*				
annuity	**-8088,47**				

Addendum 5: **Mercedes B Class NG annuity calculation**

Mercedes B Class NG

investment(€)	26269
discount rate (%)	5
o&m(€/y)	1000
fuel (€/y)	1881
resale value (€)	5000
funding (€)	500
fast ch. St. (€)	
fuel price (€)	1,1
consumption (kg/100km)	5,7
milleage/year (km)	30000

year	disc cf	nom cf	o&m	fuel	resale
0	-25769				
1	-2743,81	-2881	-1000	-1881	
2	-2613,15	-2881	-1000	-1881	
3	-2488,72	-2881	-1000	-1881	
4	-2370,21	-2881	-1000	-1881	
5	1660,292	2119	-1000	-1881	5000
npv	*-34324,6*				
annuity	**-7928,12**				

Addendum 6: **Driver 1 data sheet**

Data Sheet

Driver 1

№	Date	Shift Start	Shift End	Break (h)	Stay time (min)	100 km reached (time)	Mileage (km)	Duration of Shift (h)
1	05.05.15	21 h	05 h	30 min	180	07h	93	8
2	06.05.15	20 h	05 h	30 min	140	04h	122	9
3	07.05.15	21 h	05 h	20 min	120	03h	130	7
4	08.05.15	22 h	06 h	30 min	130	02 h	150	8
5	09.05.15	21h	06 h	40 min	120	02h	196	9
6	12.05.15	21h	04 h	30 min	160	04h	86	7
7	13.05.15	21 h	04h	30 min	140	02 h	116	7
8	14.05.15	20h	04 h	30 min	140	02h	120	8
9	15.05.15	21h	06 h	30 min	120	02h	206	9
10	16.05.15	21h	06 h	30 min	120	03 h	162	9
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Average Mileage: 138,1 km

Addendum 7: **Driver 2 data sheet**

Data Sheet

Driver 2

№	Date	Shift Start	Shift End	Break (h)	Stay time (min)	100 km reached (time)	Mileage (km)	Duration of Shift (h)
1	5.5	18h	4	40 min	160	3h	110	10
2	6.5	18h	4	40 min	180	3h	106	10
3	7.5	18h	3	30 min	150	1h	152	9
4	8.5	18h	6	50 min	120	1h	208	12
5	9.5	18h	6	30 min	130	1h	198	12
6	12.5	17h	3	30 min	160	2h	116	10
7	13.5	17h	4	30 min	170	2h	123	11
8	14.5	18h	5	30 min	140	1h	144	11
9	15.5	19h	6	50 min	120	10^{30} h	212	11
10	16.5	19h	6	40 min	110	12h	201	11
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Average Mileage: 157 km

Addendum 8: Driver 3 data sheet

Data Sheet

Driver 3

№	Date	Shift Start	Shift End	Break (h)	Stay time (min)	100 km reached (time)	Mileage (km)	Duration of Shift (h)
1	05.05.2015	20.00	04.30	30 min	150	23.30	165	9
2	6.05.2015	20.00	04.30	30 min	180	03.00	116	9
3	7.05.2015	20.00	04.30	30 min	140	00.00	190	9
4	8.05.2015	20.00	05.30	30 min	120	00.00	208	10
5	9.05.2015	20.00	05.30	30 min	100	22.30	274	10
6	12.05.2015	20.00	04.30	30 min	130	00.00	225	9
7	13.05.2015	20.00	04.30	30 min	150	00.00	157	9
8	14.05.2015	20.00	05.30	30 min	140	00.30	163	10
9	15.05.2015	20.00	05.30	30 min	100	01.00	255	10
10	16.05.2015	20.00	05.30	30 min	110	00.30	204	10
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Average Mileage: 195,7 km

Addendum 9: **Driver 4 data sheet**

Data Sheet

Driver 4

№	Date	Shift Start	Shift End	Break (h)	Stay time (min)	100 km reached (time)	Mileage (km)	Duration of Shift (h)
1	5.5	17^{00}	02^{00}	30 min	140	23^{00}	163	9
2	6.5	16^{30}	02^{00}	30 min	150	23^{00}	155	9,5
3	07.05	18^{00}	03^{00}	30 min	160	00^{00}	161	9
4	08.05	18^{00}	05^{00}	30 MIN	140	00^{00}	216	11
5	09.05	18^{00}	05^{00}	30 MIN	120	23^{30}	208	11
6	12.05	17^{00}	02^{00}	30 MIN	140	23^{00}	127	9
7	13.05	17^{00}	02^{00}	30 MIN	160	22^{30}	113	9
8	14.05	16^{00}	01^{00}	30 MIN	160	22^{00}	129	9
9	15.05	18^{00}	05^{00}	30 MIN	140	23^{00}	186	11
10	16.05	18^{00}	05^{00}	30 MIN	120	23^{00}	179	11
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Average Mileage: 163,7

Addendum 10: Driver 5 data sheet

Data Sheet

Driver 5

№	Date	Shift Start	Shift End	Break (h)	Stay time (min)	100 km reached (time)	Mileage (km)	Duration of Shift (h)
1	05.05.15	09^{00}	20^{00}	50 min	180	18^{00}	120	11
2	06.5.15	10^{00}	21^{00}	60 min	170	18^{00}	126	11
3	07.5.15	9^{00}	21^{00}	60 min	190	17^{00}	142	12
4	08.5.15	9^{00}	20^{00}	60 min	180	16^{00}	143	11
5	09.5.15	9^{00}	19^{00}	60 min	200	19^{00}	103	10
6	12.5.15	9^{00}	21^{00}	80 min	200	21^{00}	100	12
7	13.5.15	9^{00}	20^{00}	50 min	180	16^{00}	127	11
8	14.5.15	9^{00}	20^{00}	60 min	160	16^{00}	140	11
9	15.5.15	9^{00}	20^{00}	50 min	170	17^{00}	120	11
10	16.5.15	9^{00}	18^{00}	30 min	190	16^{00}	116	9
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Average Mileage: 123,7