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FACULTY OF ELECTRICAL ENGINEERING

Department of Economics, Management and Humanities

Implementing Sustainable E-mobility System in Czech Electricity Market

MASTER'S THESIS

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Business model of e-mobility systems, analysis of possible schemes
Proposal and case study for business model

Bibliography / sources:

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III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce her thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

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I hereby declare that this master's thesis is the product of own independent work and that I have clearly stated all information sources used in the thesis according to Methodology Instruction No. 1/2009 – "On maintaining ethical principles when working on a university final project, CTU in Prague".

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Abstract

This thesis aims to explain how e-mobility can be implemented and developed in Czech Republic. Firstly, the reason why transition to e-mobility is important and required are explained. Then in the first chapter, current situation of the e-mobility market and how it is expected to develop in the future especially in Europe and particularly in Czech Republic are discussed. An important background related to basic features of electric vehicles are given. In the second chapter, e-mobility ecosystem is explained. Electric vehicle provision, support policies applied in Europe and Czech Republic, e-mobility infrastructure and infrastructure providers, some examples of e-mobility services and business models applied in the world are explained. Moreover, the impact of e-mobility on power systems, and oil consumption and import are mentioned. The battery requirements for e-mobility are briefly discussed. Chapter 3 describes the National Action Plan of Czech Republic for e-mobility and how country plans to develop the e-mobility infrastructure. The incentives applied and planned to be applied; legislation and responsible authorities are explained. Moreover, how the electric utilities can use the e-mobility as a new business solution and how they can have a place in e-mobility market are discussed. Their current situation in e-mobility market, what kind of services they provide and their place and targets as a public charging provider are explained. In the final chapter, financial analysis of constructing and operating 250 fast charging stations is carried out to see if providing fast charging stations is a profitable business for electric utilities. It is also discussed what should happen for this business to bring income; and how it can help electric vehicle deployment in Czech Republic. The results of financial analysis and possible pricing schemes are shown. The annual charging prices per car are compared with the annual fuel costs.

Keywords*: charging tariff, e-mobility, e-mobility business models, electric vehicle deployment, e-mobility providers, e-mobility as a business for electric utilities, public charging stations*

Diplomová práce se zaměřuje na problematiku rozvoje elektromobility v podmínkách České republiky. V úvodu je uveden širší kontext problematiky a důvody přechodu k elektromobilům. Následuje popis současného stavu elektromobility a diskuze očekávání jejího budoucího vývoje v Evropě a v ČR. Tato část obsahuje popis základních vlastností elektromobilů. Dále je popsán celý ekosystém elektromobility – trh s elektromobily, podpora rozvoje elektromobility v Evropě a v ČR, infrastruktura potřebná pro elektromobiliy a její poskytovatelé. Současně jsou uvedeny příklady služeb spojených s elektromobilitou a obchodních modelů s nimi spojených. Spolu s tím jsou diskutovány dopady rozvoje elektromobility na elektroenergetický systém, na import a spotřebu konvenčních paliv a na potřeby dodávek baterií pro elektromobily. V další části práce je popsán Národní akční plán čisté mobility pro ČR, očekávaný rozvoj infrastruktury elektromobilů a legislativní nástroje pro dosažení plánovaných cílů. Práce dále obsahuje analýzu možností, jak mohou současné distribuční společnosti využít rozvoje elektromobility jako nové tržní příležitosti. Je popsána současná situace distribučních společností, v současnosti poskytované služby a jejich aktuální plány rozvoje veřejných dobíjecích stanic. V závěrečné části práce je provedena ekonomická analýza výstavby a provozu 250 rychlodobíjecích stanic s cílem posoudit, zda jde o ekonomicky efektivní aktivitu pro distribuční společnosti. Součástí je i analýza potřebných změn, aby se tyto aktivity staly ekonomicky zajímavými pro distribuční společnosti a aby došlo k podpoře rozvoje elektromobility v ČR. Jsou uvedeny výsledky ekonomických výpočtů včetně možných cenových schémat pro dobíjení elektromobilů. Roční náklady na dobíjení jsou porovnány s náklady na palivo u konvenčních automobilů.

Klíčová slova: tarify pro dobíjení, elektromobilita, obchodní modely elektromobility, rozvoj elektromobility, poskytovatelé služeb elektromobility, elektromobilita jako příležitost pro distribuční firmy, veřejné dobíjecí stanice

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List of Abbreviations

AC: Alternating Current
ACEA: European Automobile Manufacturers' Association
a. s.: Czech abbreviation for Joint Stock Companies
avg.: average
BEV: Battery Electrical Vehicle
CHN: China
CNB: Czech National Bank
CNG: Compressed Natural Gas
COP: Conference of Parties
CR: Czech Republic
DC: Direct Current
DSO: Distribution System Operator
E-car: Electric car
EAFO: European Alternative Fuels Observatory
EC: European Commission
EU: European Union
EV: Electric Vehicle
EVSE: Electric Vehicle Supply Equipment
GDP: Gross Domestic Product
GHG: Green House Gases
Gt: Gigatons
HEV: Hybrid Electric Cars
HV: High Voltage
IEA: International Energy Agency
ICEV: Internal Combustion Engine Vehicle
IND: Indian Subcontinent
LAM: Latin America
LV: Low Voltage
MEA: Middle East and North Africa
NAM: North America
NAPCM: National Action Plan on Clean Mobility
NEE: North East Eurasia
OECD: Organisation for Economic Co-operation and Development
OEM: Original Equipment Manufacturer
OPA: OECD Pacific
PEV: Plug-In Electric Vehicle
PHEV: Plug-In Hybrid Electric Vehicle
PLDV: Passenger Light-Duty Vehicles
PXE: Power Exchange Central Europe
RES: Renewable Energy Sources
SEA: South East Asia
Spol. S.r.o: Czech Abbreviation for Limited Liability Company (LLC)
SSA: Sub-Saharan Africa
TOE: Tonnes of Oil Equivalent
V2G: Vehicle-To-Grid
V2H: Vehicle-to-Home
VAT: Value Added Tax
VHV: Very High Voltage
ZEV: Zero emission vehicles

Introduction

With the Industrialization, the need for raw materials and the usage of fossil fuel to meet the high energy demand has increased. This high usage of fossil fuels started to threaten the environment and the natural resources. The policies which had been developed to eliminate environmental pollution and prevent the environmental problems before they occur, has also become approaches for protecting the environmental, social and economic rights of the future generations towards the end of 1980s. The sustainable development model has become more important in the following years with the Brundtland Report (Our Common Future Report) which was published by the World Commission on Environment and Development (WCED) in 1987. After the United Nations Conference on Environment and Development (UNCED) which was organized in Rio de Janeiro in 1992, many international agreements are done for sustainable development and many environmental policies have been organized. International initiatives aimed at reducing environmental damages with the goal of sustainable development have not been enough to remove the global environmental problems and the threats on the natural resources. The inadequate measures taken to control the negative impacts of the economy and human activities on the environment have led to climate change becoming a pervasive global problem. Economic systems that were focusing more on production and growth but becoming less labour-intensive and more polluting have also aggravated social problems such as poverty and unemployment, as well as environmental problems. The need to establish a balance between economic, social and environmental issues and the need to strengthen the pace of implementation of sustainable development have emerged. The economic, social and environmental problems that lived elsewhere in the world have been transforming into global crises, so it has become increasingly clear that economic growth and stability in the 21st century cannot be handled independently from the social and environmental elements. As a reflection of the situation in question, the need for the development of new growth instruments in the wake of the global economic crisis that broke out in 2008 was born. For this reason, the concepts of ‘green growth’ or ‘green economy’ have begun to be presented as new means of guiding not only the crisis but also the sustainable development. E-mobility one of the leading areas of green growth. The commercialization of standards by environmental and environmental criteria has now become a competitive element to preserve the productive environment. E-mobility systems are among the best-known examples of competition because of the reduction of greenhouse gas emissions. According to the study conducted European Environment Agency in 2013, transportation is the second largest contributor to the increase in GHG in Europe after the power generation sector. The passenger cars make up about 12% of carbon dioxide emissions in the EU and the technological improvements in the conventional vehicle industry have not been helpful to reduce the carbon dioxide emission level due to the increase in number of vehicles. To reduce the CO_2 emission, EC has passed EU Regulation No 443/2009 to set emission performance standards for new passenger cars. With this regulation, the CO_2 emission level is limited to 130g CO_2/km and a target limit of 95g CO_2/km has been set for 2020 [1]. In EU’s Energy and Climate 2020 and 2030 packages, it is targeted to reduce GHG emissions, increase energy efficiency and use RES. By 2020, 10% of the energy used for transportation sector should be from RES [2]. According to White Paper, the use of ICEVs should be reduced by half by 2030 and the ICEVs should be totally out of the market by 2050 [3]. These regulations have encouraged the shift of automobile industry towards the electrical vehicle market. Electrical vehicles have huge potential for reducing the CO_2 emissions of transportation industry significantly. Electrical cars are more efficient since they need lower energy; they are less noisy and they do not emit CO_2 and dust. Even though electrical vehicles were invented more than 150 years ago and have many ecological aspects, there are some issues regarding them which should be solved to make them more attractive than ICEVs which are dominant in market. Firstly, electrical cars do not perform as well as the conventional vehicles especially in mileage. Conventional cars go longer distances than electrical cars. Secondly, charging stations for electrical cars need to be built up. There needs to be investments in energy distribution infrastructure for charging the batteries and refuelling hydrogen fuel cell vehicles. And finally, the electrical cars have higher costs for the consumers and producers as economies of scale cannot be applied to this new sector yet. Moreover, the perception of people on new technologies is an important factor for the transition to new technologies so e-mobility technologies should also be recognized and accepted by the society. For a technology to be acceptable, it should be convenient in terms of price, accessibility, user friendliness. Therefore, implementing a sustainable system is not only about technical implementation but also a social implementation where people recognize the new system and accept it. For people to accept this rather new technology in large scales, profitable and sustainable business models should be developed. Many countries have been conducting researches and developing programs for EVs and the batteries, charging stations, testing different technologies and business models.

Business model describes how organizations creates, delivers and captures value from their product and service offerings in economic, social, cultural and other contexts, by giving attention to how they configure their activities with partners and suppliers and deliver value to customers [4]. In e-mobility industry, business model parameters such as the value proposition, target customers, and the roles within industry are still not defined clearly [5]. As the e-mobility market is at its early stages, various business models are being tested. Business models differ according to the business type; municipalities, electric utilities, EV and EVSE producers will have different business models according to their interests. However, they all aim for enhancing e-mobility market and gaining profit from this new business. This is only possible when they collaborate as they need each other for the areas which do not some within their area of expertise. For example, car producers cannot provide electricity so they need electric utilities; or e-mobility service providers need cars from car producers. The components of e-mobility system have already started to collaborate to get the best business outcome from e-mobility. Some business model examples applied in different parts of the world will be mentioned in this thesis along with the possible models which can be applied in the future when e-mobility has become a mass phenomenon. E-mobility is a business opportunity for many industrial areas. It is difficult to analyse it for every industry. Therefore, in this study, e-mobility will be analysed as a business solution for electric utilities, especially from the aspect of providing charging infrastructure. However, how the players in each segment of e-mobility ecosystem can take part in e-mobility, how they can contribute to e-mobility deployment will be explained. These players vary from authorities such as government bodies and municipalities, to EV and EVSE manufacturers. As the market is in early stages, it requires many investments for infrastructure; therefore, the business is not profitable at this stage. How e-mobility can be supported to become a profitable business will also be explained in this study.

Methodology of Collecting Data

For this thesis, information about e-mobility is acquired through following ways:

- Policy documents of the EU and Czech Republic
- Energy Regulation Reports from Czech Energy Regulatory Authority (ERU)
- Reports published by International Associations and Agencies
- Reports from European Commission and Organisation for Economic Co-operation and Development
- Scientific Papers
- Technical information from EV and EVSE producers
- Information from e-mobility service providers' websites
- Information from electric utilities' websites
- Reports from consulting companies
- Sources which keep statistical information about energy consumption and efficiency and alternative fuels such as ODYSSEE-MURE and EAFO
- Interviews with experts (2 of 3 biggest electric utilities of Czech Republic have been contacted). In these interviews, the experts from the utilities are asked about their perception and motivation of e-mobility; what they have done and what they are doing and their plans for developing e-mobility market in Czech Republic; whether they see e-mobility as a business opportunity; their plans on e-mobility services and public charging stations; their plan for determining tariff for charging; their solution for load balancing; the approximate costs of public fast charging stations and the motivation behind installing charging stations; technical information about the charging stations (charger types, current, voltage and power levels etc.) subsidies they are receiving if any and so on.

1. E-mobility and Its Expected Development

1.1 E-mobility & Its Development in Europe

E-mobility, electrified automobility in long, is more than being about the electrification of the car and its technological implications. It is a system innovation towards more sustainable mobility system. It is transformation from an oil-based transportation system to electricity-based system which is integrated and multi-modal intelligent traffic system. It is a system innovation towards more sustainable mobility system which concerns on mobility, environment and energy sectors that includes motorized passenger transport, public transport and transport of goods. The need for e-mobility systems emerged from Europe's policy commitments on climate change as decarbonizing the transport systems is the key for reducing the GHG. The Directive 2014/94/EU is adopted by European Parliament and the Council on 22 October 2014 for the usage alternative fuels as power sources instead of fossil oil sources in the energy supply and the transport sector to contribute to decarbonization and improve the ecological performance of the transport sector. The directive encourages private investments for the development of alternative fuel infrastructure rather than using public sources. The directive has three main measures [6]:

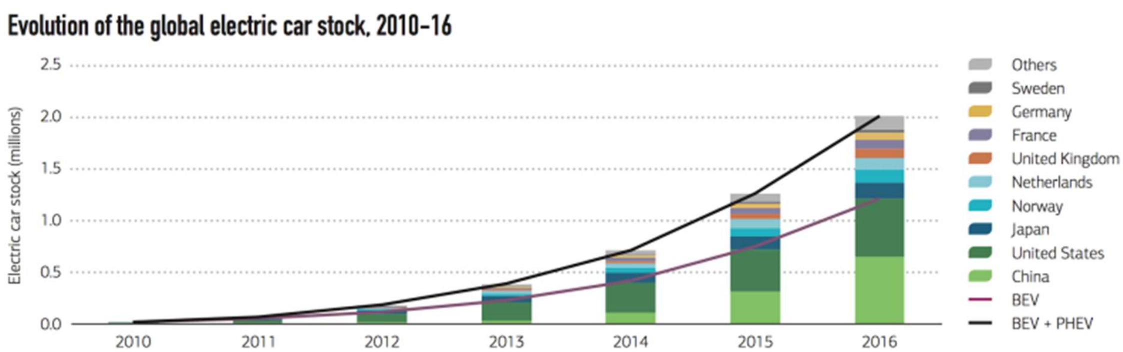
-Member states should submit their own national policies, objectives and the refuelling and recharging points for alternative fuels to the EC and EC will publish them after evaluating them whether they are sufficient at EU level.

-The EU standards should be applied to the infrastructure; common plugs should be used. Common standards should be developed for future technologies like wireless charging point, battery swapping technology and plugs for buses and motorbikes.

-There should be understandable information available on the compatibility of the cars with the charging stations in EU market or any other information applicable within the traffic as a part of Intelligent Transportation Systems.

By 2050, 60% reduction against the measured level in 1990 is expected in GHG emissions from transport in the EU and complete decarbonization is required in passenger cars' emissions due to COP21 commitment to limit the temperature rises to 1.5°C [7]. Therefore, with decarbonization motivation, the transition to zero emission vehicles has started and electrification of transport systems has a large role in this transition. The most cost effective zero emission technology until 2030 is considered to be BEV. By 2050, hydrogen fuel cell based technology or a new technology can become more cost-effective; however, hydrogen fuel cell vehicles are not zero emissive [8]. BEVs are not as feasible as the cars powered by internal combustion engines (ICE) in terms of price and range; also, they do not fulfil the same functions as conventional cars like how hybrid or fuel cell electrical vehicles do. However, they promise a radical change in transport systems if they are thought as a part of an integrated mobility system where BEVs are not only privately-owned cars but also are used as electric bikes and public transport services where they are part of changed energy infrastructure [9]. But, of course, this does not mean that BEVs will automatically change the modern transport system. There are many issues that should be overcome such as the shortness of the car model lifetimes, non-availability of the popular models, low density of battery, high costs and the requirement for replacements or upgrades to maintain the market share. There is also massive investment in energy distribution infrastructure needed for charging the BEVs. However, once these barriers are removed, the transition may be demand driven as it is assumed that BEVs will have less costs than ICEVs in the next decade. As electrical cars are easy to manufacture and as they are based on electronics, software and batteries, there are new players in the car market like Tesla. Many car companies are shifting to e-cars and some of them already have several e-car models in the market. The EV market has been expanding over the last decade and the registrations of EVs hit a new record in 2016 with over 750,000 sales worldwide (Figure 1). However, despite the significant increases, market growth rate has been declining in the past 5 years and in 2016, e-car stock growth rate fell to 60% from the rates 85% in 2014 and 77% in 2015. In spite of this decline, 2025 sales objective can still be met if 2016 rates can be maintained [10].

The electric market is growing but the achieved number of e-cars globally is still very small that it only corresponds to 0.2% of the total number of PLDVs. However, with the continuous improvements in the EV technologies and mass production will lead to decline in EVSE costs especially in battery costs and increase in energy efficiency. As the cost difference between EVs and ICEVs decreases, the competitiveness gap between them will also decrease. The researches show that the e-car stock will range to between 9 million and 20 million by 2020 and between 40 million and 70 million by 2025 [10]. Norway is a good example for showing that if the EVs have similar price as ICEVs have, then customers will buy EVs in large numbers. In September 2016, the EVs market share was close to 50% and it was only 3% in 2010. This shows that market can easily switch to EVs if the EV price is similar to ICEV price [11]. The e-car sales number was 215 thousand in Europe in 2016 and it is unevenly distributed due to different incentive and policies applied in different countries. Norway, the United Kingdom, France, Germany, the Netherlands and Sweden were accounted for most of these sales with 75%. Norway has the largest e-car deployment rate with 29% market share in the world. Netherlands follows it with market share of 6.4% and then Sweden follows them with 3.4%. China, UK and France have e-car market share close to 1.5%. In 2016, the e-car stock surpassed 2 million vehicles globally. It was 1 million in 2015 (Figure 1) [10].



Source: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

Figure 1: Evolution of Global Electric Car Stock, 2010-2016, [10].

In the first half of 2017, 450,000 EVs have been sold globally which corresponds to the 1.2% of the total passenger cars sales. 65% of these EVs were BEVs and the remaining were PHEVs. Even though the market growth rate has decreased compared to 2016, the car sales increased by 44% compared to the first half of 2016. This increase in EU was 37% compared to 2016 with 97,000 EVs sold.

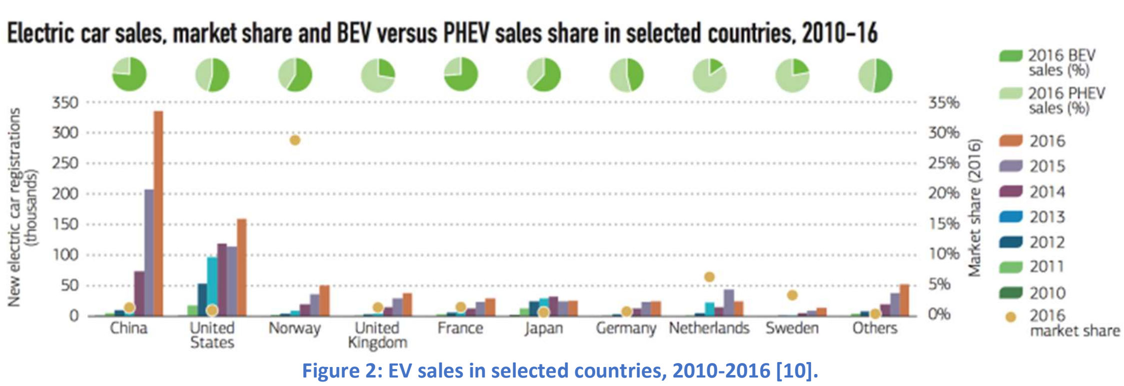


Figure 2: EV sales in selected countries, 2010-2016 [10].

Before putting the more detailed tables for EVs, it is better to give some information about the car types. There are 3 main categories of cars [7]:

• **ICEV**: Internal Combustion Engine Vehicle: The cars which are using natural gas, LPG, diesel and gasoline as fuels. Advantages: Various models, many refuelling stations. Disadvantages: Carbon emission, fossil fuel dependency, higher engine noise, low energy efficiency. HEVs are in this group.

• **PHEV**: Plug-in hybrid electric vehicles. Hybrid vehicles have both a conventional engine and a battery powered electric motor (Figure-3). Advantages: Higher energy efficiency, private charging and many refuelling stations. Disadvantages: high technological complexity. **Range Extenders (REX)** can be considered in this group. REX is powered by an electric motor and plug-in battery, with an auxiliary combustion engine used only to supplement battery charging.

• **ZEV**: Zero-emission vehicles: **BEV**s (battery electric vehicles), and **FCEV**s (fuel cell electric vehicles) (Figure-3). Advantages: Zero emission, higher energy efficiency, low engine noise and private charging possibility Disadvantages: Fever charging points, long time for charging, short driving range.

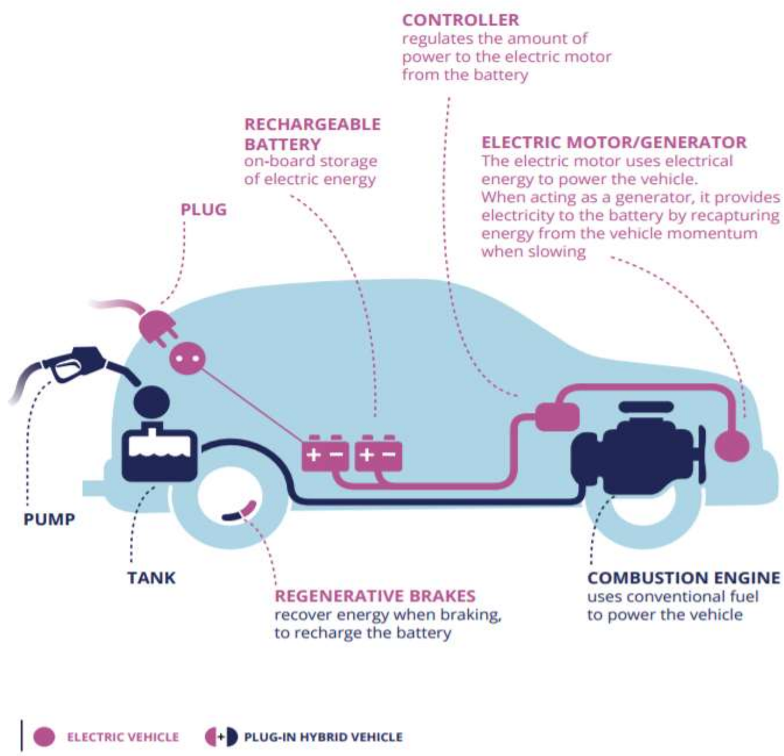


Figure 3: The main parts of e-car [12]

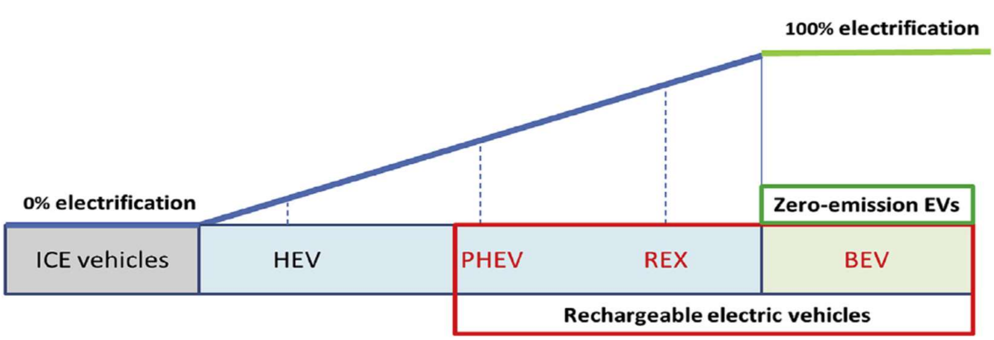


Figure 4. Level of electrification of electric vehicles [13]

Currently, HEVs have the largest share of EV market as they have similar characteristics to ICEVs. As HEVs have conventional engine which uses fossil fuels for power, they cannot be considered as a way for emission reduction but considered as a way for energy efficiency. For emission reduction, there are higher expectations from ZEVs which are fully electrified. However, their number is low due to their high costs, low operating range, limited infrastructure and low battery density. To make them economically competitive on the market, there are several policies to support them which will be mentioned in the chapter 2. Total cost of ownership (TCO) of an EV depends on the distance which is driven by the car, which can be seen from the formula below:

$$TCO = \frac{(IC + \tau_{REG}) \cdot \alpha}{skm} + P_f \cdot FI + \frac{C_{O\&M}}{skm} \quad (\text{EUR}/100\ \text{km})$$

Formula 1

IC: Investment costs
τ_{REG}: Registration tax
α: Capital recovery factor
skm: specific number of km driven per car per year
P_f: energy price including taxes
$C_{O\&M}$: Operating and Maintenance costs
FI: Energy consumption of vehicles

According to this formula, it can be said that EVs can be more economic or less economic depending on their driving activity. Especially, the vehicles which are driven frequently or driven in longer distances such as taxis, delivery and service vehicles, can be more appropriate for electrification as their travel activity will be higher and thus they will be more economical [13].

The number of EVs by each European country are shown as in Table-1:

Table 1: The number of BEVs, PHEVs and PEVs by European countries [11]

Fuel Source	BEV					PHEV		PEV	
Vehicle Category / Country	L (Motorbikes)	L6+L7 (Quadricycles)	M1 (Passenger cars)	N1 (Light Commercial Vehicles)	M2 + M3 (Buses)	M1 (Passenger cars)	M2 + M3 (Buses)	M1 (Passenger cars)	M2 + M3 (Buses)
Europe	19.767	24.499	414.394	59.245	1.603	443.982	639	858.376	2.242
EU 28	17.726	21.128	300.176	55.883	1.560	371.160	604	671.336	2.164
Austria	1.681	694	11.860	1.618	164	2.994		14.854	164
Belgium	2.629	1.329	7.312	641	3	17.393	145	24.705	148
Denmark		416	8.844	623	6	786		9.630	6
France	5.150	4.819	80.337	27.534	74	21.462	1	101.799	75
Germany		5.233	48.571	7.469	111	44.160	120	92.731	231
Italy		2.937	6.145	2.069	38	4.467		10.612	38
Netherlands	402	1.062	16.316	1.876	186	98.894		115.210	186

Fuel Source	BEV					PHEV		PEV	
Vehicle Category Country	L (Motorbikes)	L6+L7 (Quadricycles)	M1 (Passenger cars)	N1 (Light Commercial Vehicles)	M2 + M3 (Buses)	M1 (Passenger cars)	M2 + M3 (Buses)	M1 (Passenger cars)	M2 + M3 (Buses)
Norway	709	1.992	97.615	2.624	16	43.137		140.752	
Spain	2.159	2.382	7.750	2.480	37	4.353	50	12.103	87
Sweden		380	10.130	1.517	43	27.464	17	37.594	60
Switzerland	1.204	1.152	11.695	591	6	7.507	35	19.202	41
United Kingdom		625	40.358	3.540	191	71.370	153	111.728	344
Bulgaria	159	16	27		52	31		58	52
Croatia	199	100	179	61	9	86		436	9
Cyprus		2	50	3		59		109	
Czech Republic	**1.495**		**1140**	**202**	**22**	**581**		**1721**	**22**
Estonia	2		1.149	29	24	71		1.220	24
Finland	367		1.029	163	2	3.084		4.113	2
Greece			109			114		223	
Hungary			523	98	33	232		567	
Iceland	28	16	1.380	92	1	1.713		3.093	
Ireland		15	1.693	98		573		2.266	
Latvia	46	26	280	12	2	44		324	
Lithuania	33	5	116	8	6	44		160	
Luxembourg	12	12	905	138	26	791		1.696	
Malta		80	92	22		7		99	
Poland		10	588	34	98	459	50	976	148
Portugal	250	275	2.816	264	20	2.744		5.560	20
Romania		23	165	15	6	203		368	6
Slovakia			341	23	9	227		568	
Slovenia	33	65	483	70		237		720	
Turkey		52	278		10	191		469	

The number of FCEVs by European countries are shown in Table 2:

Table 2: The number of FCEVs by European Countries [11]

Country	Passenger cars	Buses	LCV	Heavy duty trucks
Austria	21	0	0	0
Belgium	25	11	0	0
Denmark	83	0	0	0
Finland	1	0	0	0
France	21	0	182	0
Germany	109	16	0	0
Ireland	1	0	0	0
Italy	11	13	0	0
Luxembourg	2	0	0	0
Netherlands	39	5	5	0
Norway	66	5	0	0
Poland	0	0	0	0
Sweden	28	0	0	0
Switzerland	51	5	2	0
United Kingdom	54	20	7	0

The electric market is growing but the achieved number of e-cars globally is still very small that it only corresponds to 0.2% of the total number of PLDVs. As the number of EVs have been increasing, the number of charging stations have been increasing too. In 2016, the growth rate of public charging infrastructures was 72% while the growth rate for e-car stock was 60%. It is normal that the growth for chargers was higher than e-cars as the chargers are prerequisite for EVs and its market. However, still e-cars are 6 times of public charging stations. This shows that most of e-car drivers rely on private charging stations. Publicly available chargers and e-car stock can be compared as in the Figure 5 [10].

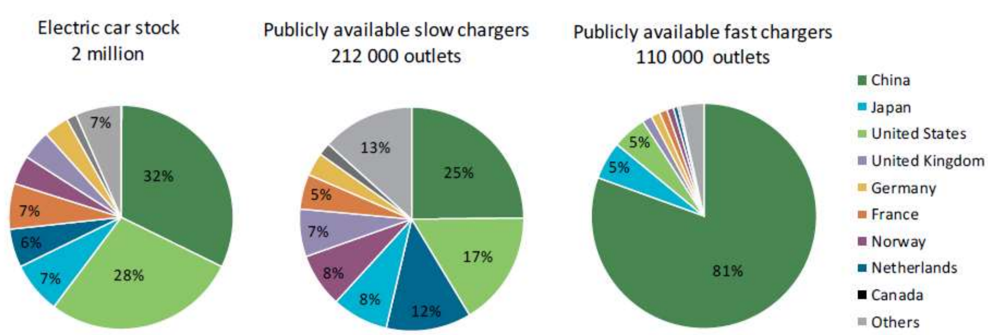


Figure 5: Electric car stock and publicly available EVSE outlets, by country and type of charger, 2016 [10]

Figure 5 shows the regional distribution of electric cars (left-hand chart), publicly accessible slow chargers (centre chart) and fast chargers (right-hand chart). As can be seen from Figure 4, the shares of publicly available chargers are not evenly distributed across the countries, this is normal as EV deployment is still at early stages.

In Europe, the number of normal power charging points was 101 947 and fast power charging points was 14 824 in 2017 [11]. The Netherlands have the most public charging stations with over 29 000. Germany has more than 14,000, France has more than 13 000, UK has more than 11 000 and Norway has more than 7 600 public charging stations [12]. Number of publicly accessible charging positions (normal and high power) and the number of PEVs per position in Norway, the United Kingdom, France, Germany, the Netherlands (top 5 countries which have the most charging stations) and Czech Republic are shown in the Table-3:

Table 3: Number of Charging Positions and Number of PEVs per position in selected countries [11]

Country	Charging Power	kW	# positions	# PEV per position
Czech Republic	Normal Power	<= 22	459	4
	High Power	> 22	225	9
	Totals		684	3
France	Normal Power	<= 22	14.407	9
	High Power	> 22	1.722	77
	Totals		16.129	8
Germany	Normal Power	<= 22	18.334	5
	High Power	> 22	1.961	54
	Totals		20.295	5
Netherlands	Normal Power	<= 22	29.813	3
	High Power	> 22	680	173
	Totals		30.493	3
Norway	Normal Power	<= 22	7.947	18
	High Power	> 22	1.686	87
	Totals		9.633	15
United Kingdom	Normal Power	<= 22	11.117	10
	High Power	> 22	2.407	49
	Totals		13.524	8

1.2 E-mobility in Czech Republic

Czech Republic (CR) has population of 10.535.000 and total land area of 78.866 km2 [11]. The GDP is (in billions): USD 389,03 and GDP per capita is USD 36.927 [14]. Total Primary Energy Supply (TPES) per capita is 3,92 toe/cap which is lower than IEA average 4,42 toe/cap. Electricity consumption per capita is 6,46 MWh/cap which is lower than IEA average 8,69 MWh/cap. CO2 emission per capita is 9,44 t CO2/cap which is lower than IEA average 9,88 t CO2/cap (2015 data) [15]. Total length of highways is 1.247 km. Total movement of passenger road transport is 82.512 million passenger km [14]. The total number of passenger cars in Czech Republic is 4.729.000 as of 2017 [11]. Automotive is the most important sector in CR as it has the largest industrial output and export with 20% rate among the other sectors. The automotive industry is growing with the increasing numbers of cars produced. 85% of the cars that are produced in CR are exported to mainly Western European countries. In 2016, almost 260,000 units were registered in the Czech Republic. CR was the 4th largest car producer in Europe with the total 1,375,814 units of motor vehicles production in 2016 and the growth of motor vehicle production was 8.3%. All the car producers in CR are growing. Skoda is the largest car producer that produced 765,171 passenger cars (55.6%) in 2016. The second biggest car producer is Hyundai Motor (358,400 units; 26%) followed by Toyota Peugeot Citroën Automobile (220,611 units; 16%) [16]. The total number of passenger cars has been increasing over the years (Figure 6):

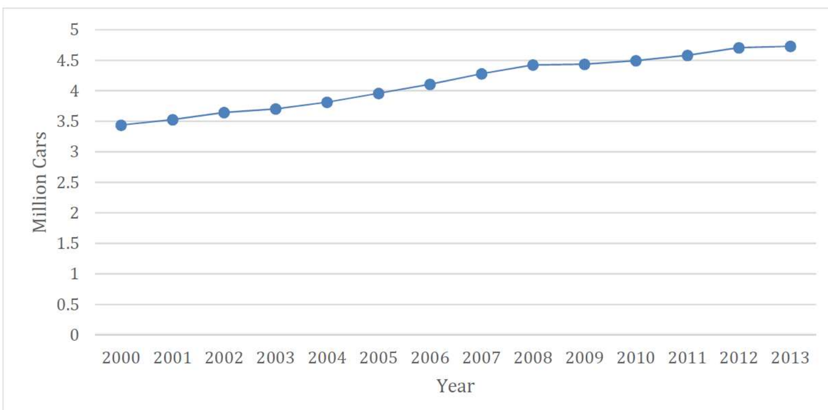


Figure 6: Number of passenger cars in the Czech Republic [17]

The annual distance travelled by passenger cars in CR can be seen in Figure 7:

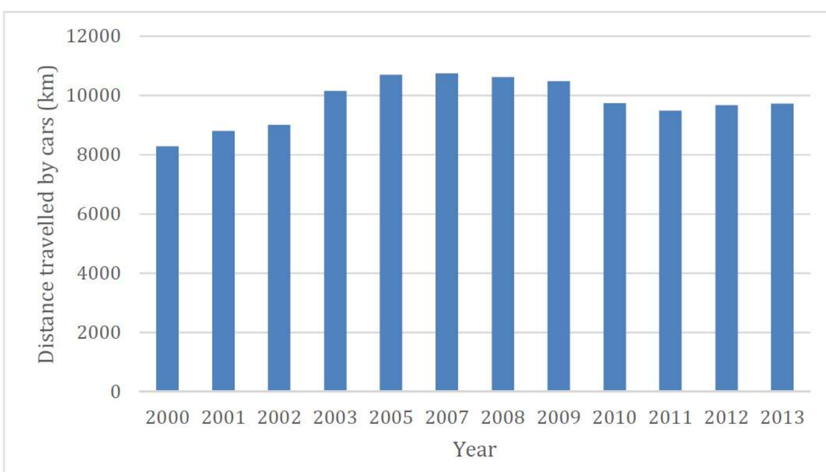


Figure 7: Annual distance travelled by passenger cars in the Czech Republic [17]

The energy efficiency index of transport in Czech Republic has been decreasing slowly in the last years. It decreased only by 7.8% in the years between 2000-2013. This happened due to growth of road transport instead of public transport and lower capacity utilization in road transport. Importing old cars from Western Europe also had a negative impact on the index. The energy efficiency index improvement in the Czech Republic was by 6.3%, worse than in the EU28 in average during the period 2000 – 2012 [17].

To reduce the emissions from road transport and to increase the efficiency in transport, the EV has gained attention in CR too. The current market share of EVs can be seen in Figure 8.

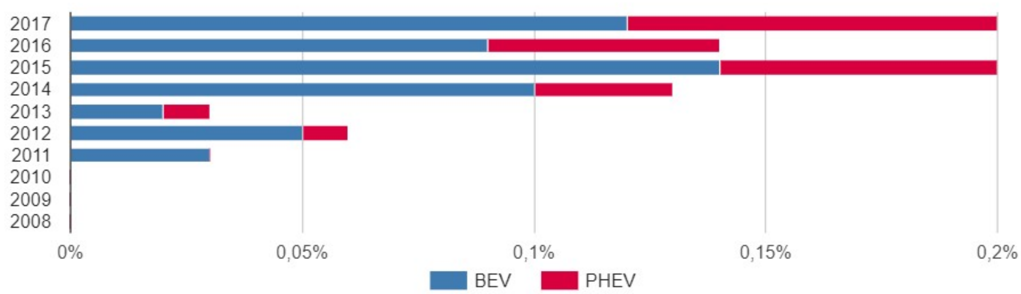


Figure 8: Market share of electric cars, BEV and PHEV in CR [11]

The number of newly registered EVs over the last decade can be seen in Figure. This can help us to analyse the trend for having EVs. In 2017, 139 units of PHEVs and 201 units of BEVs have been registered. As of now, there are 1140 BEVs and 581 PHEVs in Czech Republic making 1721 EVs in total. Compared to beginning of 2017, the total number of EVs increased by 12% in beginning of 2018. BEVs share was 62% in total EV number in 2017; this ratio is 58% in 2018 [11].

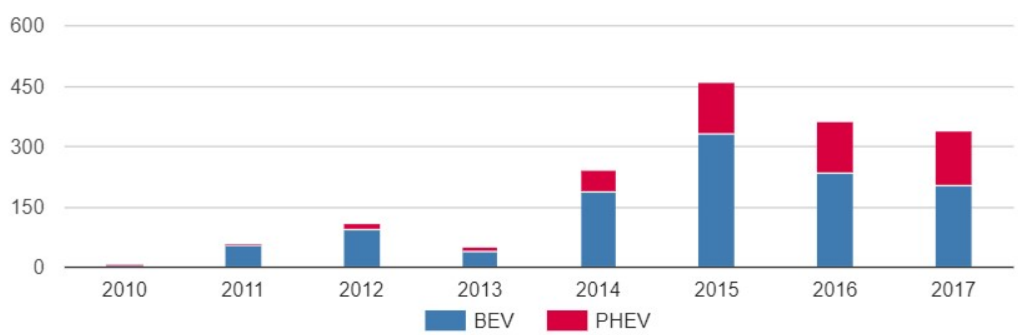


Figure 9: The Number of newly registered EVs in CR [11]

The total market share of EVs among passenger cars can be found as:

$$\frac{Total\ number\ of\ EVs}{Total\ number\ of\ passenger\ cars} = \frac{1721}{4.729.000} * 100 = 0{,}04\%$$

Market leaders with electric vehicles in 2017 were BMW (53 units of BMWi3 & 35 units of X5 40e), Volkswagen (37 units of e-Golf), Nissan (36 units of Nissan Leaf) and Tesla (27 units of Model S). Market share of the car companies in Czech Republic can be seen in Figure 10.

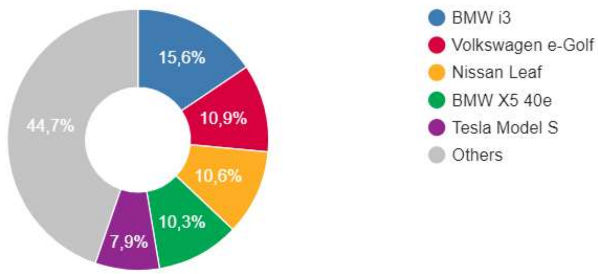


Figure 10: Top bestselling models in CR [11]

As mentioned before, the charging stations are the major factor for the deployment of EVs in the car market. Currently, there are 546 charging points in CR (Table 4).

Table 4: The Normal and Fast Charging Points in CR [11]

Country	Charging Power	kW	# positions	# PEV per position
Czech Republic	Normal Power	<= 22	459	4
	High Power	> 22	225	9
	Totals		684	3

At the end of 2015, Czech Republic adopted a strategy called 'National Action Plan for Clean Mobility (NAPCM)' to support eco-friendly mobility. NAPCM is one of the non-legislative tasks of the Ministry of Industry and Trade. The Government approved this National Action Plan on 20 November 2015. The NAPCM is closely related to the Czech Republic's Transport Policy for 2014-2020. The objectives of the NAPCM are also in line with the State Environmental Policy, which is submitted by the Ministry of Industry and Trade in cooperation with the Ministry of Transport and the Ministry of the Environment. One of the main objectives is to ensure the transposition of the European Council Directive 2014/94/EU on the implementation of alternative fuels (CNG (compressed nature gas), LNG (liquefied nature gas), and electricity) infrastructure in the Czech legislation. NAPCM fulfils the requirement of Directive 2014/94/EU for Member States to develop a national framework policy framework for the market development of alternative fuel infrastructure and to define targets for building minimum infrastructure for different types of alternative fuels. The aim is to make the EVs equal to ICEVs in terms of costs and market share. This plan includes the subsidies for the new vehicles and construction of the charging network. For example, it is planned that the EVs can be parked for free in the cities and they can be used in the public transport lanes. By 2020, it is aimed that there will be charging infrastructure in every city and in the highways; there will be 1,300 recharging points, 6,000 BEVs and 11,000 PHEVs in operation; the annual sales of EVs will be 7,000. By 2025, it is aimed that there will be charging infrastructure in towns; there will be 35,000 BEVs and 66,000 PHEVs in operation; and the annual sales of EVs will be 25,000. By 2030, it is planned that the vehicles which use alternative fuels will have 10% market share; the number of EVs in operation will be 250,000 and the annual sales of EVs will be 44,000. After 2030, it is most likely that the subsidies will be ended as the e-mobility will be perceived as a standard technology. It is predicted that there will be 400,000 EVs in operation and the annual sales of EVs will be around 50,000 which would be approximately 23,7% of new car sales [18].

Objectives of NAPCM will be explained in Chapter 3 in more detail.

2. E-mobility Ecosystem

An e-mobility ecosystem consists of vehicles, infrastructure (charging points), providers and regulations & subsidies (Figure 11). Each of these segments contribute to the ecosystem with its own upsides and downsides. A successful e-mobility system implementation is possible by having the right combination of these segments [19].

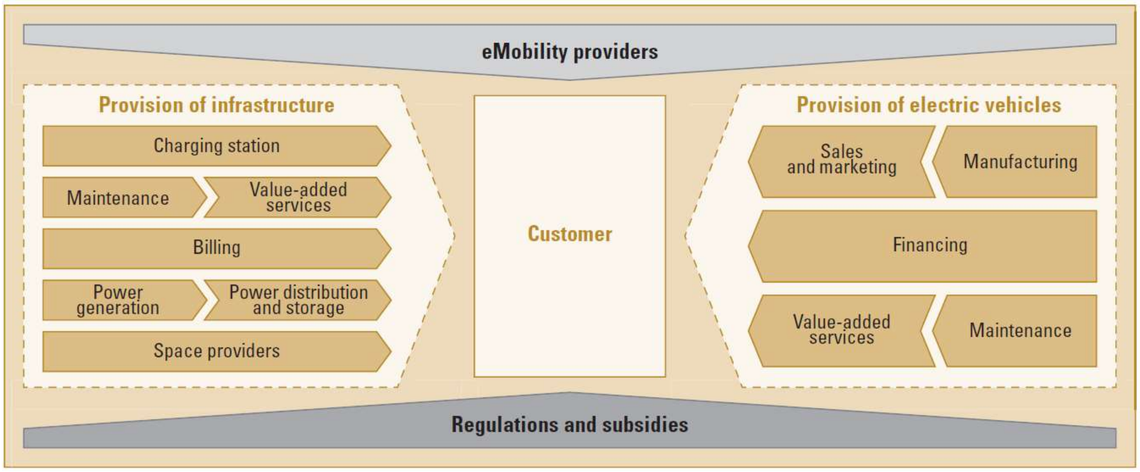


Figure 11: The E-mobility Ecosystem [19]

2.1 Provision of Electric Vehicles

This segment consists of automotive original equipment manufacturers (OEM), automotive component providers, small-scale service providers, battery manufactures. With the increasing strict emission regulations, car producers are developing new solutions to avoid the penalties or the loss of market share. Producing EVs is an opportunity for the manufacturers to maintain/increase their market share and to satisfy the regulations set by the government authorities. Moreover, they can benefit from the subsidies and incentives that are provided by the authorities for their business.

Car producers specialize in engine and transmission systems. However, they outsource other components like batteries. Major producers are now trying to produce their own batteries or they are partnering up with battery companies to step up in the market. At this stage of the market, equipping the car with the best battery, achieving economies of scale and providing the customer the best value are the factors which shape the competition. In the future, having better electronics and software systems will gain more importance.

Battery producers have started to see the growing EV market as an opportunity to make investments. They are investing in R&D vehicle applications. Some of them have already started to partner up with the car producers to gain knowledge about the EVs and their platforms. As the EV market grows, the battery industry will evolve as well. Now, the battery prices are extremely high but with R&D and mass production, the battery costs will decrease and the battery performances will improve. Battery producers may want to expand their business into other systems of EVs to gain more profit. It is foreseen that they will also start to manufacture part for the power and thermal systems of EVs.

EVs have many new systems which do not exist in the conventional cars. The new systems consist of new gear boxes, electric power steering and water pumps to cool the electric engine. Batteries will also have their own supply chain consisting of battery packs, cell components, and some other basic materials. Mass production of EVs will bring out opportunities for battery component manufacturers and their suppliers while overthrowing the ICEV component manufacturers eventually. In Figure 11, the comparison between the ICEV and EV supply chain can be seen [20]:

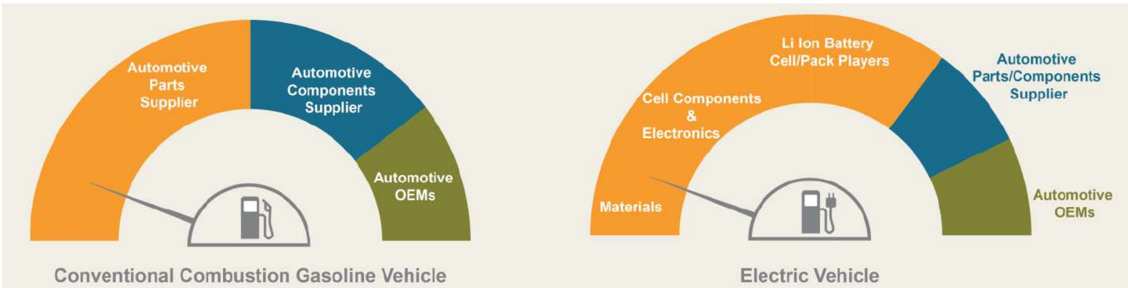


Figure 12: Industry structure for conventional and electric vehicles [20]

For EV and EVSE manufacturers, it is important to build strategic partnership with the infrastructure providers and electricity providers in order to have a successful business in EV market. Car producers need to decrease their costs to provide the best price for their prices. Therefore, they need to negotiate the costs of the materials with the suppliers. This is a good opportunity for start-up companies to step up in the game by making alliances with the car producers. Both sides can make profits by working together. The government authorities also help the EV and EVSE manufacturers by providing support policies. In the following topic, the support policies applied in EU and Czech Republic along with the environmental targets will be explained.

2.2 Targets and Provision of Support Policies

To increase the EV deployment, policy support is critical for making people adapted to this new technology. Policies increase the market share of EVs by making them appealing to public, reducing risks for investors and supports manufactures to encourage them to make more cars. [10]

The policies are a set of actions policymakers control, such as the providing legislation for public transport operations or constructing additional bicycle lanes or adding a lane for only EVs.

State and local authorities have a significant role for adapting the EV usage with their role to build a policy environment. They can support both demand side with incentives such as tax discounts/exemptions and special lane allowances for EVs and supply side with incentives such as easing the construction process of charging points.

For EV adaption, the authorities can play the following the roles:

-They can purchase PVs for their municipal fleet.

-They can ease the permission processes for constructing the charging stations

-They can provide incentives to manufacturers.

-They can invest in workforce training programs and consumer education programs. They can provide these training programs as well.

-They can revise the building codes suitable for EV deployment.

-They can provide charging points, tax rebates/exemptions/credits, dedicated lanes and parking spaces for EVs and other demand side incentives

-They can invest in pilot projects conducted by the utilities for EV deployment. They can work together with the utilities to develop a profitable business model for e-mobility.

-They can provide education programs to suppliers and consumers to inform them about the support policies that they are providing.

-They can provide R&D funding to the universities and research centres for EV research.

-They can work with banks to get the required financial loans for the EV research and construction projects and EV purchases as well.

-They can ally with investors to invest in EV and EVSE manufacturing. [20]

The EU governments are obliged to comply with the EU regulations. They set up and apply policies to reach the global and EU environmental targets. In this study, the carbon emission targets are mentioned as this study is about EVs.

2.2.1 Targets

In Paris agreement (2015), an expression 'carbon budget' is defined for showing how much carbon can be emitted to the atmosphere while keeping the global temperature rise below 1.5°C. Carbon budget can be seen as a threshold for the remaining GHG emissions. According to the Intergovernmental Panel on Climate Change (IPCC), maximum allowable carbon amount to keep the global temperature rise to 2°C is 2900 Gt for the period from the Industrial Revolution year 1870 to today and 2050 Gt of this budget has already been spent. Remaining amount is estimated to be spent by 2041. To keep the temperature rise below 1.5°C, then the remaining 850 Gt carbon budget will be spent by 2023 [21] & [10]. Carbon emission should be kept as minimum as possible so that we can have more time until the carbon budget is spent. For this, GHG emissions from each contributing sector should be decreased. Transport sector accounts for 20% of total GHG emissions in EU and 72% of these emissions are from road transport. To decrease the GHG emissions, EU has set targets and implemented some policies to reach them. Some policies are set at country level, and some of them are set at EU level [22]. In this chapter, the policies which are applied and the targets which are set in some EU countries and Czech Republic will be studied.

Targets to be reached by 2020 [22]:
-Increasing the share of RES in final energy consumption to 10%
-A target limit of 95g CO_2/km
-Ideally one charging point per 10 EVs

Targets to be reached by 2030 [22]:
-Reducing the GHG emissions by at least 40% compared to the 1990's GHG level, 20% compared to 2008's level.
-Increasing the share of RES in final energy consumption to 27%
-Increasing energy efficiency by at least 27% [21]
-ICEVs should be reduced by 50% [3]

Targets for year 2050:
-60% cut in transport emissions
-No more ICEVs in cities

The above-mentioned targets can be shown together in Figure 13 below:

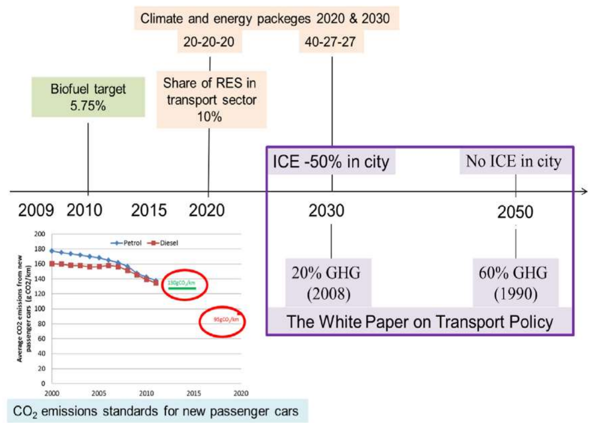


Figure 13: Development of EU targets regarding reduction of GHG emissions in transport. [22]

As the EV market is growing, state and local authorities will need to reconsider their support policies. Incentives for EV purchase will not be needed as the car prices will decrease. The subsidies will not be economical for the authorities for the larger sales volumes of EVs. Governments will need to consider how the state budget will be affected when the taxes collected from conventional fuels decrease due to EV transition. There may come a point where the states increase the taxes for the electricity to compensate the fiscal deficit. Reusing and recycling the EV batteries will also become important. Policies will be needed for the issues regarding batteries [10].

Assuming that the current subsidies overcome the initial hurdles, it is expected that price/performance ratio for BEVs will be around the same as for ICEVs' by 2022. Vehicle cost is not the only concern for an EV car owner as the charging stations are limited and there are additional costs. In developed countries where the electricity distribution is well developed and subsidized, new BEV penetration curve will almost follow the vehicle cost parity. In Europe, BEVs are expected to have the 50% new car market share by 2025 (Figure 14) [21].

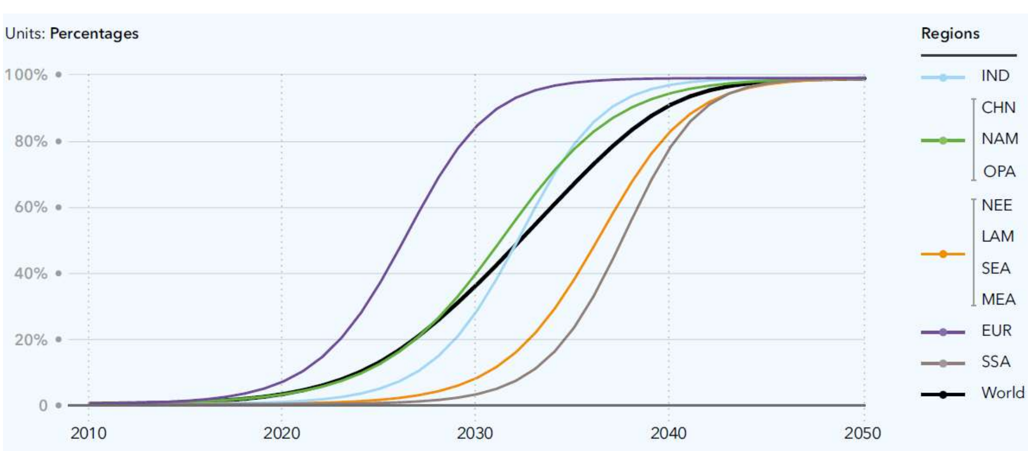


Figure 14: Market Share of EVs in New Light Vehicle Sales [21]

2.2.2 Main Support Policies for EVs in some EU countries and Czech Republic

The support policies for EVs vary in different countries depending on their country policies. Some examples for policies which are for increasing the value proposition of e-cars can be given as below:

-Restricting the availability of licence plates for the ICEVs and exempting the EVs from the restriction.

-Banning the vehicles which do not meet the exhaust emission standards from traffic. This encourages the use of electric, hydrogen and hybrid cars.

-Exempting the EVs from paying the fees for special roads, parking places, highways etc.

-Dedicating park lots for EVs.

-Constructing publicly available charging points.

The main policies of the EU countries where the e-car market is bigger, are given as follows [10] & [11]:

Denmark:
-EU tailpipe emission standard (Euro 6 in 2016) is applied

-E-cars were exempt from registration until 2015 and this exemption is planned to be cancelled between 2016 and 2022. 20% of the full tax rate will be applied for BEVs by 2016 and full tax rate will be applied by 2022.

-Starting from 2017, battery capacity-based purchase tax rebate has been applied (USD 225/kWh with maximum 45 kWh).

France:
-EU tailpipe emission standard (Euro 6 in 2016) is applied.

-Fixed grant is available for changing an end-of-life vehicle with a new EV: CO_2/km-based eco bonus-malus scheme (bonus of EUR 6 300 (USD 6 900) for BEVs and EUR 1000 (USD 1 100) for PHEVs, up to EUR 10 000 (USD 11 000) for BEVs and EUR 3 500 (USD 3 900) for PHEVs when returning an old diesel car).

-Tax discounts for company cars

-Electricity and hydrogen tax exemption

-Government has committed that 50% of their fleet will consist of EVs which uses electricity produced from RES starting from 2017. This rate is 20% for local authorities' fleet. For these EVs, discounts will be applied depending on charging during peak or off-peak times.

Germany:
-EU tailpipe emission standard (Euro 6 in 2016) is applied

-Purchase rebates of EUR 4000 (USD 4 400) for BEVs and EUR 3 000 (USD 3 300) for PHEVs, at the limit of 400 000 cars until 2020 or EUR 600 million (USD 674 million)

-Car producers should provide half of the incentive amount while the government covers the other half

-EVs are exempted from circulation tax for 10 years. This will be reduced to five years starting from 2021

-Tax discounts for company cars

-Providing different plates for EVs to allow them for differentiated measures

-Dedicating parking places to EVs and

-Allowing access to EVs for bus lanes

-Discounts for charging EVs based on peak and off-peak prices

Netherlands:
-EU tailpipe emission standard (Euro 6 in 2016) is applied

-Exemption from registration tax for ZEVs. The registration tax for PHEVs depends on gr CO_2 level per km. It is € 6 per gram for Level 1 (1-79 gr CO_2/km) PHEVs, € 69 per gram CO_2 for level 2 (80-106 gr CO_2/km) and € 476 per gram for the final level (174 g CO_2/km or over)

-Ownership tax exemption for BEVs, 50% discount for PHEVs. The ownership tax is EUR 400 to EUR 1 200 for ICEVs.

- CO_2/km-based taxation on the private use of a company car: 4% income tax for BEVs; 15% for PEVs with < 51 g CO_2/km, 21% for ones with 51 – 106 g CO_2/km and 25% for ones with over 106 g CO_2/km level.

-EVs are considered as tax deductible investments for companies due to their fully or partly exemptions from taxes.

Norway:
-EU tailpipe emission standard (Euro 6 in 2016) is applied

-Purchase/import tax exemption for BEVs & FCEVs. Reduction for PHEVs up to € 11 000

-VAT exemption for BEVs (25% of vehicle price before tax)

-Further purchase rebates and purchase tax waivers introduced for PHEVs in 2016 (maintaining VAT)

-VAT exemption for leased BEVs

-Circulation tax exemption

-Maintaining BEV taxation schemes until 2020 while possibly revising PHEV taxation schemes

-Public funding for fast charging stations every 50 km on main roads.

-Waiver on road tolls and ferry fees

-From 2016 on, free parking measures have started to be managed at the municipal level.

Czech Republic:

-discounts for charging electric vehicles based on peak and off-peak prices

-no purchase taxes

-For companies, no road tax for their electric, hybrid and other alternative fuel vehicles [11]

-By the end of year 2017, the amendment to Decree No. 343/2014 which introduces the special licence plates for EVs will be approved. From 2018 on, EVs with special plates will be able to use bus lanes, enter low emission zones and benefit from discounted parking with this amendment. [24]

Table 5: Comparison of Incentives of some EU countries including Czech Republic [11]

Countries	Purchase Subsidies	Registration Tax Benefits	Ownership Tax Benefits	Company Tax Benefits	VAT Benefits	Other Financial Benefits	Local Incentives	Infrastructure Incentives
Czech Republic		√	√					
Denmark	√	√		√			√	√
France	√	√	√	√			√	
Germany	√		√	√		√	√	
Netherlands		√	√	√				
Norway		√	√	√	√	√	√	√

2.3 Provision of Infrastructure

Provision of infrastructure involves various industries; charging station business, power generation, service offerings and billing and tariff systems.

2.3.1 Technical infrastructure for recharging systems

Charging infrastructure is crucial for operating EVs. The availability of charging stations is one of the driving factors for EV deployment. The EVs can be charged in three ways: plug-in charging, battery swapping or wireless charging.

Wireless charging:

This method is also known as induction charging. It is contactless way of charging which is the newest method. An EV is placed on a charging pad. Around this pad, the system creates an electromagnetic field. The battery is charged by electromagnetic induction. This method is used only in some pilot locations and has not started to be used commercially yet. In Belgium, Germany, the Netherlands and the UK, this method is used for charging buses at bus stations.

Battery swapping:

This method is changing the used battery with a fully charged one at a swapping place. This is a fast way for charging the EV. Currently, there are not any major providers for battery swapping in Europe. There are some barriers hindering this method to be commonly applied: lack of EVs which support battery swapping, no standard for battery types and sizes and high costs of charging and swapping stations.

Plug-in charging:

The most common method for charging the EVs. This method involves charging the EVs by physically connecting them to a charging point with a cable and a plug. Plug-in charging points can be built in private and public locations [12].

Plug-in charging systems consist of cables, connectors, communication protocols between EVs and EVSEs, EVSE-distribution system operator (DSO) communication. The charging equipment for EVs has three main characteristics [10]:

• **level** describes the power output of an EVSE outlet

• **type** refers to the socket and connector being used for charging

• **mode** which describes the communication protocol between the vehicle and the charger (the way to manage the charging process).

There are four modes for charging and each of them have different combinations of power level (kW), type of electric current used (AC or DC) and plug types. The batteries can only store DC and the grid supplies AC; therefore, the current should be converted. This conversion can either be done by a converter inside of the charging point or a converter inside the vehicle. DC-fast charging stations have these AC-DC converters inside of the charging points so the stations convert the current from AC to DC and charged the EV with DC electricity. The simplified charging system can be seen as the below:

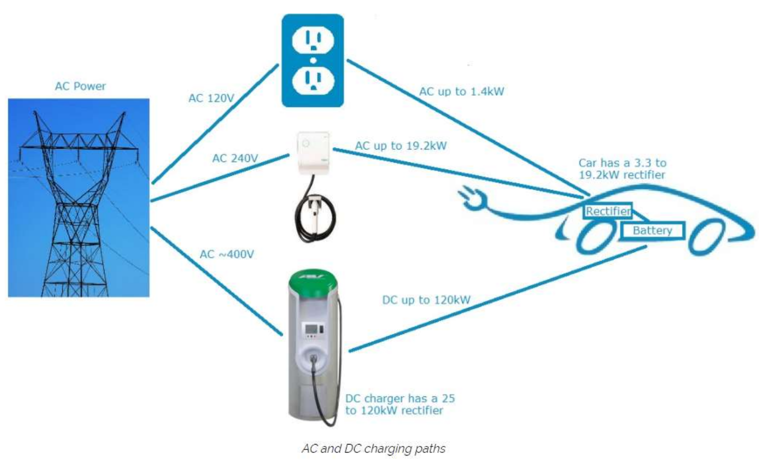


Figure 15: Charging Paths Diagram [25]

The power of charging can be determined with the voltage and the maximum current of the power supply. The more power the supply has, the quicker the charging is. The power of charging points varies from 3.3kW to 120kW.

Mode 1 (Slow Charging): The power level is 3.3kW. It is commonly used in houses and offices as it allows EVs to be charged by household sockets and cables.

Mode 2 (Slow or semi-fast charging): Household sockets can be used but a special charging cable should be used. This cable is provided by the car manufacturer. It provides AC.

Mode 3 (slow, semi-fast or fast charging): Uses dedicated socket and cable for allowing safe charging at higher power levels. The charging point can be installed to the wall with a box which is commonly used at residential places or as a stand-alone pole which is commonly used in public places (Figure 16). It provides AC.

Mode 4 (fast charging): This mode is also known as 'off-board charging'. An AC/DC converted is inserted in the charging point so DC is delivered to EV. This high-power level charging has some disadvantages. Firstly, the efficiency is lower as the power loss is higher at higher currents. Secondly, fast charging can decrease the battery lifetime. Thirdly, Fast DC charger are three times more expensive than the AC chargers. Also, only some new models of EVs have DC charging feature, others need additional device for DC charging which is an additional cost. Thus, investors are reluctant to invest in DC charging [12].

Figure 16: Wall box charger [26] & Stand-alone charger [27]

Table 6: Charging times to charge 80% of an average electric vehicle battery [12]

Power, Current, Mode	Time	Location
120kW, DC, Mode 4	10 min	Motorway service area or dedicated charging stations in urban areas (future standard)
50kW, DC, Mode 4	20-30 min	Motorway service area or dedicated charging stations in urban areas (current standard)
22 kW, AC, three-phase Mode 3	1-2 hours	Most public charging poles
10 kW, AC, three-phase Mode 3	2-3 hours	Household, workplace wall box
7.4 kW, AC, single-phase Mode 1 or Mode 2	3-4 hours	Public charging poles
3.3 kW, AC, single-phase Mode 1 or Mode 2	6-8 hours	Household, workplace wall box

Commercial places generally use 3-phase distribution system so they can provide higher power for charging whereas the households use single phase distribution system which allows a limited power load. Chargers operating on AC power use same charging port on the EV. DC chargers, on the other hand, require specific vehicle port. 80% of an average battery can be charged in 30 minutes with DC charger. The remaining 20% charging will take the same amount of time as charging is nonlinear and the energy transmitted over time decreases with the increasing percentage by charging the battery. it often takes the same time to charge the vehicle battery from 0% to 80% as from 80% to 100%. If the station has multiple charging connectors, it must be adapted for the mode of operation with the measured kWh measurement so that each connector has its own power consumption.

Charging points can be private, semi-public and public places. Private charging points are found in households and companies. These charging points have charging wall boxes or common household plugs. Home charging is the most convenient way of charging as there needed no subscription or membership to charge the vehicle. Home charging is more for suburban and urban areas as it requires a garage to charge the car. However, in city centre where cars are parked in the streets, this option cannot be applied. Common charging points are needed in the streets for urban areas. Semi-public charging points are built in private premises but they are for public access. In some cases, the users pay for the service they are using (parking or utilization fee) not directly for the power they use. Generally, the users are not charged as the operators see the charging points as a complimentary service or as an advertisement. Shopping centres, commercial car parking places, leisure facilities, fast charging facilities are examples for semi-public charging places. Public charging points are found alongside the road parking places or in public car parks. These points are generally standalone charging pole type. In some cities, the municipality provides these charging points [12].

In some cities, public charging places are free for consumers as an incentive. Tesla offers fast charging places for free in Europe for people who have certain models. However, in the long term where the EVS become more common, this incentive is likely to disappear as it will be loss for the service providers. In some cities where the EVs are more common, there are already some payment methods applied. Generally, the users have smart cards from the service providers which they have subscribed to, and they are charged for the amount of the power and the time they use. This means that users need to have several cards to use different service providers. In some cases, the EVs are given an identification number. When the user wants to charge the vehicle, s/he only needs to put the digital ID number without needing a card. This is known as ‘plug and charge’. Other methods that are used for user or car identification are phone hotlines, text messages, smart cables which have a SIM card inserted or directly paying after charging through a smart phone app.

In Europe, the aim is to construct a system where the different charging providers are consolidated under and use eRoaming to simplify the process as there will be no different smart cards needed for each charging operator. eRoaming is an e-mobility market model which defines contractual relationship with involved e-mobility market players. With this system, people can charge their EVs at all charging stations and they are billed through their own provider who they have a contract with.

To briefly mention, there are several standards used for the connector types and the communication protocols. CHAdeMO is an association of vehicle manufacturers and utilities which has developed standard type of connector and protocol for DC quick chargers. CharIN is another association who promotes standardization in global scale. Tesla also has its own standard which supports all levels and modes of charging through the same connector type. Tesla has become a member of CharIN to comply with the European standards [10].

2.3.2 Developing charging point infrastructure in Europe

The main part for the EV deployment already exists which is the electricity grid. The charging points remain to be developed. Number of EVs will not increase if the charging infrastructure does not increase. However, it does not make any sense to increase the charging points without knowing how the EV market will grow. There are two general approaches for building up charging points: building a complete electric vehicle charging network in one go or expanding the network as the demand increases which is more common (incremental approach). The first approach is hard to apply in real life as public funding is limited and the investments to be made cannot be justified if the demand does not match the supply [28]. To minimize the deployment costs of EV deployment, charging infrastructure should develop in accordance with the EV growth. Charging infrastructure network should not only ensure to serve the existing EVs but it should consider the mass production of EVs and be ready for the market growth. The European Automobile Manufacturers' Association (ACEA) estimates a 3-10% market share by the mid-2020s. This means that new EVs between 450,000 and 1,500,000 units are estimated to be registered by 2020 to 2025 [29]. The Alternative Fuels Infrastructure Directive (2014/94/EU) estimates that there should be at least one public charging point for every 10 EVs always considering new developments in vehicle, battery and charging infrastructure technology, and that most private EV owners install their own charging points. The same directive requires the EU countries to identify the number of charging points needed to fulfil the demand within urban and suburban areas until 31 December 2020 [23]. Therefore, there is need for estimation for the number of recharging points which to be installed in urban and rural areas in EU. The ACEA's methodology to calculate the number of charging points which is based on motorisation and urbanization rates is given in Figure 17 [29]:

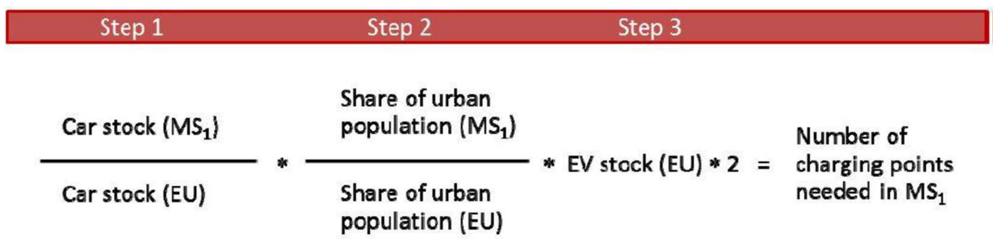


Figure 17: Methodology for Estimating the Minimum Number of Recharging Points [29]

For urban areas, OECD and EU proposed a definition for defining which areas should be considered as "functional economic units". The following criteria are considered when calculating the number of recharging points:

- future fleet of EVs (Directive 2014/94/EU considers 2020 as time horizon);
- demographic and land use data such as:
  - population,
  - population density,
  - working population,
  - locations of railway stations, ports or airports,
  - existing refuelling stations;
- traffic level emitted/attracted by each district.

According to the EMEA'S formula given in Figure 17, we can calculate how many charging points required in Czech Republic now. Currently, there are 1 743 EVs registered and 684 charging points in Czech Republic. Total EV stock in EU is currently 671 336 [11]. The total passenger car stock in Czech Republic is 4 729 000 units and in EU, it is 235.441.444 [11]. Urban population (% of total) in Czech Republic is around 73 % [61]; thus, the urban population can be found by the total population of Czech Republic multiplied by 0,73 which is 10 535 000 * 0.73=7 690 550. Urban population (% of total) in EU is around 75 % [62] and the total EU population is 510 464 684 [11]. Therefore, the urban population can be calculated as 510 464 684 * 0,75= 382 848 513. As all the components are known in the formula, the total number of charging points can now be calculated as:

$$\frac{4\ 729\ 000}{235\ 441\ 444} * \frac{7\ 690\ 550}{510\ 464\ 684} * 671\ 336 * 2 = 406$$

It can be seen that the Czech Republic has enough charging points for the current EV stock as the charging points needed is 406 and the charging points already existing is 684 which is more than enough for now from the point of number of EVs.

Electric power is totally different from gasoline. It cannot be stored in large amounts and must be kept in real-time balance between power generation and consumption. Therefore, it is very difficult to optimize the charging stations. Moreover, there are other factors which should be considered when optimizing the charging network: Various forms of power sources, different features in different geographical regions, difficulty of obtaining relevant data, diversity and flexibility of travel behaviour, multiple entities involved with different interests and objectives, complexity of modelling the road network and traffic condition and so on [30].

2.3.3 Electric Utilities as Infrastructure Providers

With the increasing market share of EVs, demand for charging them is increasing. EV charging network will require considerate amount of investment. It is still unclear whether the public sector or the private sector should meet the need for the charging points and the required investments. When and where the cars will be connected to the grid is a high concern for utilities as excess amounts can burden the grid especially at peak hours. One thing for sure that the low voltage distribution grids will be affected and this impact on the power network will highly depend on the technologies and charging modes used. Electric companies will face a variety of challenges when meeting electricity demand, integrating new variable and distributed resources, improving operating efficiency, and reducing costs for all customers. However, utilities can do more in e-mobility market other than dealing with the power demand and providing electricity. Electric utilities can finally have a bigger place in transportation sector with the rise of EVs. They have the potential to increase their presence in the e-mobility ecosystem as they are the main electricity providers. They have direct access to the customers they provide electricity so it is easy for them to provide charging service at houses or at companies. They can start by improving the existing infrastructure [31]. In the short term, utilities can locate the charging stations strategically and work with regulators to incentivize electricity rates during peak hours. In the medium term, utilities may need to add new power capacity to meet the electricity demand. For fast chargers, the use of stationary storage at local or grid level will probably be needed to meet the power demand. In the long term, they can install smart grids to improve the ability to manage the load [20]. The electric utilities have a good position for EV market but they need to act fast if they want to gain leverage as there are many other players in the market who are chasing the same opportunities.

Utilities can manage infrastructure constructions and charging for their customers. They can collect data to understand the charging behaviour. There are two residential charging plans possible: one meter which combines charging and household electricity spending or one meter only dedicated for charging. The utilities are generally reducing the price for off-peak hours so that the EV load can shift to off-peak hours.

The utilities can collaborate with universities to conduct research on e-mobility and its effects on grid. The possible works that utilities can do for e-mobility deployment [20]:

- Meeting with local stakeholders to create a detailed EV readiness plan
- Providing or certifying house and commercial chargers which are compatible with grid

- Arranging the electric rates for peak hours to manage the charging times
- Educating consumers about EVs.
- Helping local/state government to plan EV transportation
- Providing electricity rate incentives to EV owners
- Educating companies who own EV fleets about charging and incentives; installing/certifying charging points for them
- Collaborating with universities on e-mobility R&D projects.
- Working with municipalities or other service providers to install public charging stations [20]

In Europe, some large companies have already started to be a part of e-mobility market by being responsible for significant amount of public charging stations. In Germany, RWE, Vattenfall, E.ON and EnBW have 35% of all public charging stations. Power companies and DSOs also collaborate to install charging network. In Netherlands, Clever, a company owned by major Scandinavian energy companies, collaborates with seven network operators to construct Europe's first ultra-fast charging network for EVs. Local municipal utilities have also started to enter the market. In China, for example, State Grid Cooperation of China and China Southern Power Grid have collaborated on installing more than 27 000 charging stations and 800 battery swapping stations for electric buses [10].

2.3.4 OEMs as Infrastructure Providers

OEMs have also been deploying charging services. Tesla has supercharger network consisting of more than 5 000 fast charging points on major highways. Tesla plans to increase this number to 9 000 charging points which are located in public places such as hotels, restaurants and so on. A UK-based firm POD Point which is specialized in EV chargers had made a deal with Nissan to offer a home charging station to every Nissan Leaf buyers. They made another deal with British Gas for installation and maintenance services of energy [19]. The car brands are also taking initiative to construct charging points. BMW, Daimler, Volkswagen and Ford are planning to collaborate on a joint project to construct a fast charging network on the major highways of Europe [10]. Toyota is collaborating with French electric utility EDF and Citelib, a e-mobility service provider, to provide 70 EVs and 30 charging stations in Grenoble, France. Customers reserve and pay for the service by using smartphone app [31].

2.4 Provision of E-mobility Services

E-mobility services are MaaS (mobility as a service) models which combines transport modes with services to provide user oriented transport solutions under a single interface in exchange for a 'pay after use' or subscription type payment methods. EV sector is at an early stage where the companies are designing and testing new business models. One possible business model for EVs is to be used in car rental and car sharing service. Car rental and car sharing services are already being used in daily life with ICEVs. MaaS aim is to encourage public usage of the vehicles instead of private usage. This helps to reduce the carbon emissions. By using EVs as MaaS, it will help even more to reduce the GHG. Providing EVs to car rental and car sharing fleets can be a good start for EVs to be used as a service. By 2020, it is assumed that 10% of the car fleet in car sharing and renting services will be EVs and the market potential will reach $23 billion. The players in e-mobility ecosystem can collaborate on providing e-mobility services as success lies behind the strategic partnerships. Main challenges for the service sector is the high sticker prices, variations in battery performances and amount of time required to reach to customers and inform them about services. These partnerships can help to reduce the EV industry's problems. Mobility providers can collaborate with existing car rental and car sharing companies. This way they would not have to spend time on advertising themselves to be known by the customers. E-mobility providers can offer car sharing locations near for example public transportation areas like railway stations. An example comes from Switzerland. A Swiss car sharing company made a collaboration with a company called M-way Solutions which provides the EVs. For the infrastructure, they made a collaboration with Siemens. The car sharing services are located at Swiss railway stations and some other places [19] & [32].

For e-mobility providers, partnerships with OEMs, infrastructure providers, municipalities and public transport companies are necessary to build successful business models. Building business models depends on two things: organizational complexity and technical complexity of realization of the model. Organizational complexity indicates how many different industries or stakeholders should cooperate in order to develop a certain e-mobility service. Technical complexity indicates if a new technology is needed for a particular business model or the model can be developed with the existing infrastructure. E-mobility business models can be grouped according to these two complexities [5]:

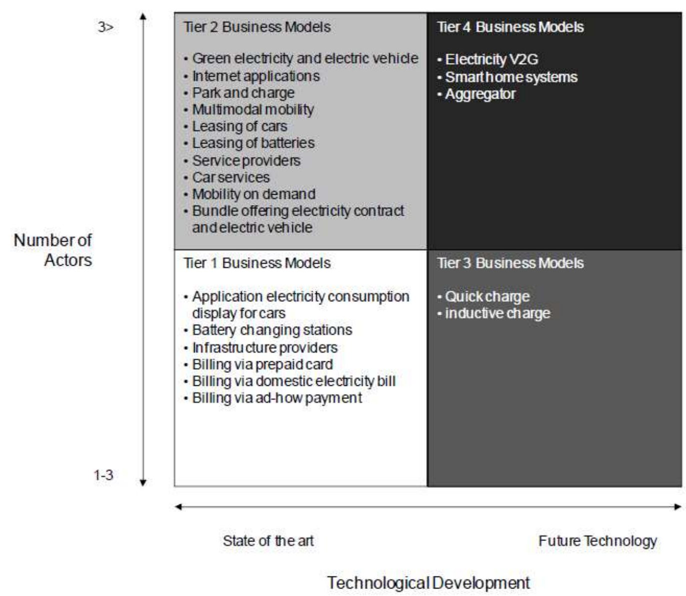


Figure 18: Complexity Matrix of E-mobility Business Models Implementation [5]

Tier 1 Business Models: These models require low operational and organizational complexity as they can be applied with the existing technology. These models can be applied at the early stage of e-mobility. Infrastructure providing is in this tier. Infrastructure providing can be costly but the technology is existing as electricity is already being generated and distributed.

Tier 2 Business Models: They require low technical complexity but high organizational capability and complexity. Car and battery leasing services are examples to these business model group.

Tier 3 Business Models: These models require high technology complexity which are difficult to develop and need innovations in technology. The organizational complexity is low. Inductive charging is in this group.

Tier 4 Business Models: Both technical and organizational complexity is high. It is the future of the sector. V2G is one these models.

In the following chapter, some examples of business models of e-mobility applied in the world will be explained.

E-mobility Service Example Business Models

Electric taxis:

Every major city in the world use large fleets of fossil fuelled taxis. Promoting EVs through electric taxis is a great idea as the people will be exposed to EVs, the taxi drivers will benefit from low costs and carbon emissions will reduce. There is already demand for e-taxis all around the world, especially in China, India and the Philippines. A good example can be given for e-taxis usage. In 2013, City of Bogota (Colombia) has started a project to create the largest e-taxi fleet in America. This is a joint project done with C40 Cities Climate Leadership Group which is a global network of megacities committed to addressing climate change. They started with 50 e-taxis as a pilot project and they are planning to expand the program. In Bogota, taxis are the most responsible for the carbon emissions per passenger as they are highly utilised. Taxis have high maintenance and fuel costs. However, with EVs, these costs are decreasing significantly. The e-taxis have 57% less maintenance costs than the gasoline or CNG ones. Moreover, these e-taxis are producing 60% less GHG emissions than the gasoline taxis and 49% less than the CNG taxis. Research and Markets forecasts that global electric taxi market will grow by 33% over the period 2013-2018 as e-taxis are cost effective especially for the short distances. E-taxis is a good example to tier 2 business model as it does not have complex technology but it requires complex organization [33].

Integrated Urban Transportation System:

An intelligent network which connects the EVs together. A project called Ha:mo in Toyota City, Japan is a multi-navigation system which involves different forms of transport such as cars, buses, taxis, electric bicycles. This system has an app which informs customers about the traffic situation, parking space availability and car sharing possibilities and offers the best route and solution. The system also collects real time information and gives feedback to the system operators. The system operators use this feedback to adjust the capacity according to user needs. This model is also an example to Tier 2 group [33].

Wireless Charging:

This new technology started to gain attention due to its advantages of eliminating the cable need, reducing the battery sizes and decreasing the need for building charging infrastructures. However, this technology has disadvantages such as power loss, need for precise alignment between transmitting and receiving systems. Major OEMs intend to introduce new wireless charging products to market as there will be a need for dynamic charging in the future. Wireless charging can be in 3 ways: Stationary charging where the car is charged when it is parked; semi-dynamic charging where EVs stop temporarily at a road junction or a bus stop for charging as a part of their journey; or dynamic charging where EVs are charged in motion by drawing current from the technologies embedded in special lanes on main roads or highways. An example for wireless charging can be seen in a project in Gumi, South Korea. The wireless charging system which called Online Electric Vehicle System (OLEV), developed by researchers at Korea's Advanced Institute of Science and Technology (KAIST), have been built on an inner-city road to power electric buses. OLEV buses have batteries of about 1/3 of the regular electric bus battery size which makes these busses a lot cheaper. Wireless charging is an example to Tier 3 business models as inductive charging is a breakthrough in technology [33].

Electric Bus Fleet:

Electric buses have high upfront costs but they are becoming more cost effective as more suppliers are entering the market, battery costs are declining and they have also lower operation and maintenance costs than conventional buses. Operating electric buses for public transportation in cities will not only be cost effective, it will also reduce the GHG emissions significantly as the buses are operating 5-10 times more than the average passenger cars so they account for carbon emissions more than passenger cars. Electric buses have also more electrification options such as battery swapping, overhead lines, wireless charging and so on. Rome has one of the largest e-bus fleet. 60 electric minibuses operate on five routes, carrying 945 million passengers per year since 1989. The minibuses use battery swapping for electrification and as they are minibuses, the amount of necessary charging is small. Rome also has trolley bus lines including a hybrid bus line which uses overhead lines for electrification until it reaches city centre and then it uses battery. In addition to being zero emission vehicles, these buses are also more comfortable and silent. This model is an example to Tier 2 business models [33].

Vehicle to Grid (V2G):

This business model is explained more detailed in Chapter 2.5. This model considers EVs not just as vehicles but also batteries which can help to balance the electricity demand. In US, the University of Delaware has established a research centre for vehicle-to-grid (V2G) technology. The university has partnered up with OEMs, energy companies and DSOs to work on the economic opportunities that V2G will bring. They are also publishing reports about how this technology will help for frequency regulation. There is also another bi-directional charging model called Vehicle-to-Home (V2H). This model considers EVs as a back-up storage for houses. In emergency cases like power shortage or shutdowns, EV batteries can replace diesel generators and provide power back to grid. It can help to balance power demand and supply fluctuations. In 2012, a V2H project called “LEAF to Home” was started by the collaboration between the city of Kitakyushu and Nissan in Japan. The charging connector of the vehicle LEAF is feeding electricity back to house distribution board through a PCS (Power Control System). The system has enough power to supply all household electronics to function at the same time. It also provides a stable electricity supply during the peak times. When the electricity is supplied from the vehicle during the peak times, the electricity bills can decrease as the power is not used from grid. The battery can be recharged during the night when the demand is low. There are 225 household and 50 work places in this project. Average power consumption of a house in Japan is approx. 10-12kW. Nissan LEAF’s battery capacity is 24kW meaning that it can provide power to a house for 2 days. Navigant Research predicts that by 2020 there will be around 200.000 EVs equipped with bi-directional charging ability. V2G belongs to Tier 4 business models group as the technological and organizational complexity is very high. It is not applicable now with the existing stage of e-mobility sector. However, it will be very important in the future with its help to load balancing [33].

Mobility Sharing:

Shared mobility business models and services is one of the ways to overcome the early e-mobility market barriers. Car sharing is a convenient and cheap alternative for people who are facing high TCOs of cars and limited availability of parking spaces. Also with this way, people do not have to buy EVs which currently have high prices. Also, people can have a chance to try the EVs without owning them and they can get used to them. Global car sharing has been expanding drastically and according to Navigant Research, it would be worth $6.2 billion by 2020. Mobility sharing includes various business models such as university car sharing fleets, peer-to-peer car sharing, one-way car sharing, and services run by vehicle manufacturers. Car sharing is a great way to make people get acquainted with EVs and decrease the economic and environmental burden of personal transportation (no service, maintenance, highway, insurance, parking costs). There are various e-mobility car sharing service examples in the world. In Paris, all e-car sharing project called Autolib was started in 2011 by the collaboration of City of Paris and a French company called Bollore. Autolib is a huge car sharing network project consisting of over 2500 EVs and 4710 charging stations. The programme has attracted over 6.6 million trips and 178,000 individual subscribers, while logging over 60 million km and saving 7,575 tonnes of CO_2. Another car sharing example can be seen in Prague. Prazska Energetika (PRE), one of the main electric utilities in Czech Republic, offer car sharing services with CAR4WAY. There are 15 entirely new Volkswagen e-Golf EVs in their car sharing fleet along with other brands and customers can also use the PRE Group's charging stations. With this car sharing service, people can have an opportunity to try an EV for an hour. If one is a customer of PRE, then s/he has 50% discount on registration and Tariff Optimum for 2 months for free. The vehicles are available 24/7 and 365 days a year. The users can also use the blue and purple parking zones for free. Registration can be made by using smart phone app or from their website [34]. This model is an example to Ter 2 group [33].

Figure 19: **CAR4WAY EV and the smart phone app [115]**

Car Rental:

Like e-car sharing services, e-car renting business model is also a way to overcome the initial hurdles of e-mobility market. People can get used to EVs with car renting services by experiencing how it is to drive them. There are many examples of EV renting services. The leading car rental companies like Enterprise and Sixt have EVs in their fleet. Some companies offer renting service for electric bike and scooters as well. In Prague, for example, PRE offers contractual rental and leasing services for cars for a period up to 5 years. They also offer renting services for electric bikes and scooters. Rental services are in Tier 2 business model group [33].

Battery Swapping:

Changing an EV battery with a fully charged one is one of the ways to extend EV range. This model is suitable for especially companies who are offering transportation or delivery services. These companies can lose money when the EVs are out of service to be charged for a long time so battery swapping is profitable for them. Urban taxi fleets, buses, delivery and courier companies can use this model for their EVs. Battery swapping is becoming more common in China, especially in Beijing and Shenzhen. In the city of Hangzhou, China, there are currently about 500 electric taxis and battery swapping model is being used to charge them. The daily travel distance of one taxi is 230km; therefore, for a normal daily operation, a taxi’s battery will be swapped 2-3 times a day at swapping stations located throughout the city. There are fully automated swapping process examples. In Qingdao, for instance, a fully-automated process for swapping e-bus batteries takes only seven minutes. There are battery swapping projects in other countries as well like Slovakia, USA, Taiwan and so on. This technology brings out some challenges. People are concerned about that grid would be affected from swapping high amount of batteries and also about the difficulty of standardising batteries across all different manufacturers. However, this model has already started to be used and it is becoming more and more common, especially in China which is leading the EV market. Battery swapping can be considered in Tier 3 group. For this model to be commonly used, the batteries should be produced massively and they should be standardized [33].

City Logistics:

Supporting logistic companies to use EVs for their services can bring many social and environmental benefits. It can be a good way to advertise e-mobility and raise the awareness about it. Logistic companies are looking at EVs as a way to serve the cities in a clean and quiet way and to save money. Logistic operations in urban areas are suitable for using EVs as the distance travelled is not long and there are multiple collections and drops. Food companies can also use EVs to deliver food; electric bikes and scooters can be very suitable for food delivery services. The municipalities can encourage logistics/delivery/courier or other service companies to use EVs in their fleet by allowing them access to bus lines, free parking or priority access to public charging points. This model is an example to Tier 2 group [33].

This model can be applied in Prague as well. The companies who are giving services by cars can use electric vehicles in their fleet. The companies like Ceska Posta and Kosik who are frequently used by people can use EVs and benefit from their benefits such as being able to use blue zones for parking. This is an important feature as it is almost impossible to find a free parking place in the city centre.

Plug Sharing with Mobile Metering:

If technology allows EVs to be charged from the existing electric outlets, there would be high-density of charging stations to support EV deployment at a large scale. Currently, standard outlets cannot meter the electricity used for charging EV separately and bill it. However, a technology like mobile metering built into vehicles or charging cables could allow charging from normal outlets and meter it. There are examples for mobile metering in Germany. A company from Berlin named Ubitricity has developed a solution which builds metering into standard charging cable. This solution provides access to Ubitricity socket systems which are attached to existing electrical outlets in the city. With the mobile meter, the charge cable is accepted by the outlet and the electricity consumed is metered. The information recorded is sent to Ubitricity through a cellular connection and then it is passed to the relevant utility. In Frankfurt, Ubitricity is working with Verband der Automobilindustrie (VDA) to install socket systems in street lights throughout the city. Municipalities can also consider plug sharing as it can reduce the construction costs as they will not have to construct many public charging stations if the existing electric outlets are used for charging. Of course, this system will not replace all the charging stations as it will provide only low voltage power. With proper business models and legal frameworks, plug sharing can be an effective way to increase charging opportunities and thus EV deployment. This technology will be a breakthrough in e-mobility market if it can be applied commonly. Technological and organizational complexity is high; therefore, it belongs to Tier 4 group [33].

Figure 20: UBITRICITY Socket System [33]

2.5 E-mobility impact on power systems

There will be significant increase in the electricity demand due to charging and this will bring strains to electricity network. Utilities will need to increase the capacity both in generation and distribution network. In IEA Two Degree Scenario (2DS)[1] (electrification of 10% of total PLDV fleet), the additional power generation to meet the demand occurs due to EV usage is 1.5% by 2030 which is only 6% of the total increase in demand which occurs also due to electrification in industry, residential and commercial areas (Figure) [10].

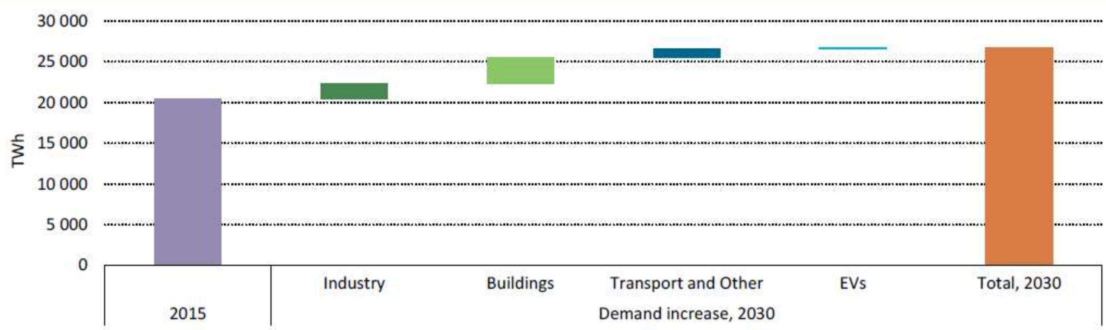


Figure 21: Impact of electric car deployment on global electricity demand, 2DS [10]

It is estimated that 100% electrification of the car fleet in Europe will add around 21% (130 GW) to peak load in 2035. However, using a fully electrified road transportation will save €1 billion per day in oil imports. A study conducted by EURELECTRIC in 2014 using data from 11 member states that current electric system in Europe has enough capacity to power fully electrified car fleet in Europe if these EVs are charged smartly [10].

Higher deployments of EVs can impact the capacity at different levels:

- At generation level: High demand and scarce capacity can increase prices.
- At transmission level: Stress on the system during peak times requires more handling like frequency control and maintaining reserve capacity.
- At distribution level: Power lines and transformers can overload and voltage drops can occur.

There is a solution for meeting the capacity demand aside from smart charging: Vehicle-to-grid (V2G) technologies. V2G is a reverse charge system where EVs are connected to the grid and their batteries act as back-up power for balancing the grid and storage. Studies state that a 100% electrified car fleet connected to the grid with a low power level (5 kW) has the same capacity as the total EU power generation capacity of 3,000 GW. Even some part of fleet connected to the grid will help to balance the capacity [7]. EVs can help to decrease the electricity rates with this system. EVs are generally charged at night when it is cheapest to generate electricity. There is excess generation capacity in the grid and by charging the EVs, the excess power can be balanced. If EVs are connected to the grid between day and night during peak hours when the demand is very high, they can act feed power back to grid. Thus, electricity rates can decrease as the demand is balanced thanks to EVs. EVs can also help to use more clean energy with this system as they are generally charged at night when the large portion of power is generated from clean sources like wind. Moreover, with V2G system, EV owners can make money if they provide their car batteries as a backup power source for quick response utility markets

[1] IEA Two Degree Scenario (2DS): The scenario for 1 170 $GtCO_2$ of cumulative emissions for the 2015-2100 period with a 50% chance of limiting average future temperatures increases to 2°C [10]. In this scenario, the PLDVs stock exceeds 150 million units which is 10% of the total amount by 2030.

where frequency regulation is needed. To regulate the frequency, output is adjusted about 400 times a day and EVs can respond to this need within seconds. EVs can make money in frequency regulation market up to $5,000. This technology is new and being tested in pilot projects. In Denmark, Nuuve Corporation is managing a pilot program where 30 EVs are tested in frequency regulation market and they expect to pay EV owners up to $10,000 over the lifetime of the car. An example for EVs beings used as power sources comes from US. BMW, PG&E (Pacific Gas and Electric) and a US utility tested the feasibility of using EVs as flexible power sources for grid over 18 months. In the project, 100 BMW i3 EVs and a battery system made up of reused batteries were used and 100kWh were provided from this project which contributed 20% target kW reduction. 92% of the participants stated that their roles were passive and they did not get affected in any significant way. Now PG&E is aiming to enrol 250,000 EVs by 2030 to provide load-dropping of 77.6MW per event. Another example comes from eMotorWerks which is an energy and e-mobility solutions company and leading supplier for EV charging stations. Enel, Italian multinational electricity and gas manufacturer and distributor, acquired eMotorWerks to enrich its e-mobility solutions including smart charging solutions, grid-flexibility services, distributed energy management systems and battery storage solutions. Even though V2G is still in trial period, it is a game changer technology which will solve the additional capacity demand that the EVs will bring [20].

2.6 E-mobility impact on oil consumption and import

According to Eurostat, EU had oil consumption around 430 million TOEs (1 tonnes of oil equivalent = 7.3 barrels of oil), 80% of this was consumed in transportation. According to EAFO model, 70% of total EU oil consumptions for transport is used for cars. Therefore, transition to EV fleet will reduce the oil consumption for transport by 238 million TOEs per year by 2050 compared to 2015. This would save €78 billion from the amount spent on oil import. This model assumes that the remaining ICEVs will use bio fuels. EU imports almost all oil. Therefore, the total savings from EV deployment can be considered as the reduction in oil imports. By 2050, in EU, €42 billion per year at current oil prices can be saved with EV deployment. As the demand for oil will decrease globally, the oil prices will decrease. So EVs have more benefits than only reduction in oil import [7].

2.7 Battery requirements for EV transition in EU

EV transition requires battery market to grow as well. The global production capacity of lithium-ion batteries is set to grow from the current 100 GWh per year to around 270 GWh per year by 2021, of which 65% will be produced in China. In Europe, battery production is very low and there are limited plans to expand it. European OEMs generally buy the batteries from Asia. European Commission Vice-President in charge of energy Maroš Šefčovič stated that Europe should be aware of the fact that the United States and China are moving a lot faster on electric mobility than Europe and he has put emphasis on the need for an airbus for importing batteries from overseas. An estimation for battery requirement in EU sales of EVs are given in the Figure 22. To reach 100% EV fleet for passenger cars, battery manufacturing capacity should be between 400 and 600 GWh which would cost €40 to 60 billion on a yearly basis and would require 14 to 20 "Giga factories" to be built and operated by 2035. Anything less than this number would mean that EU will have to import lithium-ion batteries for EVs [7].

Year	BEV sales Million cars	GWh total 30 kWh/car	Value @100€/kWh € billion	GWh total 45kWh/car	Value @100€/kWh € billion
2025	3.5	105	11	158	16
2030	7	210	21	315	32
2035	14	420	42	630	63

By 2025: 3 to 5 "Giga factories @ 35 GWh needed for EU BEV sales
By 2035: 14 to 20 "Giga factories @ 35 GWh needed for EU BEV sales

Figure 22: An estimation for battery requirement in EU sales of EVs by years between 2025-2035 [7]

For this calculation, a cost of €100 per kWh is taken. In the study, the battery price reduction is limited to € 120 per kWh as bottom price however recent indications are that prices as low as € 65 per kWh could be reached by 2030.

3. E-mobility as a Business Solution for Czech Electricity Utilities

Czech Republic has energy intensity more than twice of the EU average and has the 3rd most energy intensive economy among EU countries due to its industry. Energy intensity in industry have been decreasing over the years; however, energy intensity in transport increased in the last years. This increase happened due to industrial production which resulted in increase in export of products which required freight and rail transport. Transport sector itself also increased its contribution to energy consumption [64]. Czech Republic is obliged to implement policies to address energy efficiency. National Action Plan on Clean Mobility (NAPCM) is an important document for supporting e-mobility as it lays out measures to increase energy efficiency by promoting development of alternative transport fuels and to meet the targets in the areas of energy, transport and the environment. The development of electromobility in the Czech Republic is still in its early stages. The main reasons include the following (according to NAPCM) [24].:

- "Absence of a regulatory framework (electromobility as a form of clean transport has not been the subject of support in the Czech Republic except for excise duty, the strategy of its development is missing).
- Economic reasons (electromobility is not fully commercial yet, the market is still in the infancy).
- Restricted supply of vehicles (a limited range of models of different segments in mass sales is related to the fact that the Czech market is not so attractive for the main players and can be expected to be delayed compared to Western Europe).
- Absence of recharging infrastructure (low density of the recharging network, especially in fast charging).
- Prejudice and distrust of users due to limited practical experience (great weight for risks associated with electric drive, distrust of untested technologies).
- Low sensitivity to environmental issues, especially CO_2 reduction"

As can be seen from points above, there is work that needs to be done in different areas to increase the number of EVs. Different possible subsidies to improve the EV deployment have been discussed in the previous chapters. To support the e-mobility deployment, NAPCM proposes some measures [24]:

3.1 Measures to support e-mobility listed in National Action Plan on Clean Mobility (NAPCM)

3.1.1 Facilitate the construction of rechargeable infrastructure:

To eliminate the disadvantages of EVs having limited availability, the following measures are defined to support the network of recharging stations [24]:

- Investment support for the construction of public recharge infrastructure.
- Investment support for the construction of recharging infrastructure for public transport (non-public).
- Investment support for building a corporate recharge infrastructure (non-public).
- Unified methodology in the process of approving the construction of charging stations.
- Increase in depreciation in the first year of depreciation for the rechargeable infrastructure.
- Mandatory quotas for developers for the connectivity of the rechargeable infrastructure.

3.1.2 Stimulating demand for electric cars

In order to achieve this goal, the following measures were proposed [24]:

- Increase in depreciation in the first year of depreciation for EVs in company fleets.
- Introducing a possibility for public contracting authorities to apply a methodology for calculating life cycle operating costs under Directive 2009/33/EC for vehicle purchases.
- Support for the acquisition of an electric vehicle by state and local government entities and their subordinates, managed and established organizations.
- Support for the purchase of electric vehicles for entrepreneurs.
- Use of innovative financial instruments to support the purchase of alternative fuel vehicles for non-business individuals.
- Supporting the acquisition of alternative fuel vehicles to the fleets of transport companies and to the fleets of carriers providing urban public transport and public transport.
- Exemption from paying motorway tolls for alternative fuels.
- Reducing the road tax rate for electric vehicles weighing over 12 tones.

3.1.3 Creating conditions to improve the perception of electromobility on the part of potential customers

In order to achieve this goal, the following measures were proposed [24]:

- Use of lanes for buses and taxi vehicles with electric drive.
- Parking on public car parks for free of charge.
- Free parking in other reserved areas (blue zones).
- Dedicated road sign for electric vehicles.
- Designation of electric vehicles (labelling).
- Fulfilling the requirements of Directive 2014/94/EU on the charging and refilling infrastructure standards.
- Fulfilling the requirements of the Directive 2014/94/EU in relation to the performance of businesses in the operation of public charging stations.
- Fulfilling the requirements of Directive 2014/94/EU in relation to the operators of public charging stations.
- Targeting training events for experts and public in the field of alternative fuels.
- Ensuring that road users are informed of the type and equipment of recharging stations through Intelligent Transportation Systems (ITS).

3.1.4 Improving the conditions for doing business in areas related to electromobility

In order to achieve this goal, the following measures were proposed [24]:

- Adaptation of Decree No. 50/1978 Collected on Professional Qualification in Electrical Engineering.
- Fulfilling the requirements of the 2014/94/EU Directive in relation to the performance of businesses in the operation of public refuelling stations.

3.1.5 Coordination of the development of the charging infrastructure and distribution system

In the development of electromobility, an increasing number of electric vehicles and charging stations will most likely cause problems in the field of electricity distribution. As mentioned in Chapter 2.5, in case of large deployment of EVs, the grid will experience new and powerful take-offs. This problem can occur mainly in areas of the highest concentration of population. The distribution system needs to be prepared for these conditions. Otherwise, there could be a lack of grid capacity limiting the development of the recharging infrastructure.

According to the Energy Act, the DSO is obliged to set the conditions and the term of connection to anyone who so requests. The request to connect a new charging station can be seen as any new sampling point with certain parameters to be connected to the system. On the other hand, the DSO has the right to reject the connection request if the capacity of the distribution network at the required connection point is insufficient to maintain the required power quality. When refusing such a request, a technical design of the connection solution procedure must be proposed by the distributor. Such a proposal may include a variant of a connection from another point of the distribution system, a connection from another voltage level, a timetable for the strengthening of the distribution system and the subsequent realization of the connection, etc. It is therefore necessary to plan the construction of the rechargeable infrastructure in good time and in coordination with all interested parties [35].

3.2 Incentives and the Responsible Authorities

The overviews of the e-mobility measures to be implemented and the responsible authorities for them are listed in the following tables:

Table 7: Authorities and their Abbreviations

Authority	Abbreviation
the Ministry of Transport	MD
the Ministry of Regional Development	MRR
the Ministry of Industry and Trade	MPO
the Ministry of the Environment	MZP
the Ministry of Labour and Social Affairs	MPSV
the Ministry of Finance	MF

3.2.1 Legal / legislative measures

Table 8 Legal / legislative measures [24]

Measures	Primary responsibility	Year (s)
Introducing the option for public contracting authorities to apply a methodology for calculating life cycle operational costs when purchasing vehicles	MMR	2016
In the tendering procedures for the selection of the operator of public transport, the energy and environmental impacts of vehicles shall be taken into account	MD	2017-2020
Fulfilling the requirements of Directive 2014/94/EU on charging infrastructure standards	MPO, MD	2015
Fulfilling the requirements of Directive 2014/94/EU on charging station operators	MPO, MD	2015-2016
Fulfilling the requirements of the 2014/94/EU Directive affecting the performance of business in the operation of public payloads	MPO, MD	2016
Fulfilment of the requirements of Directive 2014/94/EU on User Information on Alternative Fuels	MPO, MD	2016
Specification of Electrical Vehicle Qualification Requirements for Electric Vehicles	MPSV	2016

3.2.2 Direct incentives to buy vehicles

Table 9: Direct incentives to purchase vehicles [24]

Measures	Primary responsibility	Year (s)
Support for the acquisition of alternative fuels for the fleets of transport companies and the fleet of carriers providing public transport	MMR	2017-2025
Acquisition of alternative fuel vehicles to municipal fleets operating municipal waste collection vehicles	MMR	2016-2030
Creation of a program for the replacement of the state vehicle fleet for alternative fuel vehicles	MZP	2016-2020
Aid for the purchase of an electric vehicle by state and local authorities and their subordinates, management or founding organizations	ME, MD	2016-2020
Support for the purchase of trolleybuses and trams with battery trolleys to the fleets of transport companies and the fleet of carriers providing public transport	MMR	2017-2025
Innovative financial instruments to support the purchase of electric vehicles for entrepreneurs (for business purposes)	MPO	2016

3.2.3 Direct incentives to build a rechargeable infrastructure

Table 10: Direct incentives to build infrastructure [24]

Measures	Primary responsibility	Year (s)
Support for the building of the public recharge infrastructure	MD	2017-2020
Support for building a non-public charging infrastructure for public transport	MMR	2016-2020
Unified methodology in the process of approving the construction of the infrastructure of the recharging stations	MMR	2015-2016
Investment support for building a corporate recharging infrastructure for electric vehicles	MPO	2016-2020

3.2.4 Tax incentives

Table 11: Tax incentives [24]

Measures	Primary responsibility	Year (s)
Introducing a lower road tax for electric vehicles over 12 tonnes	MF	2016
Increase in depreciation in the first year of depreciation for the charging station infrastructure	MF	2016-2025
Increase in depreciation in the first year of depreciation of a vehicle with electric drive	MF	2016-2020
Benefiting from the purchase of vehicles with lower CO_2 emissions	MZP	2016-2030
Relief from paying for motorway tolls for alternative fuels	MD	2015-2020

3.2.5 Non-financial incentives on the demand side

Table 12: Non-financial incentives on the demand side [24]

Measures	Primary responsibility	Year (s)
Parking on public car parks free of charge for alternative fuel vehicles	Municipality	2016
Use of lanes for buses and taxi vehicles with electric drive	Municipality	2016
Dedicated road sign for electric vehicles	MD	2016
Mandatory quotas for developers for rechargeable infrastructure connectivity	MMR	2016
Marking of vehicles with electric drive (labelling)	MD	2016

3.3 Operational Program Enterprise and Innovation for Competitiveness (OPPIK)

In 2016, the Ministry of Industry and Trade launched a program called Operational Program Enterprise and Innovation for Competitiveness to achieve a competitive and sustainable economy based on knowledge and innovation. This program includes e-mobility as one of the technologies which will be supported. Total support of up to CZK 80 million is intended for the purchase of electric vehicles and the construction of non-public recharging stations for the applicants' own needs. Supported activities include the purchase of electric vehicles and the purchase of recharging (non-public) stations for electric cars within the business premises for their own use. Regarding the acquisition of electric vehicles, several restrictions are mentioned in the call (according to [36]):

- "Supported business class vehicles by SDA (Automobile Importers Association) are: mini, small, lower middle, medium, MPV (minivan).
- Not supported: Higher middle, luxury, field or sports classes.
- It is not possible to promote the purchase of used cars."

Aid for the purchase of electric vehicles is at least 70 thousand and up to CZK 3 million. The only condition for getting support for the acquisition of recharging stations is that it will be non-public recharging station. The amount of support is at least 50 thousand. CZK and maximum according to the ‘de minimis’ state aid rules. The ‘de minimis’ is such aid which, together with the other de minimis aid granted to one beneficiary over the previous three years, must not exceed the amount of EUR 200 000. The degree of support is also further dependent on the size of the business. If the beneficiary is a small enterprise, the aid is granted up to 70% of the eligible expenditure. In the case of a medium enterprise it is up to 60% and in the case of a large enterprise 50% of the eligible costs.

Support can therefore be claimed by small, medium and large enterprises. The applicant may also be enterprises owned by up to 100% of the public sector. All legal forms of applicants are supported. The project requesting support must not apply to the territory of the City of Prague. If the project is implemented in an economically problematic region or a high unemployment region, the project will receive a higher score. Each application and the project contained therein will be evaluated by the MPO, and at least 60 points out of 100 will be awarded. This program can be an interesting opportunity, for example, for delivery companies or some service work with a regular or predictable mileage [36].

3.4 Electric Utilities of Czech Republic and Their Place in E-mobility

There are three major electric utilities in the Czech Republic: CEZ., E.ON Czech Holding VwGmbH and, finally Prazska Energetika (PRE) a. s. [37]. These companies have the necessary knowledge and capital to support e-mobility in Czech Republic. Electric companies can do more than to educate and incentivize customers to buy EVs, they can become major players in installing EV charging infrastructures. They can also be prepared for the increased demand for electricity and changing load patterns due to EV deployment by developing smart grid technologies to manage and control the load [31]. In fact, Czech utilities have already started to have a big role in e-mobility. In the following part, what the Czech utilities are doing for supporting e-mobility will be explained. The information on CEZ and PRE is collected from their respective companies' websites and the interviews carried out with them. The interviews can be found in Appendix A in full form.

There are several essential requirements in the Directive for public electric vehicle charging stations. Member States must ensure the following (according to [23]):

- For public charging station operators to freely purchase electricity from any EU electricity supplier, subjects to contracts with the supplier.
- All public charging stations can offer ad hoc recharging without prior conclusion of a contract with the electricity supplier or operator concerned.
- The prices charged to the public by public charging station operators should be easily and clearly comparable, transparent and non-discriminatory.
- Distribution system operators to cooperate on a non-discriminatory basis with all persons who set up or operate public charging stations should be ensured.
- The legal framework should allow the electricity supply contract for the charging station to be concluded with suppliers other than the supplier of the household or service where the charging station is located.

Czech DSOs apply to these rules. They compete on equal conditions and their prices are transparent and comparable.

3.4.1 CEZ Group

CEZ has a strong position in the electricity market with its 57.6 % of installed capacity, 73.7 % of gross electricity production and 64.1 % of electricity distribution which helped it to have the largest share of public charging stations. CEZ Group started to deal with electromobility already in 2009 when it launched the pilot phase of the project /E/MOBILITA. The project began with first-time cooperation with Peugeot, which provided the vehicles needed to start the whole project. The project started by building the first public stations located in suitable locations in cooperation with newly acquired partners who are generally owners of business centres or similar premises where there is a significant amount of car movement. CEZ's long-term goal is to offer a comprehensive service of electric mobility. CEZ also tests the use of electric vehicles in its fleet. From 2015 on, employees started to use VW e-Golf for business trips. CEZ has the largest EV fleet with its more than 40 EVs. It has partnerships with more than 8 leading OEMs such as ABB, Skoda, Volkswagen and Peugeot. CEZ is managing e-mobility projects with many partners including ministries, municipalities and leading commercial companies. One of the latest CEZ project is the commissioning of the first electric bus lines in Prague which are the BB1 and BB2 lines connecting the BB Centrum and the Budejovicka metro stop [38].

CEZ provides charging infrastructure for residential and public places:

CEZ's Provision of residential charging

CEZ offers home chargers in the form of wall box. On the CEZ website, the customer can select from the variety of wall boxes and cables depending on his/her requirement (indoor or outdoor, output level etc.). Outdoor wall box has 2 different types: one with fixed cable with certain output level and one without a cable. Second offers multiple outputs, which may vary in output power allowing charging EVs with different charging types and standards. Usually, this output is in the form of a conventional 230 V, 16 A socket and one charging standard output. The last important parameter when choosing a home charging station is performance. CEZ's wall boxes offers power levels of up to 3.7 kW, 7 kW, 11 kW and 22 kW. The prices of these rechargeable stations on the wall range from CZK 20,000 to CZK 60,000 including tax. More expensive ones include, for example, features of programmable charging, recharging control via mobile phone applications and so on. The brands that offer the wall boxes are Schneider, Ensto, CCL, Etrel. Some examples of wall boxes that CEZ offer can be seen at Figure 23 [38].

Figure 23: Different kind of wall boxes. First 2 can be used for indoor/outdoor charging. The third one is for outdoor charging.

In addition to recharging stations, CEZ offers a relatively wide range of charging cables, which differ from the combination of standard terminals and power that can be transferred during charging. Generally, the cables are offered with the wall boxes as a package. The standards of the cables from vehicle side are Mennekes which is European standard for most European cars (BMW, Mercedes, Volkswagen) and Yazaki which is generally for Japanese and French cars (Nissan, KIA, Peugeot, Citroen) (Figure 24) Few examples of cables can be seen in Figure 25 [38].

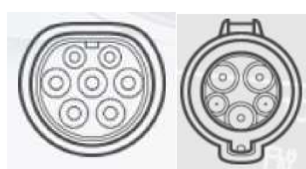


Figure 24: Standards of cables (from left to right): Mennekes and Yazaki

Figure 25: Different kind of charging cables that CEZ offer

Electricity charging rates that are applied in the distribution rate for household charging is labelled as D27d, for the business segment as C27d. CEZ offers the Electro Mobility product within its eTarif FIX product line. eTarif FIX offers for Household e-mobility prices as 19 CZK fixed price per month, 1511 CZK per MWh in High Tariff, 1060 CZK per MWh in Low Tariff, all without VAT (2018 prices). [38]

CEZ's Provision of Public charging stations

CEZ aim is to construct optimal charging infrastructure in whole Czech Republic. When installing charging stations, they consider the commercial potential of the place, easiness of reaching a lease contract with the land owners, availability of the grid connection and the construction costs. Currently, CEZ has 53 normal charging stations (16 of them are in Prague) and 42 fast charging stations (13 of them are in Prague) and their locations can be seen in Figure 26. They are planning to have 200-300 DC chargers in operation by 2020/2021. For Prague, they are planning to have around 30-40 DC chargers in the upcoming years [38].

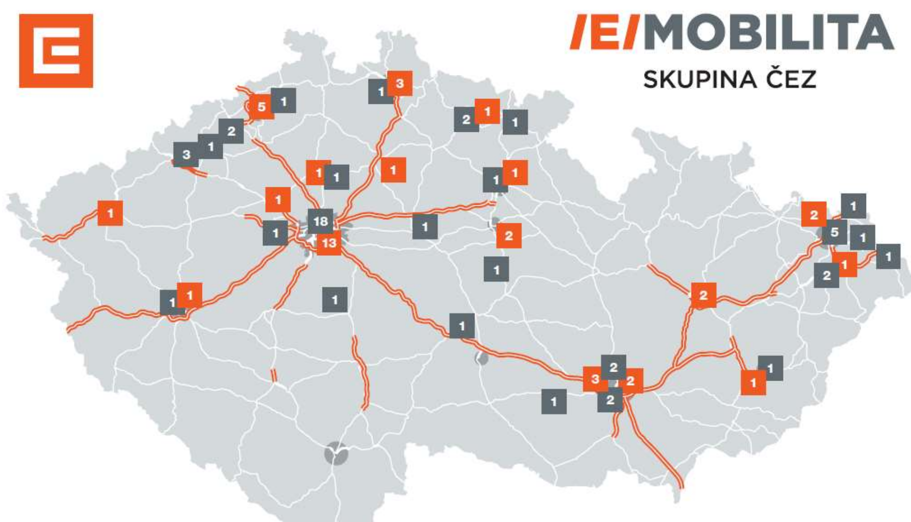


Figure 26 : CEZ Charging Station Map (Orange Points are DC fast charging stations and Grey ones are AC normal charging stations) [38]

CEZ normal charging AC stations is equipped with two independent sockets. One is equipped with the Mennekes standard with 32A/400V or 16A/400V charging parameters, the other is equipped with a standard "home" socket with 16A / 230V parameters.

CEZ fast charging DC stations are equipped with CHAdeMO12 and CCS13 charging connectors that enable charging up to 50kW with DC power. These charging stations are supplied by ABB. ABB DC stations are connected to a cloud based platform that allows real-time monitoring of the charging facilities and remote diagnostics, including energy consumption for each of them, or statistic reports for a certain period of time. These are "Drive Care" and "Charger Care" applications. Combined with an integrated predictive maintenance application on the Microsoft Azure platform, the system can respond before a malfunction affects the quality of the service provided. For electromobility, the reliability of stations is essential.

In addition, these chargers have also AC charging sockets with a standard Mennekes connector which enable charging up to 22 kW. 50kW DC charging is more efficient due to high performance, and most electric cars' batteries are charged by 80% in between 20 and 30 minutes. With AC charging, it takes 1-3 hours. For the use of public stations built by CEZ, it is necessary to conclude a contract with the company. To use CEZ charging stations, customer needs to have a chip which is CZK 450 per month (excl. VAT) which authorizes him/her to use all CEZ charging stations unlimitedly. Payments are made every 6 months so the customer needs to pay CZK 2700 (excl. VAT) per half a year [38]. The charging stations can be seen in Figure 27.

Figure 27: CEZ AC charging station and DC charging station [38]

3.4.2 The PRE Group

The PRE group calls its activities in the field of electromobility as PREmobility and deals with this topic on a wider scale. PRE currently offers rental of electric cars, sale & rental of electric bikes and wheels, car sharing services and operates a network of recharging stations.

Electrokola

The sale of the electric bikes has been underway since 2010 and the Haibike ™, Leader Fox ™, Scott ™, Apache ™, EVBIKE ™ and Selvo ™ brands are currently being sold. The range of bikes is broad with about 150 models. PRE offers more discount for their customers. In addition to the bikes, PRE sells wide range of parts needed to convert a classic bicycle to an electric bike. Another additional service is the repair of old batteries. Batteries are repaired by using Samsung products and the company provides a 24-month warranty. All information about renting, services and prices can be found in PRE's website [39].

PRE's Leasing and Renting Services for EVs

A service called operative leasing is offered by PRE for BEVs and PHEVs. Operative leasing periods are longer than normal renting periods. The customers make contacts with PRE for durations of 36, 48 or 60 months. At the end of the agreed lease period, the vehicle remains as the property of the leasing company. The company states on its website that they can offer advantageous operating leases due to the fact that they are buying EVs in larger volumes, therefore, at lower prices. The customer has the right to purchase the vehicle at the end of the contract. PRE offers for customers having leasing contract free charging at PRE charging stations, rental of a convection vehicle, checking the capability of the electrical network at the planned site, discounted installation of home charging station. PRE customers use the D27d and C27d distribution rates for charging. Operational service is offered to both corporate and private clients [16].

PRE's Provision of Public charging stations

The construction of PRE network charging stations started in 2011. Currently, 34 public charging points are in operation and 28 of them are in Prague (Figure 29). Among the charging stations in Prague, there is one fast DC charging station which also offers standard AC charging and 3 SMIGHT chargers (Figure 28). The rest are standard AC chargers [39].

- STANDARD – RFID (Radio frequency identification) card / chip control; AC - 1 unit of 1x 16 A / 230 V, AC - 1 unit of 3x 32 A / 400 V (Mennekes)
- FAST - fast charging stations (up to 50kW); RFID card control; DC - 1 unit 120 A / 500 V (CHAdeMO), AC - 1 unit of 3 x 32 A / 400 V (Mennekes) (2 stations together)
- SMIGHT – RFID card control; AC - 1-unit 1x 16 A / 230 V, AC - 1 pcs 3x 32 A / 400 V (Mennekes)

Figure 28: Standard, Fast and Smight Type Charging Station Types [39]

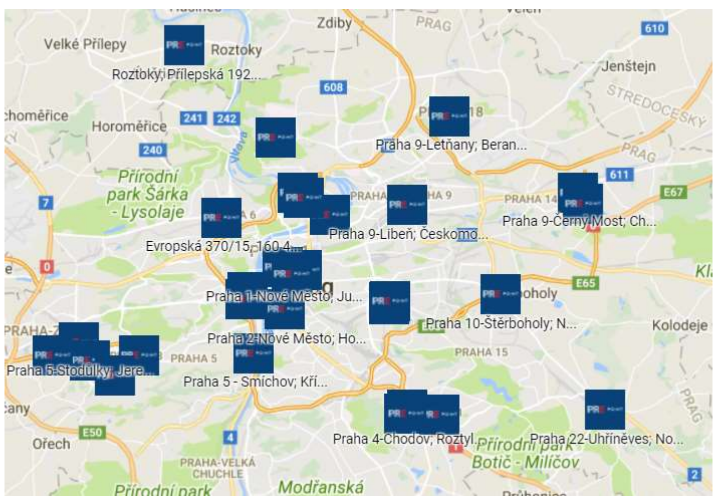


Figure 29: PRE charging station locations in Prague [39]

To use these charging stations, it is necessary to conclude a purchase agreement between the customer and PRE. The contract is for an indefinite period and can be terminated with a 30-day notice period. The price list for using this service is shown in Table 13:

Table 13: The charging price list for PRE stations (Prices are without VAT, in parentheses with 21% VAT) [39]

Fixed price for each card / chip [CZK / quarter]	Price for electricity taken [CZK / kWh]	Charging price [CZK /min] *
30,00 (36,30)	2,50 (3,03)	0,20 (0,24)

*In first 120 minutes of charging, this price is not charged. After 2 hours, CZK 0,20 is charged per minute in addition to kWh used.

The pricelist is smartly built to consider the different charging capacities and capacities of the various electric car models, and to reduce the unnecessary blocking of stations which are already occupied with the vehicles being recharged. The question is whether the two-hour threshold is too low. Since PRE operates mainly AC stations, it is likely that the batteries will not fully charge within two hours. However, the additional fee of 0.20 CZK per minute is not overly exaggerated. When charging an electric car with a capacity of approximately 25 kWh (for example, e-Golf, i3, etc.), this fee may amount to 30% of the total charging charge. Service billing is executed quarterly, and customer authorization at recharging stations takes place using the RFID key that the customer receives when signing the contract, and returns it after termination. Thus, the customer pays a flat fee of CZK 360 for a year, excluding VAT, and the remaining charges are dependent on the amount of electricity used and also on the time the electric car is going to be connected to the charging station.

The company also offers its know-how in the construction of both public and non-public recharging stations and provides comprehensive services ranging from consulting, design, construction to recharging station services. This service can be used by companies that have EVs in their fleet and want to provide charging stations in suitable locations. PRE also offers a wide variety of wall boxes suitable for indoor and outdoor use, with power outputs ranging from 3.6 kW to 22 kW and at a price ranging from CZK 20 to 40 thousand (excl. installation and any modification of the wiring system costs). More information about the products and the prices can be found in PREmobilita website [39].

3.4.3 E.ON Group

E.ON is an international, privately owned energy supplier. The E.ON Group was of the first big players on the Czech market to build the first public recharging station. The company has been testing e-mobility projects for a long time. One of their EV project is called 'Smart Fortwo' electric drive. As Smart Fortwo is a small car, it was not necessary to build large charging stations; therefore, both E.ON and their partners used wall boxes to charge them. E.ON provided this vehicle as part of its project, for example, to the Prague Medical Emergency Service, Prague Zoo or Brno Airport. In its fleet, the company also had a Mercedes-Benz E-Cell, which was transferred to Brno Airport again after testing [40].

E-rental

E.ON provides rental services for electric bikes and electric scooters since 2013. E.ON is producing its own scooters. They even provide electric boats for renting in Vranov dam. In all areas they provide service, there are several recommended routes available for bicycles or scooters. On these routes, there are charging points for bikes and scooters but these chargers are not suitable for e-cars. It is often possible to return the borrowed bikes or scooters at a different rental facility than they were rented. The prices and more information about these rental services can be found in company website given in the references [41] & [42].

E.ON's Public charging stations

The E.ON Group put into operation the first recharge station in the Czech Republic already in 2010 at the indoor parking lot of the Vankovka Gallery in Brno, the second public station is in operation at the Brno Airport. They have 3 charging points in Prague. There is also one station located in Ceske Budejovice and one in Vystrkov. Charging at these stations is completely free, and the RFID chip needed to unlock the stations is always available at the charging station [43]. E.ON has few stations now. But, they are planning to expand the power grid for EVs along the Czech highways with Fast-E project for which they have received CZK 36 million as funds from EU. The main objective is to cover main highways with fast charging stations and connect Czech charging network with other European countries. The plan is to build at least 15 stations at suitable existing filling stations. [43]

Currently, E.ON operates 7 public charging stations, it will soon be more than 20 with the Fast-E project.

3.4.4 Evselect Spol. S.r.o.

Evselect is not DSO but an important e-mobility service provider in Czech Republic. It is a subsidiary of NetDataComm s.r.o. based in Brno. Evselect has been engaged in electromobility for over 10 years and currently offers 2 major products. The first product is EVMAPA, which is a free-rechargeable charging station database. The map shows the charging points of the operators who cooperates with Evselect. The user has an account in EVMAPA app and use this app to unlock the stations and then recharge the electric car. The user should register a credit card in her/his account to pay for the charging. No RFID chip or key is needed. Unlocking takes only 60 seconds. The user can comment on and evaluate the stations s/he used. Evselect itself operates two fast charging stations, one in Brno and the other in Troubsko at the headquarters of the company. Any charging station operator may cooperate with Evselect, and if the station is free of charge or for the price of electricity consumed, Evselect will not charge for its services. The map view of EVMAPA is shown in Figure 30 [44].

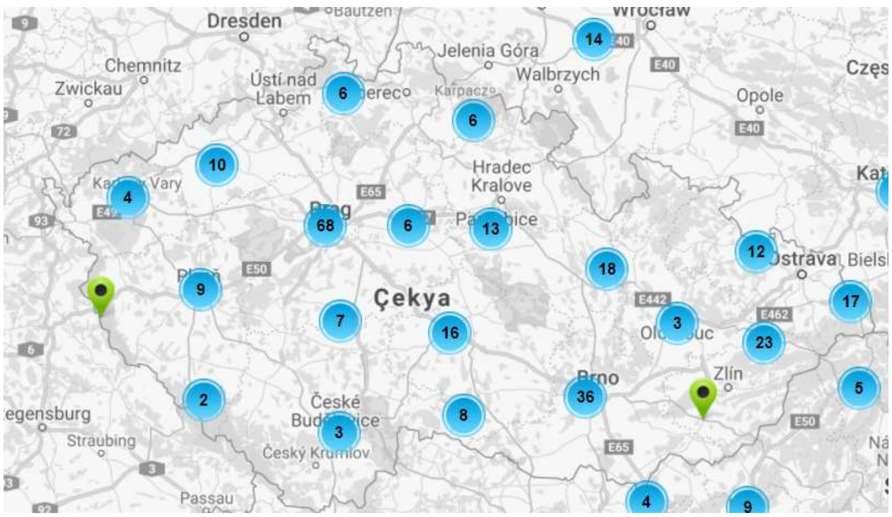


Figure 30: The map view of EVMAPA [44]

There are many other recharging stations in the Czech Republic operated by companies as a part of their marketing activities or as an ancillary service.

3.5 Czech Utilities' Motivation and Plans on E-mobility

CEZ and PRE state that their motivation for e-mobility was mainly driven by the regulations. However, they are aware of the fact that the market will change sooner or later; so, they have been developing themselves in e-mobility in the last years. As the market is at early stages, utilities want to have as much place in the market as possible. Because, if they become one of the first key players, then they will have the say in the market. Like how the telecommunication companies used wide land coverage as a strategy to attract more customers in early stages of telecom market, the utilities want to cover Czech Republic with public charging stations so that they can show that they cover the most areas. Utilities are aware of that they have the advantage of offering e-mobility services as a package. OEMs, for example car manufacturers, can only offer the product; but they cannot offer the electricity, delivery, installation or ground work services. Utilities, on the other hand, can offer all these services but not cars. That's why OEMs are seeking partnerships with utilities to offer a package to customers with everything included.

Utilities also state that they want to increase their services. They do not want to provide only electricity or charging infrastructure but also other services such as vehicle leasing or selling services. PRE and

E.ON already provides rental of electric bikes, scooters and cars; and also selling of electric bikes, scooters and some supply equipment. CEZ is planning of providing car rental and sharing services in near future. CEZ is also planning to lease the electric buses to municipalities.

When asked about energy concerns of e-mobility, CEZ stated that the energy demand from e-mobility will not affect the current energy system in Czech Republic. They have made some calculations based on future possible scenarios and concluded that the energy required for EVs can be supplied easily. Coal is the main source for power; therefore, more electricity demand would mean more energy produced from coals. This may, in fact, increase the carbon emission when the main purpose of EV transition is protecting environment by decreasing GHG emissions. When asked about environmental concerns of providing electricity for e-mobility, they stated that they will open more RES plants and try to supply power requirement from RES and nuclear plants. In the future, the coal plants will be closed in Czech Republic, the state and the utilities are working on this. The main concern of EV transition is not energy supply but when and how the electricity will be delivered to EVs. Just like the case with the renewables, the peaks that will be created during the day due to e-mobility. The charging times should be arranged in a way that the frequency will not be disturbed. That's why, utilities are planning to encourage the charging during the night which is off-peak time. When asked about if V2G could be a solution for supporting grid during peak demand, CEZ stated that at these early states, it is not a possible solution. The batteries are very expensive and when the people are asked to feed back to grid from their car batteries, they would ask for compensation as their batteries are used more, thus battery life time decreases. It would be too expensive to compensate for the batteries. Also, it would be hard to control the individuals one by one. However, in the future, when the batteries are more commonly produced and cheaper, V2G can be applied for large fleets like bus or taxi fleet. It would be easier to have a contract with a company which has large fleet of cars and can provide a lot of energy. When asked about battery swapping solutions, again they stated that it can be possible for large fleets in the future when the batteries are more common and cheaper.

The current e-mobility market situation in Czech Republic can be summarized as in Table :

Table 14: Number of EVs, fast (DC) and normal (AC) public charging stations

DSO	number of registered vehicles	number of DC public charging stations	number of AC public charging stations	total number of public charging stations	share of public charging stations
CEZ	750	42	53	95	70%
PRE		1	33	34	25%
EON		0	7	7	5%
Total	1721	43	93	136	100%

Share of EVs in passenger cars: total number of EVs/total number of passenger cars=

1 721 / 4 729 000 * 100=0,04%

4. Financial Analysis of Public Electric Vehicle Charging Stations

In this part, financial viability of constructing fast charging stations will be analysed for Czech electric utilities. As CEZ is planning to have 200-300 DC chargers in operation by 2020/2021, operation of 250 DC charging stations starting from 2020 will be considered for this analysis. The information for the installation of the charging stations (equipment prices, installation and maintenance costs, etc.) is provided by the utilities and obtained from their respective websites. Assumptions are made based on National Action Plan on Clean Mobility of Czech Republic. Electric market prices are obtained from OTE, a.s, the electricity market operator in Czech Republic. The regulated prices are obtained from ERU (Energeticky Regulacni Urad), the main regulatory body in Czech Republic.

The fast charging station which will be considered will be the ABB Terra 53 CJG, 50 kW on DC side (2 standards) and 22 kW AC socket (Figure 31) with the features specified in Table 15 [45].

Figure 31: ABB Terra 53 CJG Fast Charging Pole [45]

Table 15: ABB Terra 53 CJG Specifications

Station type	Box-type fast charging stations
Connectors	1x CHAdeMO, 1x CCS, 1x Type 2
Maximum charging power	50 kW DC + 22kW or 43 kW AC
Input voltage	3-phase, 400 V
Size of the circuit breaker	3x125 A
Efficiency	~ 90 %
Connectivity	Ethernet, GSM, CDMA, 3G, RFID
Environment	Indoor, outdoor
Capacity	150 kW

In terms of the number of recharging stations, it is also important to distinguish between a location (multiple charging stations can be located on one location) and a station type where the DC fast charging station can quickly charge only one vehicle. A charging point for fast recharging at AC charging stations allows the recharging of two vehicles independently of one another, i.e. one ABB Terra 53 CJG station = two recharge points. In this context, it should be noted that terminology is used in the NAPCM, which differs slightly from the definitions used in the Alternative Fuel Infrastructure Implementation Directive. The main difference is that the directive divides the station primarily according to power (normal / high power) and not according to the charging method (AC / DC), respectively. Recharging mode can only be distinguished by high-performance stations. In the text of the action plan, localized terminology is used to avoid misunderstanding or confusion with existing stations. The following definitions were used to define the target under the Action Plan [24]:

"Recharging point" = an interface that allows the recharging of one vehicle (the directive in this case uses the term "recharging station").

"Charging station" means a device that contains one or more charging points operating independently of one another.

"DC charging station" = DC charging station (the directive uses the term high-power DC charging station).

"AC charging station" = AC charging station (the directive uses the term conventional AC charging station for power up to 22 kW or a high-performance alternating current charging station for power over 22 kW).

4.1 Methodology for Financial Analysis

For financial analysis, Discounted Cash Flow Analysis is used which is a common method in finance to value a project, company, or asset. Incoming and outgoing cash flows are estimated and then a discount rate is applied to those cash flows to arrive at a present value. The sum of those present values is the Net Present Value or NPV (Formula 2). The DCF model takes the time value of money into account, which is the idea that money in the present is more valuable than the same amount of money in the future due to the ability of money to earn interest. Simply put, it is the sum of discounted CF cash flows over the lifetime. Discount rate is marked with r:

$$NPV = \sum_{t=0}^{T} CF_t \times (1+r)^{-t} \quad [CZK]$$

Formula 2

Investments that have a NPV greater than zero are preferred. In the case of more than one investment, the higher NPV value is preferred.

The Internal Rate of Return or IRR, which is the rate of return that makes the NPV zero, will also be used to assess each charging scenario (Formula 3).

$$\sum_{t=0}^{T} CF_t \times (1+IRR)^{-t} = 0$$

Formula 3

Operation of public charging stations will start from year 2020. The lifetime and depreciation of stations are taken as 10 years. Therefore, the analysis is done for the years between 2020-2029. If a positive value for NPV and an IRR bigger than discount rate (WACC) are obtained, then it can be concluded that this project is financially viable and CEZ can gain profit from this project.

Discount Rate (WACC) that CEZ uses is 7,95% [46]. As the inflation will be considered in NPV calculation, the real discount rate should be used. $WACC_{real}$ can be found as follows:

$$WACC_{real} = [(1+WACC) / (1+\text{inflation rate})] - 1 = 0{,}0583$$

$WACC_{real}$ is found as 5,83%.

4.2 Assumptions and Inputs for the Case Study

In the base scenario stated in NAPCM for e-mobility, zero state support for e-mobility development is considered. Sales volume development is only driven by the development of market parameters that are decisive for the EV acquisition. In this study, only the main assumptions listed in NAPCM will be briefly described and considered. The full assumptions of the scenario are given in Chapter 3.2.1.2 of the NAPCM, 27 et seq. [24]. The scenario assumes PHEVs are only recharged in households. Therefore, the number of EVs considered in this study is the number of BEVs.

The following assumptions have been defined for the financial analysis:

- The average mileage of the electric car on a single charge is 120 km. A single charge means charging 80% of an average EV battery: An EV can go 150 km on average with 100% charged battery; therefore, with 80% charged battery, it can go 120 km on average.

- A car travels approximately 50 km per day on average (Average EV annual traffic= 365*50=18250km).

- Average charging duration (for charging 80% of battery) with fast charger will be taken as 30 minutes:

An 50kW DC fast charger (high power) can charge 80% of an average size battery in 20-30 minutes while 22kW AC charger can charge it in approximately 60-120 minutes. As ABB Terra 53 CJG has chargers for 3 charging standards (CCS, CHAdeMO and Type-2), it is considered that all EVs (CHAdeMO compliant, CCS compliant and AC compliant) can be charged with this charging box. The average duration is considered as 30 minutes for DC charging and 60 minutes for AC charging.

- Average number of charging events of an EV in public charging stations is 30,4:

As an EV is assumed to go 120 km with an 80% charged battery, total number of charging per year can be found by dividing average annual traffic of 18 250 km by 120 km/per-charge which is approximately 152 charges per year for one EV. It is considered that 80% of the electric car recharging takes place at home or at work (i.e. not in public) and therefore 20% of the recharging is carried out at public recharging stations. Then number of charging carried out in public charging stations for one EV is 152 * 0.2=30,4.

- An average battery capacity in the vehicle is 25 kWh. An EV will consume 20 kWh for one charging event: Per charging event=25 kWh * 80%=20 kWh

The case of a driver charging his/her EV more than average time to charge the battery fully is also considered in this study. The probability of this event is taken as 10%. Thus, at 10% probability, an EV will stay at charging station to charge the battery fully meaning that it will consume 5 kWh more than the average charging consumption. To charge 5 kWh in addition would take 30 min. with DC charger and 60 min. with AC charger on average as it takes the same time to charge the vehicle battery from 0% to 80% as from 80% to 100%. So, the extra charging minutes are taken 30 minutes for DC charger and 60 minutes for AC charger in this study.

- An EV will consume 608kWh electricity per year from charging in public fast charging stations:

Electricity consumption of an EV per year from fast charging station=Number of charging events of EV*power consumption per charging event = 20 kWh * 30,4 = 608 kWh/year. This will not be used as input as the electricity consumed will be based on number of charging events carried out per charging station.

- Number of average charging events per charging station is found by multiplying number of EVs expected per year with number of average charging events of one EV per year:

For example, in case of 20% rate of public charging usage, the number of charging events is 30,4. In 2020, the number of EVs estimated to have subscription in CEZ is 4192. For example, the number of average charging events for year 2020 in total is 30,4 * 4192=127 437. The number of average charging events per charging station can be found as 127 437 / 250 = 510 for year 2020. Average charging numbers per charging station are found for each year between 2020-2029.

- Purpose of installing DC charging station is to enable fast charging in 15-30 minutes. However, there might be some cases where the driver can use AC charger of this station (DC charger might me occupied). This situation will also be considered as an extra case at the probability of 5%.

- It is known that CEZ will receive fund for the 85% of the installation costs for 105 stations, meaning that they will pay only 15% of the installation and charging costs for these 105 stations. It is assumed that they will not receive any funding and they will pay 100% of the installation and charging costs of the remaining 145 stations:

This assumption is made based on the reality that they received funds under TEN-T (Trans-European Transport Network)[2] program for at least 105 fast charging stations which will be built along major roads across Czech Republic between years 2016-2020. These funds (85% of the project budget) are granted by the CEF (Connecting Europe Facility) of the European Commission [47] & [48]. As the 85% of project investment is covered by funds, only 15% of the investment will be depreciated for 105 stations. CEZ, in fact, received 85% CEF funding for constructing 105 public fast charging stations which are being constructed under the TEN-T program.

In the case study, 250 stations are distributed in Czech Republic according to the utilities' shares on Czech distribution system. CEZ has 65% of the Czech distribution system. Therefore, it is assumed in this study that 65% of these 250 charging stations will be installed in CEZ distribution areas and 35% of them will be installed in E.ON and PRE's distribution areas. This means that 162 stations will be installed in CEZ area and the remaining 88 stations will be installed in E.ON and PRE's regions. According to interview carried out with CEZ a.s., CEZ's aim is to have 30-40 DC public charging stations in Prague. CEZ already has 13 DC stations in Prague; thus, 27 DC stations more are assumed to be installed in Prague by 2020. Remaining 61 stations are assumed to be constructed in E.ON's distribution region (250-162-27=61). Therefore, for 162 stations, CEZ electricity prices are considered; for 61 stations,

[2] TEN-T is a new program by EU to support installing infrastructure of DC fast charging stations in core corridors (in main highways and cities) to support the transportation in Europe. So far, 105 high power charging stations in CR have been supported under this program.

E.ON electricity prices are considered; for 27 stations, PRE's electricity prices are considered. The prices will be explained under the Electricity Pricing section. The number of stations to be constructed and under which utility's region they will be constructed are summarized in the Table 16.

Table 16: Number of Stations and Their shares in each utility's distribution region

Utility	Number of charging stations to be constructed	Utility's Share in Distribution System	Share of Charging Stations in 250 Charging Stations
CEZ	162	65%	65%
EON	61		24%
PRE	27	35%	11%
Total number of charging stations	250	100%	100%

The shares of stations in each utility region will be used when calculating the electricity prices as every utility has its own price for distribution.

- The stations can be connected to HV grid or LV grid. Both cases and mixed case where half of them connected to HV grid and the other half connected to LV grid will be considered.

- Average life time of charging equipment is taken as 10 years.

- Chargers are depreciated for 10 years according to CEZ accounting rules.

- CZK/EUR exchange rate is taken as 24.3 for the years 2020-2029:

This rate is the prediction of Czech National Bank (CNB) for the last quarter of year 2019. It is assumed as constant for 10 years as it is hard to predict what will happen to the exchange rate as there are many factors affecting it (lack of working force, fluctuations of commodity prices or some external factors such as oil prices). In the long run, it is expected that CZK will have appreciation; it will get stronger along with the growing Czech economy [49].

- Inflation rate is taken 2% for the next decade (2020-2030) as it is CNB's target rate [49].

- Value Added Tax (VAT) rate of Czech Republic is 21%.

- According to the base scenario in NAPCM, the number of EVs will increase as seen below:

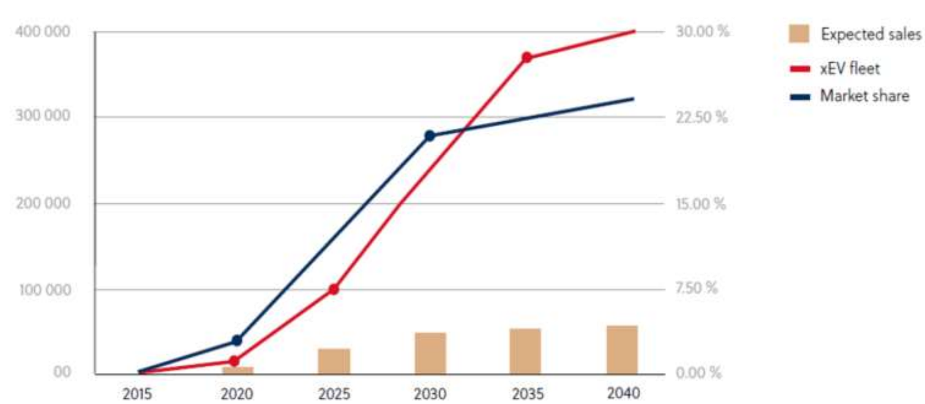


Figure 32: Expected EV sales in base scenario [18]

The expected number of EVs in Czech Republic (explained in Chapter 1.2) can be summarized in the Table 17:

Table 17: Expected numbers of EVs in Czech Republic for years 2020, 2025, 2030 and beyond

year	2020	2025	2030	Beyond 2030
Number of BEVs expected	6 000	35 000	90 000*	145 000*
Number of PHEVs expected	11 000	66 000	160 000*	255 000*
Total number of EVs expected	17 000	101 000	250 000	400 000
Market share of EVs	2,9%	11,9%	20,9%	23,4%

*These numbers are estimated based on the ratio between PHEVs and BEVs in years 2020 and 2025.

It can be seen from the table that the baseline scenario forecasts a higher increase in the number of plug-in hybrids than pure battery electric vehicles. As the PHEVs are assumed to be charged only at households, only the number of BEVs are considered in this study. It is hard to predict the future of the e-mobility market; thus, the share of the utilities on the number of BEVs registered in their systems is taken as the shares of public stations that they have currently (Table 16) and it is assumed that they will keep this share for registered EVs as well. Accordingly, number of BEVs & PHEVs registered in Czech utilities are predicted as in the Table for the years between 2020-2030.

Table 18: The predicted numbers of BEVs & PHEVs in CR are predicted for the years between 2020-2030

year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
BEV	6 000	11 650	17 650	22 950	28 950	35 000	45 400	63 050	75 635	145 000
PHEV	11 000	21 350	32 350	42 050	53 050	66 000	83 200	115 550	138 655	255 000
Total	17 000	33 000	50 000	65 000	82 000	101 000	128 600	178 600	214 290	400 000

These numbers are estimated based on ratio between BEV and PHEV numbers. As prediction is made for years 2020, 2025 and 2030, the numbers for years in between these years are calculated. In 2020, 2025 and 2030, BEVs share in the market is expected approximately as 35%; thus, 35% is taken when calculating the number of BEVs expected in years between 2020-2030. The number of EVs change over the years between 2020-2030 can be seen in the Figure 33:

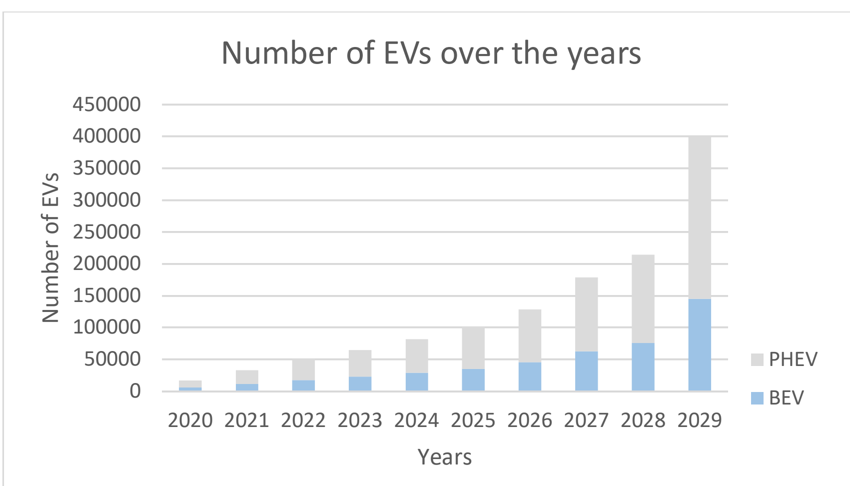


Figure 33: Graph of Number of Electric Vehicles in Czech Republic over the years between 2020-2030.

As the share of CEZ in public charging stations is 70% now, the number of registered BEVs in their system will also be taken as 70%. The number of BEVs registered in CEZ system are considered as in the Table 19 below:

Table 19: The predicted numbers of BEVs registered in CEZ and other utilities for the years between 2020-2030

years	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
BEVs registered in CEZ	4 192	8 138	12 329	16 032	20 223	24 449	31 713	44 042	52 833	101 287
BEVs registered in others	1 808	3 512	5 321	6 918	8 727	10 551	13 687	19 008	22 802	43 713

These numbers are just estimation. No one could predict how the e-mobility market will grow; total number of EVs can be more or less than these numbers. But, for simplification, these numbers will be taken into consideration for calculations. And it is important to note that these numbers are forecasted number for base scenario where no regulation (subsidy) exits for the development of electromobility.

4.3 Costs:

4.3.1 Electricity Costs:

The final price of electricity consists of several basic components. The components are the price of the commodity (energy), price for transmission services (capacity reserving costs), price for using distribution services, price for system services, the contribution to support renewable sources, value added taxes (VAT) on electricity and trader's margin (Figure 34) [50].

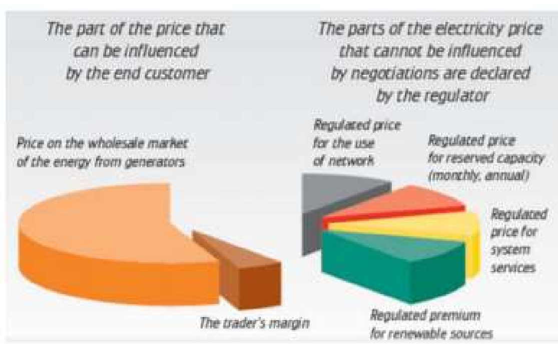


Figure 34: Structure of Electricity Pricing [63]

The electricity price calculation includes both fixed and variable items. The market prices which can be influenced by the end customers are variable. The prices for using network, reserving capacity, system services and supporting renewable sources are regulated by the Energy Regulatory Office (ERU) and these prices are fixed for a certain period of time which is decided by ERU.

4.3.1.1 Regulated Prices:

Prices for capacity reserved: The reserved grid collection capacity is applied for a calendar year with a fixed monthly price for an annual booked capacity or a calendar month with a fixed monthly price for a monthly booked capacity. The price for the reserved capacity of the distribution system operators are as follows:

Table 20: Prices of capacity reserved of Czech DSOs according to voltage levels [51]:

Distribution system operator	Voltage level	Monthly price for annually booked capacity in CZK / MW and month	Monthly price for monthly reserved capacity in CZK / MW and month
CEZ Distribuce, a. s.	VHV*	71 304	79 382
	HV*	171 705	191 158
E.ON Distribuce, a.s.	VHV	61 196	71 215
	HV	143 903	167 464
PREdistribuce, a.s.	VHV	77 872	87 640
	HV	193 631	217 919
LDS Sever, spol. s r.o.	HV	258 144	278 796
SV servisni, s.r.o.	HV	152 488	164 687

**VHV stands for very high voltage and HV stands for high voltage*

When the public charging stations are connected to high voltage grid, the prices for reserving capacity at high voltage level should be considered. In this study, monthly prices for annually booking of capacity on CEZ, E.ON and PRE distribution systems are considered as they are cheaper compared to monthly prices for monthly reserved capacity:

Table 21: Monthly prices for annually booking of capacity on CEZ, E.ON and PRE distribution systems

Distribution system operator	Voltage level	Monthly price per year booked capacity in CZK / MW and month	Booked capacity in CZK / kW/year
CEZ Distribuce, a. s.	HV	171 705	2 060
E.ON Distribuce, a.s.	HV	143 903	1 727
PREdistribuce, a.s.	HV	193 631	2 324

These prices will not be considered in case of connecting public charging stations to LV grid as it is paid inside of the electricity tariffs applied by DSOs. According to the shares of 250 charging stations in each DSO region, an average price is calculated:

Table 22: Average Capacity Booking Costs

DSOs	CEZ	EON	PRE	unit
Monthly price per year booked capacity	171 705	143 903	193 631	CZK/MW/month
Per kWh price	2 060	1 727	2 324	CZK/kW/year
Shares of the 250 charging stations	65%	24%	11%	
Price per charging station (capacity of 150kW*capacity booking prices)	309 000	259 050	348 600	CZK /year
Calculation for average price per charging station:	309 000*0,65+259 050*0,24+348 600*0,11= **=301 089**			CZK/year

Prices for the service network are the distribution services from the customer perspective. All the prices stated in the following content are acquired from [52] & [53]:

- Price for electricity supply: It is decided by ERU for distribution operators. It consists of price for electricity consumed and permanent fee of 450 CZK/month which is same for all DSOs.

- Distribution Part of the price consists of price for distributed amount of electricity and permanent payment for the reserved power per circuit breaker. These prices are different for each DSOs. For the HV connection case in this study, standard tariff C is considered as the tariff that the charging station provider is paying to the DSO who is responsible for the region where the station is installed. The reason that C – tariff is being used is due to the fact that public charging stations are not considered as households but rather commercial places. Which C tariff that the charging station provider choose is up to them [according to the information acquired from the interview carried out with CEZ]. In this study, C03d is chosen for the tariff which CEZ uses for paying the electricity being used in the public charging stations in case of HV grid connection. C03d is chosen because its price per kWh is cheaper compared to C01d and C02d prices per kWh. This decision is made by comparing the total prices obtained from each tariff. C03d was the cheapest solution. This calculation can be seen in Appendix B.

In case of connecting public charging stations to LV grid, electromobility tariff C27d is considered for charging station provider's payment for the electricity consumed in charging stations to DSO. CEZ did not provide any information about which tariff they agreed on with the DSOs for paying the electricity they consume for their public charging stations. Therefore, for HV grid and LV grid connections, C03d and C027d are preferred only for this study. It is not known if they are using these tariffs or some other tariff for paying the electricity.

Table 23: Calculating Payment for reserved power according to Circuit Breaker (CB) 3 x 125A:

Tariff used	CEZ	E.ON	PRE	unit
HV grid connection case: C03d Tariff	5 726	6 776	6 439	[CZK/month]
LV grid connection case: C27d Tariff	1 324	1 571	1 534	[CZK/month]

Other Prices which are the same for all DSOs, consist of the following [52] & [53]:

-Payment for electricity taken from [CZK/MWh], which primarily covers the costs of network losses, which are in direct proportion to electricity consumption. This fixed price for system services provided by the transmission system operator to electricity market participants whose equipment is connected to the electricity system of the Czech Republic is: CZK 93,63 / MWh.

-Electricity tax which is 28,3 CZK/MWh.

-Market Operator (OTE) activities: 5,40 CZK/month = 64,8 CZK/year

-Renewable Sources support price consists of two prices. One is decided according to the circuit breaker size which is 15 CZK/A/number of phases and the second one is 495 CZK/MWh.

Other prices are summarized in the table below:

Table 24: Summary of Other Payments

Other payments			
Electricity tax [CZK / MWh]	**System services [CZK / MWh]**	**Renewable Sources Support [CZK / MWh]**	**Market operator activity [CZK / year]**
28,3	93,63	495	64,8

The fixed prices which are the same for all DSOs and all tariffs are calculated as follows:

kWh dependent prices:
Electricity tax (0,0283 CZK/kWh) + System Services (0,094 CZK/kWh) + RES Support (0,495 CZK/kWh) = 0,62 CZK/kWh

Monthly permanent prices:
Reserved Power according to circuit breaker + Electricity Supply Price (450 CZK/month) + RES Support 3-Phase Connection Price (45,15 CZK/A/month) + OTE Activity (5,4 CZK/month)

For HV connection case: 11 825,2 CZK/month
141 901,8 CZK/year

For LV connection case: 7 423,2 CZK/month
89 077,8 CZK/year

4.3.1.2 Electricity Commodity Price

Czech Operator of Electricity Market (OTE) offers traders the opportunity to trade electricity and gas within one portal and the use of joint financial risk management and financial settlement. Electricity commodity price for base load is expected to be approximately 41 EUR/MWh by 2020 according to PXE (Power Exchange Central Europe) [54]. This price is approximately 1 CZK per kWh. For the next decade (2020-2030), this rate is taken constant as 1 CZK/kWh. Of course, this rate will change as the electricity price is expected to increase; however, it is hard to difficult how it will change as there are many factors affecting it. Also, CZK is expected to get stronger against EUR meaning that electricity will be relatively cheaper compared to this year. So, it can be considered that the expected increase in electricity prices may be compensated by the CZK appreciation.

The commercial and distributed part of the prices are calculated according to the share of 250 charging stations in each DSO region. All these inputs and calculations can be found in Appendix C.

Table 25: In case of HV grid connection, C03d tariff [53]:

DSOs	CEZ	EON	PRE	unit
Price for electricity supply, same for all DSOs, commercial part of price	1 148	1 148	1 148	CZK/MWh
price for electricity distribution	1 017,36	1 162,01	1 132,86	CZK/MWh
Shares of the 250 charging stations	65%	24%	11%	
the total unit price for electricity	2 165,36	2 310,01	2 280,86	CZK/MWh
the total unit price for electricity per kWh	2,17	2,31	2,28	CZK/kWh
Calculation for average price per charging station:	2,17*0,65+2,31*0,24+2,28*0,11 = **2,21**			CZK/kWh

Table 26: In case of LV grid connection, C27d tariff [53]:

DSOs	CEZ	EON	PRE	unit
Price for electricity supply, same for all DSOs, commercial part of price	1 124	1 124	1 124	CZK/MWh
price for electricity distribution	1790,15	2 031,8	2 081,12	CZK/MWh
Shares of the 250 charging stations	65%	24%	11%	
the total unit price for electricity	2 914,15	3 155,8	3 205,12	CZK/MWh
the total unit price for electricity per kWh	2,91	3,16	3,21	CZK/kWh
Calculation for average price per charging station:	2,91*0,65+3,16*0,24+3,21*0,11 = **3**			CZK/kWh

Table 27: Summarized Table for Average Electricity Costs that is paid to DSOs for per charging station:

Costs	HV grid connection	LV grid connection
Capacity Booking cost (CZK/year)	301 089	-
Yearly fixed cost (CZK/year)	141 901,8	89 077,8
kWh dependent fixed cost (CZK/kwh)	0,62	0,62
Variable cost (CZK/kwh) (price for electricity supply and distribution)	2,21	3
Commodity Price (CZK/kWh)	1	1

4.3.2 Charger, Installation, Operation & Maintenance, Rental Costs:

The price of ABB Terra 53 CJG Fast Charging Pole costs to CEZ approximately 28 000 EUR which is 680400 CZK. This price includes 5-year maintenance by ABB and connection to ABB system. This cost information was provided by CEZ.

4.3.2.1 Installation Costs

Installation costs consist of groundworks (cabling etc.) and grid connection fees. Groundwork cost per charging station is approximately 15 000 EUR which is 364 500 CZK. Grid connection cost per charging station is approximately 6 000 EUR which is 145 800 CZK. Total installation cost of one DC public charging station can be found as 364 500 CZK + 145 800 CZK = 510 300 CZK.

4.3.2.2 Maintenance Costs

As the charger has 5-year warranty by ABB, for the first 5 years, there are no maintenance costs. 10% of total installation costs are considered as the amount of maintenance costs for the last 5 years. The annual maintenance cost per charging station can be found as 10% * 510 300 CZK = 51 030 CZK.

Costs caused by unexpected events or vandalism are very low; therefore, they are negligible.

4.3.2.3 Overhead Costs

Overhead costs consist of administration costs and other costs such as management of customers, billing etc. Information on overhead costs could not be obtained from the utilities as these costs are confidential. Overhead costs in this study is taken as 20% of total installation costs based on a case study carried out by University of California, Los Angeles [55]. Then the annual overhead costs can be found as 20% * 510 300 = 102 060 CZK for one charging station.

4.3.2.4 IT Costs

Another important cost input is IT back-end system. According to information gotten from CEZ, it could be as much as 50-80 thousand EUR per year in case of using cloud system for managing the charging stations. For this case, the average IT cost is considered as 50 000 EUR which is 1 215 000 CZK.

The total annual operation costs are the sum of overhead costs and IT costs which is 102 060 CZK + 1 215 000 CZK = 1 317 060 CZK for one DC charging station.

4.3.2.5 Rental Fee

The charging station providers' rental contract with land owners are based on fixed contract prices which are rather symbolic numbers as e-mobility is not profitable now. The rent amount ranges between 1 000 – 12 000 CZK per year. For this case study, the annual rental fee is taken as 5 000 CZK.

Table 28: Summary Table for the Costs related to Charger and Its Infrastructure

Costs	EUR	CZK
Charger price	28 000	680 400
Total installation cost (one-time cost)	21000	510 300
Total operation costs (per year)	54 200	1 317 060
Maintenance costs (10% of total installation costs)	2 100	51 030

4.3.2.6 Depreciation Calculation:

The charger and its total installation costs are the initial costs of the project. As 85% of the initial costs of 105 stations are funded by EC, only 15% of their initial costs are funded by CEZ, meaning only 15% will be depreciated. For the remaining 145 stations, 100% of the initial costs will be depreciated.

Table 29: Total Initial Costs and Depreciation Amounts

Costs	Amount (CZK)
Charger costs (105 stations)	-71 442 000
Installation cost (105 stations)	-53 581 500
Charger costs (145 stations)	-98 658 000
Installation cost (145 stations)	-73 993 500
loan amount (85% installation cost funded)	41 640 480
Initial cost paid by CEZ	-191 405 025
Depreciation amount=Initial Cost/10years	-19 140 502

4.4 Revenue Inputs

4.4.1 Subscription fee:

Currently utilities charge their customers a fee to use their public charging stations and their online system. In exchange of this fee, the user is provided by a RFID chip to access the charging stations. Similar fee is considered in this case study as subscription fee. 500 CZK/month fee without VAT is applied for all customers in order for them to benefit from public fast charging stations. After subscribing, the customer is given RFID chip, a user name and password. With this user name and password, the customer can use mobile applications and websites to track the charging process or get information how much s/he consumed and how much s/he paid for consumption. On her/his account, a credit card information should be inserted to enable payment.

The subscription fee is decreased per year in the amount of 10% of the previous year for CEZ customers. This fee is charged for per EV because every EV is considered to have its own subscription in the system. For other customers who are not CEZ customers, the fee is again the same, 500 CZK/month. However, they are not able to benefit from 10% per year discount as they are not CEZ customers for electricity usage. The summarized table for subscription fee can be seen in Table:

Table 30: Annual Subscription fee over the years between 2020 - 2029

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Annual subscription fee per EV (excl. VAT)	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
Annual subscription fee per EV (excl. VAT)	6 000	5 400	4 860	4 374	3 937	3 543	3 189	2 870	2 583	2 325

Subscription fee can be thought as a protection fee for the charger provider because there is a possibility that people may use the public charging stations less than expected. The fixed costs of the fast charging stations are so high that a fixed fee is a must.

4.4.2 Tariff for DC and AC charging[3]

The tariff for charging is determined by considering three factors: electricity costs, obtaining positive NPV and gasoline prices. The tariff along with the subscription fee should compensate for the electricity costs and the operation, maintenance and rental costs. Moreover, the price for per 100 km should be similar to or less than gasoline price for 100 km so that people can consider buying EVs instead of ICEVs. For HV grid connection, the cost for capacity allocation should also be compensated. However, the tariff will be chosen the same for every region of Czech Republic since applying different prices on different places can raise questions from customers even though it makes sense technically.

To compare the charging prices with gasoline prices, the fixed monthly costs should be calculated on per charging basis. For this, the prices summarized in Table 27 is used.

Operation + Maintenance + Renting + Capacity Booking + Fixed Costs is found approximately 44,3 CZK/kWh. This fee is calculated as **37,4 CZK/kWh** after subtracting the income from subscription fee. This calculation can be found in Appendix D.

Variable distribution & supply cost per kWh=0,5*(2,21+3) = 2,61

kWh dependent cost = 0,62 + 2,61 + 1= **4,23 CZK/kWh**

Total cost per kWh= 37,4 + 4, 23 = **41,6 CZK/kWh**

Total fixed cost per charging = 41,6 * 20 kWh = **833 CZK**

For extra charging, each kWh costs: 0,62 + 2,61 + 1 = 4,23

Extra charging kWh cost: 4,23 * 5 kWh = **21,15 CZK**

Extra charging takes place at 10%. 30,4 charging events * 10% = 3 charging events (approx.)

Charging cost per EV per year= total cost for normal charging events + cost for extra charging events
= 30 * (833 + 0,1 * 21,15) = 30 * 835 CZK

Gasoline price is approximately 31,81CZK/L (VAT included) [56] and the average fuel efficiency can be taken approximately as 6,5 L/100km for OECD countries [57]. Therefore, for 100km, gasoline price is 31,81*6,5=**206,8 CZK.**

As the annual average of a car is 18.250 km, the total litres that will consume by one car is found:

18250km / 100km * 6,5 L/km = 1186,25 L

Total annual average consumption for fuel per car = 31,81 CZK/L * 1 186,25 L = **37 735 CZK/year**

[3] AC charging tariff in here is for public charging by AC charger of ABB Terra 53 CJG fast charging station (22kW-43kW). This tariff has no relation with e-mobility tariffs that are applied by DSOs to customers for charging EVs at households or working premises or at public slow charging stations.

The tariff should be decided in a way that it should compensate the kWh costs. Moreover, the annual money that a customer spends on charging should be lower than annual average spending on fuel which is 37 735 CZK.

As time is very important for DC charging stations, minute based pricing will also be determined so that the customer will feel forced to leave the charging station after normal charging session which is 20 kWh & 30 minutes (80% of battery).

The income from EV users who are not CEZ customers will not be considered as there is the possibility of CEZ customers going and charging in other providers' charging stations as well. Therefore, the costs and incomes per kWh from other customers will be considered equal to the loss in case of CEZ customers to charge their cars at other providers' stations. Only their subscription fees are fixed; therefore, they are considered in the calculations.

There are four different case considered for the financial analysis.

1) A CZK/kWh + B CZK/min (only for extra minutes): Only DC Charging Events
2) A CZK/kWh + B CZK/min (only for extra minutes): 95% DC + 5% AC Charging Events
3) A CZK/kWh + B CZK/min: Only DC Charging Events
4) A CZK/kWh + B CZK/min: 95% DC+ 5% AC Charging Events

Financial Analysis Inputs for considering only DC charging events (no AC chargers are used) case can be found in Appendix E. These inputs are for Case 1 and Case 3.

Financial Analysis Inputs for considering 95% DC + 5% AC Charging Events case can be found in Appendix F. These inputs are for Case 2 and Case 4.

4.5 Case Study

Case 1: A CZK/kWh + B CZK/min (only for extra minutes): Only DC Charging Events

Total gain from one EV per year is

30 * A * 20 kWh + 3 * A * 5 kWh + 3 * B * 30 min= 30 * (A * 20,5 kWh + 3 * B)

(A CZK/kWh * 20,5 kWh + B CZK /min * 3min) ≥ 844 CZK

6,83 A + B = 281,33

It can be seen from the equation that the prices will be high. Calculating A and B from the kWh costs is not accurate as the amounts found based on kWh costs result in big numbers. These big prices would not encourage people to use public charging stations and this will affect EV deployment negatively. After trying many pricing combinations on excel calculations, smaller numbers result in positive NPV. The reason is that when calculating NPV, depreciations are again included to cash flows as depreciation reduces net income on the income statement, but it does not reduce the Cash account on the balance sheet. Therefore, considering only kWh cost is not a correct way to determine the prices, although they can be considered as an initial reference to start trials on excel.

To achieve a positive NPV (IRR > 5,83%), many trials are done on excel; and kWh and minute based prices are found as:

23 CZK/kWh + 10 CZK/extra minutes.

The NPV for only HV grid connection= -250 mil. CZK

The IRR for only HV grid connection= 2,37%

The NPV for only LV grid connection= 257,3 mil. CZK
The IRR for only LV grid connection= 10%
NPV for 50% of stations connected to HV and 50% of stations connected to LV grid= 3,7 mil. CZK
IRR for 50% of stations connected to HV and 50% of stations connected to LV grid= 5,89%

Even though the NPV for only HV grid connection case is negative, the NPV & IRR for mixed case is considered as not all stations are connected to HV grid. The Case 1 Financial Analysis excel calculations can be found in Appendix G & Appendix H.

To find the total annual charging cost to an EV owner, remaining charging events are considered to be charged at households. Tariff considered for charging at home is CEZ's D27d night tariff for year 2018. Night tariff is chosen because it is most likely that the cars will be charged at households during night time. The fixed prices of D27d are not considered as they are already paid by the customer in their electricity billing. The electricity supply and distribution price of D27d is 1 060 CZK/MWh + 71,69 CZK/MWh which makes 1,13 CZK/kWh. Also, as calculated before, kWh dependent regulated price is 0,62 CZK/kWh. [Electricity tax (0,0283 CZK/kWh) + System Services (0,094 CZK/kWh) + RES Support (0,495 CZK/kWh) = 0,62 CZK/kWh. Therefore, the cost for charging EV at home is calculated as 1,75 CZK/kWh. Charging events are carried out at home for 152 * 80%= 122 times and average charging consumption at home is also 20kWh per charging. 1,75 CZK/kWh is 2,12 kWh with VAT included. In the table below, the charging prices are calculated for full charging and 80% charging with and without VAT included. Gasoline price are also calculated for 100 km to compare the charging and filling costs for 100km. Even though the charging price for 100 km with VAT included (463,8 CZK) is seen more than gasoline price for 100km (206,8 CZK), the total annual price for charging (29371,2 CZK) is much less than annual gasoline cost (37 735 CZK). This is because of the fact that charging at public stations are rare case and most of the charging events are carried out at households or working premises which have very low pricing tariffs.

The tariff, its respective total costs for full (100%) and normal (80%) charging and annual charging costs per EV with these tariffs are given in the following tables.

Table 31: Tariff for DC Charging and Its Total Cost in case of 100% and 80% Charging

	Tariff	Full charging, 150km	80% charging, 120km	Gasoline
CZK/kWh	23	575	460	31,81
CZK/min	10	300		
Total, CZK		**875**	**460**	
Total, CZK, VAT included		1058,75	556,6	
CZK/100km		583,33	383,33	
CZK/100km (VAT included)	0,21	705,833	**463,83**	**206,8**
AC charging at home avg. CZK/kWh	1,75	43,75	35,00	
AC charging at home avg. CZK/kWh, VAT included	2,12	53	42,35	

Table 32: Comparison of Annual Costs of Charging and Annual Costs of Gasoline to One User

	Charging times/year	Spending for charging at public station/year, CZK	1 EV subscription fee /per year, CZK
1 EV (public charging)	30 (27 normal & 3 full charging)	27 * 556,6 +3 *1 058,75= 18 204	6 000
1 EV (private)	122	122*42,35= 5 166,7	
1 EV	152	18 204 + 5 166,7 + 6 000 = **29 371,2**	
1 car total spending on fuel per year, CZK		**37 735**	

Case 2: A CZK/kWh + B CZK/min (only for extra minutes): 95% DC + 5% AC Charging Events

In this case, 5% charging events are assumed to carried out with AC chargers. For AC charging of fast public charging station, an AC tariff will be determined. For extra minutes, a minute based price will be determined for both DC and AC charging. After the analysis, the tariffs are found as below:

DC Tariff: 24 CZK/kWh + 8 CZK/extra minutes.
AC Tariff: 12 CZK/kWh + 2 CZK/extra minutes.

The NPV for only HV grid connection= -241,3 mil. CZK
The IRR for only HV grid connection= 2,49%

The NPV for only LV grid connection= 266 mil. CZK
The IRR for only LV grid connection= 10%

NPV for 50% of stations connected to HV and 50% of stations connected to LV grid= 12,3 mil. CZK
IRR for 50% of stations connected to HV and 50% of stations connected to LV grid= 6,01%

Even though the NPV for only HV grid connection case is negative, the NPV & IRR for mixed case is taken into account as not all stations are connected to HV grid. The Case 2 Financial Analysis excel calculations can be found in Appendix I & Appendix J.

When calculating the prices for DC and AC tariff, it is given importance to the fact that the normal charging and full charging of both charging types result in same costs. These DC and AC tariffs, their respective total costs for full (100%) and normal (80%) charging and annual charging costs per EV with these tariffs are given in the following tables.

Table 33: Tariff for DC & AC Charging and Its Total Cost in case of 100% and 80% Charging

	Tariff, DC	Full charging, 150km	80% charging, 120km	Tariff, AC	Full charging, 150km	80% charging, 120km	Gasoline
CZK/kWh	24	600	480	12	300	240	
CZK/min	8	240	0	2	120	0	
Total, CZK		**840**	**480**		**420**	**240**	
Total, CZK (VAT included)		1016,4	580,8		508,2	290,4	
CZK/100km		560	400		280	200	
CZK/100km (VAT included)		**677,6**	**484**		**338,8**	**242**	**206,8**
AC Charging at Home (VAT included), CZK/kWh				2,12	53	42,35	

Table 34: Comparison of Annual Costs of Charging and Annual Costs of Gasoline to One User

	Charging times/year	Spending for charging at public station/year, CZK	1 EV subscription fee /per year, CZK
1 EV (public charging) (29 times with DC + 1 time with AC)	30	18 263	6 000
1 EV (private)	122	5 167	
1 EV total spending for charging, per year	**152**	**29 429,2**	
1 car total spending on fuel per year, CZK		**37 735**	

Case 3: A CZK/kWh + B CZK/min: Only DC Charging Events

As the kWh based price seemed high as 23 CZK/kWh, a pricing will be done for each minute of the charging to make the kWh based price less than 23kWh. At the same time, the total price for 80% charging is tried to be kept less than 383,33 CZK/100km so that it would make sense for this tariff. Also, this case considers that all the public charging events are carried out with DC chargers.

Considering the tariff as A CZK/kWh + B CZK/min:

Total gain from one EV per year is

30 * A * 20 kWh + 3 * A * 5 kWh + 30 * B * 30min + 3 * B * 30 min = 30 * (A * 20,5 kWh + 33 * B)

30 * (A * 20,5 kWh + 33 * B) should be more than or equal to 30 * 835 meaning that:

(A CZK/kWh * 20,5 kWh + B CZK /min * 33min) ≥ 835 CZK

A + 1,62 B = 40,73

From this equation, A=15CZK/kWh and B=16CZK/min can be found approximately and they can be used as initial input to see what happens to NPV & IRR. IRR is found as 24,10% which is much more than $WACC_{real}$. As the purpose of the case study is to find minimum possible prices which can result in positive NPV (or NPV=0 at least) and IRR ≥ $WACC_{real}$, trials are done until reaching best possible tariff. After the analysis, the tariffs are found as below:

DC Tariff: 1,45 CZK/kWh + 14,3 CZK/min.

The NPV for only HV grid connection= -249,3 mil. CZK
The IRR for only HV grid connection= 2,38%

The NPV for only LV grid connection= 258 mil. CZK
The IRR for only LV grid connection= 9,8%

NPV for 50% of stations connected to HV and 50% of stations connected to LV grid= 4,4 mil. CZK
IRR for 50% of stations connected to HV and 50% of stations connected to LV grid= 5,9%

Even though the NPV for only HV grid connection case is negative, the NPV & IRR for mixed case is taken into account as not all stations are connected to HV grid. The Case 3 Financial Analysis excel calculations can be found in Appendix K & Appendix L.

The tariff, its respective total costs for full (100%) and normal (80%) charging and annual charging costs per EV with these tariffs are given in the following tables.

Table 35: Tariff for DC Charging and Its Total Cost in case of 100% and 80% Charging

	Tariff	Full charging, 150km	80% charging, 120km	Gasoline
CZK/kWh	1,45	36	29	31,81
CZK/min	14,3	858	429	
Total, CZK		**894**	**458**	
total, CZK (VAT included)		1082	554	
CZK/100km		596	382	
CZK/100km (VAT included)	**0,21**	**721**	**462**	**206,8**
AC charging at home avg. (CZK/kWh)	1,75	44	35	
AC charging at home avg. (CZK/kWh) VAT included	2,12	53	42	

Table 36: Comparison of Annual Costs of Charging and Annual Costs of Gasoline to One User

	Charging times/year	**Spending for charging at public station/year, CZK**	**1 EV subscription fee /per year, CZK, avg.**
1 EV (public charging)	30	18 209	6 000
1 EV (private)	122	5 167	
1 EV total spending for charging, per year (18 209 + 5 167+6 000), CZK			**29 376**
1 car total spending on fuel per year			**37 735**

The tariff obtained in this case is almost similar to the one obtained in the first case. In fact, the total price for full charging and the total annual charging costs are slightly larger compared to first case. Thus, it can be concluded that pricing for each minute from the beginning of charging session did not help to decrease the total charging cost.

Case 4: A CZK/kWh + B CZK/min: 95% DC+ 5% AC Charging Events

In this case, 5% charging events are assumed to carried out with AC chargers. For AC charging of fast public charging station, an AC tariff will be determined. For extra minutes, a minute based price will be determined for both DC and AC charging. After the analysis, the tariffs are found as below:

DC Tariff: 3,4 CZK/kWh + 13,45 CZK/minutes.
AC Tariff: 1,38 CZK/kWh + 3,5 CZK/minutes.

The NPV for only HV grid connection= -253,5 mil. CZK
The IRR for only HV grid connection= 2%

The NPV for only LV grid connection= 253,7 mil. CZK
The IRR for only LV grid connection= 10%

NPV for 50% of stations connected to HV and 50% of stations connected to LV grid= 96 061 CZK
IRR for 50% of stations connected to HV and 50% of stations connected to LV grid= 5,84%

Even though the NPV for only HV grid connection case is negative, the NPV & IRR for mixed case is considered as not all stations are connected to HV grid. The Case 4 Financial Analysis excel calculations can be found in Appendix M & Appendix N.

The tariff, its respective total costs for full (100%) and normal (80%) charging and annual charging costs per EV with these tariffs are given in the following tables.

Table 37: Tariff for DC & AC Charging and Its Total Cost in case of 100% and 80% Charging

	tariff, DC	**Full charging, 150km**	**80% charging, 120km**	**Tariff AC**	**Full charging, 150km**	**80% charging, 120km**	**Gasoline**
CZK/kWh	3,4	85	68	1,38	34,5	27,6	31,81
CZK/min	13,45	807	403,5	3,5	420	210	
Total, CZK		**892**	**471,5**		**454,5**	**237,6**	
Total, CZK (VAT included)		1079,3	570,5		549,95	287,5	
CZK/100km		594,6	392,9		303	198	
CZK/100km (VAT included)		**719,6**	**475,4**		**366,7**	**239,6**	**206,8**
AC Charging at Home (VAT included), CZK/kWh				2,12	53	42,35	

Table 38: Comparison of Annual Costs of Charging and Annual Costs of Gasoline to One User

	Charging times/year	Spending for charging at public station/year, CZK	1 EV subscription fee /per year, CZK
1 EV (public charging) (29 times with DC + 1 time with AC)	30	18 180	6000
1 EV (private)	122	5167	
1 EV total spending for charging, per year		**29347**	
1 car total spending on fuel per year, CZK		**37735**	

In this case, total annual spending for EV charging is obtained slightly smaller than the one in case 2. Pricing each minute did not make a difference. It can be concluded, the lowest possible tariff with 'price for per kWh and price for each extra minute' result in almost the same total annual charging spending as the lowest possible tariff with 'price for per kWh and price for each minute'.

All four case studies and their results are summarized in Table 39:

Table 39: Results of the Cases

		HV-grid connection		LV-grid connection		HV - LV grid connections		
Cases	**Tariff**	**NPV (mil. CZK)**	**IRR**	**NPV (mil. CZK)**	**IRR**	**NPV (mil. CZK)**	**IRR**	**total annual charging costs**
100% DC	23 CZK/kWh + 10CZK/extra min.	-250	2,37%	257,3	10%	3,7	5,89%	29 371
95% DC + 5% AC	DC: 24 CZK/kWh + 8 CZK/extra min AC: 12 CZK/kWh + 2 CZK/extra min	-241,3	2,49%	266	10%	12,3	6,01%	29 429
100% DC	1,45 CZK/kWh + 14,3 CZK/min.	-249,3	2,38%	258	9,8%	4,4	5,90%	29 376
95% DC + 5% AC	DC: 3,4 CZK/kWh + 13,45CZK/min. AC: 1,38 CZK/kWh + 3,5 CZK/min.	-253,5	2%	253,7	10%	0,1	5,84%	29 347

There are no tariff examples for public DC charging in Czech Republic as providers have flat rate fee for using public charging stations. But, if these prices are compared with the prices in other countries, it can easily be seen that these prices are expensive. In UK, charging prices at 50 kW fast charging station is around 25-35p/kWh which is around 7,38-10,33 CZK/kWh [58]. Considering 80% charging which is 20 kWh on average, the cost per charging is 148 – 207 CZK.

EVgo, who have the largest public fast charging stations in the United States, has recently announced that they have lowered the DC fast charging prices. They offer two choices to customers. First option is membership fee which is $ 9,99/month (approx. 221 CZK/month) + $ 0,18 - 0,21 /minute (4 - 4,6 CZK/min) per charging [59]. This makes around 120-150 CZK per charging. The second option is without membership and the price per minute is $ 0,2-0,35 / min. (4,4 – 7,74 CZK/min.) which makes around 132 – 232 CZK per charging.

Newmotion which has the one of the largest public charging stations has pricing for high power charging as 2 EUR for start + 0,26 EUR /kWh (51 CZK start fee + 6.7 CZK/kWh) which makes around 184 CZK per charging [60].

All these prices are less than half of the prices obtained from the case studies. This shows that CEZ should offer similar prices for charging so that they can compete with charging providers. In the future, other charger providers can penetrate to Czech market so CEZ and other Czech utilities should be ready for the competition. They already have the advantage as the electricity provider and the owner of large portion of public charging stations; if they also have competitive charging prices, then they will be the market dominator and it will be difficult for other charger providers to compete with them.

4.6 Sensitivity Analysis:

The sensitivity analysis is made to see how the rate of using public stations affect NPV and IRR when keeping the same tariffs for four cases.

Using public charging stations rate is taken as 10% and 30% and the following results are obtained:

Table 40: Obtained Results according to the rate of using public charging stations

Cases	Rate of Usage of Public Stations	HV-grid connection		LV-grid connection		HV - LV grid connections	
		NPV (mil. CZK)	IRR	NPV (mil. CZK)	IRR	NPV (mil. CZK)	IRR
1	10%	-1 394	-21,08%	-843	-12%	-1 118	-16,40%
	20%	-250	2,37%	257,3	10%	3,7	5,89%
	30%	894	16,42%	1 357	24%	1 126	19,91%
2	10%	-1 390	-20,9%	-838,4	-11%	-1 114	-16,3%
	20%	-241,3	2,49%	266	10%	12,3	6,01%
	30%	907	16,56%	1 370	24%	1 138,6	20,06%
3	10%	-1 394	-21,07%	-842	-11,5%	-1 118	-16,39%
	20%	-249,3	2,38%	258	9,80%	4,4	5,90%
	30%	895	16,43%	1 358	23,87%	1 127	19,92%
4	10%	-1 396	-21%	-845	-12%	-1 120	-16,45%
	20%	-253,5	2%	253,7	10%	0,1	5,84%
	30%	889	16%	1 352	24%	1 120	20%

As can be seen from the table, if the usage of stations decreases, the NPV and IRR decreases significantly; if the usage rate increases, NPV and IRR. The more charging activities are carried out per station, the more income the utilities can get from stations. Increase in EV deployment will increase the charging events in public stations; therefore, it is important for utilities to encourage people for e-mobility in other areas as well such as leasing activities, household charging, ad-hoc billing services etc. Each e-mobility service they provide will make them gain income and balance the spending on the costly services they provide like public fast charging stations.

Conclusion

To develop and implement a sustainable e-mobility system, it is important to know each segment of e-mobility ecosystem. This thesis aim was to introduce e-mobility and its components and analyse possible pricing schemes for public charging stations by conducting financial analysis from the perspective of electric utilities.

In the first chapter, e-mobility market and its possible development in the world, especially in Europe and Czech Republic have been explained in detail. The motivation behind the transition to EV deployment have also been described. Moreover, a background information has been provided for EV types and their basic features.

In second chapter, each e-mobility ecosystem segment has been explained along with their responsibilities and roles on developing e-mobility. E-mobility has been discussed in four main groups: EV provision, Infrastructure provision, e-mobility service provision and support policies provision. Targets, main policies, regulations and subsidies which support e-mobility have been described for several EU countries including Czech Republic. The policies and support mechanism of Czech Republic have been compared with some other EU countries. E-mobility's expected impact on oil consumption and import; impact on electricity consumption and power systems have also been discussed. Moreover, examples to business models from all around the world for using e-mobility as a service have been given and their benefits have been explained.

In the third chapter, e-mobility has been discussed as a business solution for electric utilities. Czech Republic's national action plans, regulations and incentives on clean mobility have been explained. How the demand for EVs can be stimulated; how the infrastructure can be facilitated; how the perception of people on e-mobility can be improved have all been discussed in this chapter. The Czech utilities and their role in e-mobility market have been discussed. A brief information about their e-mobility services and their motivation for e-mobility have been given. Czech utilities are already playing a major role in e-mobility in Czech Republic in terms of service and charging station provision. Currently, CEZ is providing 53 normal and 42 fast charging stations. They are planning to have 200-300 fast DC charging stations in Czech Republic which constructs the base of the financial analysis in this thesis. PRE, another major utility and e-mobility service provider, has 34 public charging stations in Czech Republic, 28 of them being in Prague. The third major utility E.ON is providing 7 public charging stations, 3 of them being in Prague. As increasing the EV deployment is the main target, provision of fast charging stations is highly important to make EVs equal to ICEVs in terms of availability of the stations. As the e-mobility is an infant market in Czech Republic and most of the countries in the world, available information on internet or on books are limited. There were not example cases for construction of fast public charging stations to refer to; therefore, the experts from Czech utilities CEZ and PRE have been consulted to obtain information and data on public charging stations. The interviews have been conducted with them to learn more about the e-mobility in Czech Republic and about their view and motivation on e-mobility. Asking directly to the e-mobility experts has been very helpful as the information about Czech e-mobility market is generally available in Czech language. Czech language was the main challenge when researching about e-mobility and electricity market of Czech Republic.

In the final chapter, financial analysis is carried out for constructing 250 fast charging stations. Half of the stations is considered to be connected to HV grid and half of them to LV grid. 105 out of 250 stations are funded by CEF of EU so 15 % of initial costs are funded by CEZ for these 105 stations; the remaining 145 stations are fully funded by CEZ. Depreciation and life time of charging stations are taken as 10 years; therefore, the years are considered from 2020 to 2030. Assumptions are made based on the basic scenario of NAPCM. Considerations on electricity market price change and inflation rate change are made according to PXE and CNB respectively. Possible tariff schemes have been tested until they result in positive NPVs. The annual charging costs of one EV are compared with the annual gasoline costs of one ICEV. Following results have been obtained:

Table 41: The tariffs and their NPV and IRR outcomes depending on the connections and rate of public station usage and their respective total annual charging costs

Tariff	Rate of Public Station Usage	HV-grid connection		LV-grid connection		HV - LV grid connections		total annual charging costs (CZK)
		NPV (mil. CZK)	IRR	NPV (mil. CZK)	IRR	NPV (mil. CZK)	IRR	
23 CZK/kWh + 10 CZK/extra min.	10%	-1 394	-21,08%	-843	-12%	-1 118	-16,40%	29 371
	20%	-250	2,37%	257,3	10%	3,7	5,89%	
	30%	894	16,42%	1 357	24%	1 126	19,91%	
DC: 24 CZK/kWh + 8 CZK/extra min AC: 12 CZK/kWh + 2 CZK/extra min	10%	-1 390	-20,9%	-838,4	-11%	-1 114	-16,3%	29 429
	20%	-241,3	2,49%	266	10%	12,3	6,01%	
	30%	907	16,56%	1 370	24%	1 138,6	20,06%	
1,45 CZK/kWh + 14,3 CZK/min.	10%	-1 394	-21,07%	-842	-11,5%	-1 118	-16,39%	29 376
	20%	-249,3	2,38%	258	9,80%	4,4	5,90%	
	30%	895	16,43%	1 358	23,87%	1 127	19,92%	
DC: 3,4 CZK/kWh + 13,45CZK/min. AC: 1,38 CZK/kWh + 3,5 CZK/min.	10%	-1 396	-21%	-845	-12%	-1 120	-16,45%	29 347
	20%	-253,5	2%	253,7	10%	0,1	5,84%	
	30%	889	16%	1 352	24%	1 120	20%	

Constructing fast charging stations is very expensive business and it is not profitable at this early stage of e-mobility market. As can be seen from the financial analysis, installing fast charging stations has a huge financial burden on even a big utility like CEZ. To gain profit from this business or at least compensate what they have invested, they have to charge customers expensive prices for using fast stations. This would not encourage people to use public charging stations while the purpose of installing public charging stations is to encourage EV deployment. If the utilities apply reasonable charging prices, then the high costs of infrastructure will not be refunded by the electricity sales. Therefore, it is important for them to get support from government or international funds. Without subsidies, it is very expensive for the companies to build fast charging stations. However, majority of CEZ chargers was built without any funding and they are planning to continue building stations even if they don't get any support. Because, as mentioned in the thesis, they want to be the major player in e-mobility market by taking good locations.

For public charging stations to bring income, at least 8-10 charging events per day should be carried out at one station. This can be seen in the excel calculations as well. After the year 2025, the charging events per station starts to become more than eight times per day and the income starts to become positive. There is a dilemma here as public fast charging stations can become profitable when the EVs are commonly used and EVs can become more common when e-mobility infrastructure is more common and convenient. The reason why electric utilities like CEZ are entering the e-mobility business even though it is not profitable now is that they want to dominate the market by being getting the best locations and they believe being the market maker will pay them back in the future. The business may be risky and may take long time to start gaining profit; but, in the long term, it will bring a lot of profit with the growing e-mobility market.

The utilities see e-mobility as a good business solution to grow themselves more than an electricity provider. In today's business life, many companies are doing business in other areas in addition to their core business to grow and gain more. Electric utilities see e-mobility a business opportunity to gain profit in the future just like how they did with telecommunication. And it is not hard for them to grow in e-mobility market as they are already in the market as electricity provider. What they are trying to do now is planning more profitable business models (new services, pricing schemes etc.) and marketing the e-mobility as much as possible so that public know more about it.

For e-mobility deployment, improving the EV technology is also important along with the charging infrastructure development. EVs have many advantages such as decreasing carbon emissions, not having complex technology like ICEVs, using electricity as fuel which is cheaper than oil and so on. However, EVs do not perform as well as ICEVs in terms of range at the moment. Therefore, the EV and EVSE manufacturers, especially battery manufacturers, are constantly working on improving the EV and EVSE technologies. For mass production of batteries, Gigafactories are constructed. With better battery technologies, the range and efficiency of EVs will increase. Also, with mass production, the battery prices which is responsible for a large portion of EV price will decrease. Thus, EV prices will decrease which means that the biggest disadvantage of EVs will be eliminated. When the EVs are equal to conventional cars in terms of price and technology, EV deployment will increase.

Along with the EV technology and e-mobility infrastructure, e-mobility services should also be developed. The service providers are working on new service models and they are also trying to improve the IT systems. E-mobility services can help EV deployment to increase, especially at this early stage of e-mobility market. Because, with e-mobility services such as EV leasing, e-bike renting, e-buses, e-taxis, people will be introduced to e-mobility as they would not have to buy EVs to try them. Providing e-mobility services is a good opportunity to advertise e-mobility. People can get the taste of EV technologies without spending too much money. Making people interested in EVs by e-mobility services will help to increase EV deployment.

The players of e-mobility system have already started to collaborate to develop e-mobility and get the best business outcome from it. Networking and building strategic alliances are must. Because, for e-mobility to be successful on a large scale, the market needs a healthy business environment to evolve sustainable business models. It is important to develop the e-mobility to the level where the customers are satisfied and the e-mobility providers are gaining profit. Hopefully, the transition to e-mobility will go as planned and the decarbonization of transport will be achieved which is the key for reducing GHG emissions and thus limiting the temperature rises to 1.5°C.

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Appendices

APPENDIX A: Interviews

INTERVIEW WITH PRE:

- **Current Business model that PRE is using**

"From e-mobility perspective we are infrastructure operator as a base, but we are trying to be active in the value chain in general, thus we are offering e-mobility services to households or businesses, developing products in commodity business and so on."

- **Incentives/support mechanism that your government is providing**

"There is support to buy EV addressed to B2B segment and B2G
There is support for development of charging infrastructure
There is plan for OPEX support of public charging operators.
There is also a plan for support to purchase EV for B2C segment."

- **Incentives/support that you are providing to customers to encourage them for using e-cars**

"We are providing advisory for free and marketing the e-mobility
We are helping customers to try and get in touch with e-mobility
We have special product for B2Bs to get EVs and chargers cheaper"

- **How many cars/charging stations registered in your system and in Czech Republic currently?**

"Estimated number of chargers is 350 and estimated number of cars in operation is 1600."

INTERVIEW WITH CEZ:

- **Do you install the stations or do you partner up with installation companies?**

"Our contract with charging station supplier (ABB for DC) is designed in a way, that the price of the charger includes its installation and putting into operation (the site has to be prepared, so all cabling, electricity installation and base for charger has to be already on place). So, we are "accepting" the charger that is already installed on place and up and running."

- **How did you decide which locations you would install the chargers in?**

"Places for installation of chargers are selected with different factors being involved. Firstly, we are trying to select the places in a way that they create together a network offering a good coverage of the country. The primary factor is a commercial potential (attractivity) of the place for the charger (in simple words - places where we "want" the charger). The other important factor is how to deal with ownership rights. We logically have to install chargers on places that are owned by others, so the easiness of reaching a lease contract for place we are interested in is another key issue. The third main factor is the availability of grid connection on the site - some sites are easily connected, on some places it is rather the opposite. The fourth main factor are the costs - how expensive it is to install all necessary cabling and other necessary groundworks."

- **What is your business model? Revenue share? Contract terms with EV providers?**

"Our business model is relatively straightforward - we own and operate the chargers on our own and our revenues are based on selling the "service" or "product" of charging the EVs (revenues form EV owners)."

- **How often is your space being used/What is the current demand or utilization?**

"There are huge differences among chargers in terms of its utilisation. In total, last year the consumption was more than 640 thousand kWh in total. The most utilised charging station locations are in Prague - consumption was 52 171 (Karlin) and 40 584 (Brumlovka). There are two DC chargers on both sites."

- **How did you determine the pricing strategy? What is your billing tariff for customers?**

"So far our charging is based on a flat fee. However, we plan to change our service to kWh based tariff."

- **Can you give me an idea of the ongoing cost of ownership? (installation, maintenance, operations)? What are the maintenance costs, installations costs, operation costs, administration costs? How much is the equipment cost? Level 1, level 2 and level 3 type chargers cost and their installation costs?**

"This is bit more complicated question. Concerning the costs of installation, on average, the price of the DC charger (ABB Terra 53 CJT, 50 kW on DC side (2 standards) and 22 kW AC socket) is around 28.000 EUR (price includes installation, wrap-up stickers for design of the station, 5-year maintenance and connection to ABB server). On average, the installation costs (groundworks, cabling etc.) could be between 8-15 thousand. EUR. On-off grid connection fee for one DC charger (125 A) are 2.500 EUR. AC charger (2x22 kW AC socket) costs around 7.000 EUR, grid connection is cheaper (around 1.500 EUR) and groundworks are also cheaper (3-8 thousand EUR).
There are of course some overheads of my team and other administrative costs (management of customers, billing etc.). Other important costs are for IT back-end system (could be as much as 50-80 thousands EUR per year in case IT back-end system for managing the charging stations is purchased as a cloud service). If you need to go into a detail, you can of course consider own consumption of chargers and its efficiency. Maintenance costs are typically considered between 5-10%, however our contract with charging station suppliers includes warranty for 5 years (so there will be no regular maintenance costs for 5 years). Costs related to vandalism and unexpected repairs are surprisingly low (negligible). Each kWh of course creates a respective cost based on purchase price for electricity."

- **Is there significant cost involved in upgrading your site's electrical meters to support EV Charging?**

"Typically, electricity connection necessary for DC charger exceeds what is normally available on site (DC charger needs 125 A, for example average house has a connection 25-32 A). So, grid needs to be strengthened when installing even a single DC charger. Connection of the charger is either made through strengthening the existing connection or creating a new one. One-off costs for connection (you pay to a distribution company) are listed above. Other costs require necessary cabling and ground works to connect the charger (between the place where the distribution company creates/build your connection and the place of the charger itself). Costs can be quite low, but sometimes extremely high".

- **How do you price this upgrade in charging rate?**

"We do not have a different pricing for charging at chargers depending on its costs. The business model is based on average costs / pricing".

- **What do you do when your equipment breaks down? How often does this happen? Who pays for the repair?**

"This is included in our service contract with charging station supplier that includes the warranty. The contract contains the rules (some repairs can be done on site, some need exchange of the charger). Contract typically includes reaction time of the charging station supplier. In case the repairs go beyond the warranty, it is paid by us. Maintenance and repairs after the warranty time will have to be paid by us. Therefore, reliability of the charging equipment is an important issue when selecting the supplier ("cheap" charges can become expensive at the end)".

- **Do you pay any fee to site owners?**

"Yes, installation is based on a lease contract with landowner and lease fee is paid. Typically, it is relatively symbolic (network is not profitable at the moment) but will increase in the future".

- **Do you pay any other fees like city permit fee?**

"Only in some locations, where the land is owned by a city itself (majority of chargers is installed on a private property). They are rather symbolic (cities understand that from economic reasons, high fees cannot be imposed and this is typically not a major source of the revenue for the city)".

- **How much are the billing and payment fees (credit card processing fees) to banks?**

"Our service is based on a flat fee, paid for half a year based on an invoice. However, there is a plan to introduce payment based on kWh. As far as we know, payment gateways are asking for fees on the level of several per cent, however a minimal fee is typically imposed (therefore for small amounts the fees are relatively higher than for larger amounts)".

- **How many years do you consider for depreciation of the chargers?**

"Chargers are - based on accounting rules- depreciated for 10 years. However, it is expected that they can become morally obsolete sooner (which is one of the risks for charging station operator)".

- **What is the cost of equity in Czech EV Supply Equipment market?**

"I am not sure that I understand the question. Price of the "money" is relatively low at the moment, however, depending on the bonito of the company".

- **What types of rebates are you receiving at the city, country level?**

"There are no measures or instruments on city level in place in the Czech Republic. The only way how a city can "support" the installation of chargers is to provide a land for a good price or to share the costs for ground works. On country level, investment subsidies are just about to be started".

- **How does that affect your pricing?**

"Investment subsidies will not affect pricing of the service as our price of the charging is still rather symbolic and is not based on costs of installation. The key effect of subsidies (that is in fact the reason why they are implemented) is to speed-up the deployment of charging stations (higher number of charger is deployed and not only on the most commercial places, but on other locations as well). Aside of country level subsidies, it was possible to get support directly from EU funds (CEF programmes) - we were successful in receiving support for 108 DC chargers to be built by 2020".

- **What do you see happening in the next few years?**

"It is expected that number of EVs should increase significantly after 2020. Based on our analysis, the operation of charging network starts to make economically sense when you achieve certain level of utilisation of chargers (such us 5-10 charging sessions per day on average). For network of some hundreds of charging stations this requires to have more than 10.000 EVs on streets. So, we expect that beyond 2020 (2023-25) the operations of network could become profitable and initial investments could start to be paid back".

- **In your website, I saw you have 13 fast charging points, 16 normal charging points in Prague. How many do you plan to install in Prague in near future?**

"In total - especially in case we will be able to gain support form Czech funds, we have ambitions to have 200-300 DC chargers in operation by 2020/2021. For Prague, we plan to increase the number of chargers up to 30-40 in upcoming years (DC chargers)".

- **If everything does roll out as predicted or even faster, how much more electricity will be consumed across the board of a normal year and will this mean much of a difference for CEZ?**

"In terms of the balance, it's not very significant. We did some estimations that if we speak about tens or hundreds of thousands of electric vehicles on the streets, which is quite a huge number, compared to what is on the streets today as we speak about percentage in increase of annual electricity consumption. Even such a high number as a million of electric cars is taking to account a typical consumption and driving range per day, or per year. We are speaking about a few Terawatts, so still a relatively low increase in total consumption. What is probably more important in terms of e-mobility is when and how the electricity will be delivered to cars. So not as much from the point of the view of the balance but rather a charging technology, power output of chargers and their location in the Czech Republic. Distribution of this electricity might become and probably will become a more significant issue than the amount itself." *Taken from:* http://www.radio.cz/en/section/marketplace/czech-power-giant-prepares-for-electric-dreams

- **Average gross profit to site owners (CZK/hour or CZK/kWh), if you share revenues with them?**

"Our contracts with landowners are due to the fact, that e-mobility is not profitable at the moment (and will not be profitable in upcoming years) mainly based of fixed, rather symbolic fee (ranging between 1.000 – 12.000 CZK/year depending on attractivity of location, number of chargers on site etc.). However, some contracts contain also a variable part of rental fee, that is being paid in situation that certain threshold of utilisation of charging station is reached (defined by number of charging sessions and kWh of electricity that was charged). In that case, fixed fee is typically increased by 0,15-0,25 per each kWh. In both cases, the rental fees are considered by both parties as rather symbolic and it is expected that once the electromobility reaches a commercial operation, new rental contracts will be negotiated (which will happen somehow automatically as the maximum length of the contract is 10 years, so in case the cooperation will continue, new leasing contract has to be negotiated anyway)."

- **Average gross profit to charger company like ABB (CZK/hour or CZK/kWh), if you share revenues with them?**

"We do not share revenues with charging station supplier. The contract is based on a fixed price per charging station."

- **Marginal cost of electricity (respective costs per kWh)?**

"This is a more complicated issue. The price we pay depends on whether the charger is connected on the low voltage grid or high voltage grid – this has an impact on the structure of the final price of electricity. The price of electricity has a variable part (depending on kWh – such as price for commodity (kWh), taxes, renewable energy sources support, system services, costs of the operator of the electricity market) and a fixed part that is the price for the use of distribution grid (based on reserved capacity in kW - this does not depend on the amount of electricity being delivered as the costs for distribution have fixed nature – they have to care about the grid even if no electricity is used).
In simple words, in case of low voltage connection, the fixed part of the price is lower, but some costs of the distribution are contained in variable part (so variable part is more expensive). In high voltage grid it is the opposite (high fix, low variable). This means that connection to high voltage grid makes sense for those, who have a relatively high and stable consumption (the final price – if they divide the sum of fixed and variable part by the number of kWh – is at the end lower then low voltage where the final price is more less fixed ad does not depend much on the level of consumption due to higher variable part). For small consumptions, the low voltage grid is of course better (which was the logic behind these principles – the construction of high voltage price much better reflects the real costs, but would result in high electricity bills for low consumption, i.e. households).
In high voltage connection, the variable part is roughly 1,8 CZK/kWh, fixed part for 1 DC charger (50 kW DC + 22 kW AC) is appx. 100 000 CZK/year. Therefore, the profitability (business model) is highly depending on the utilisation of charging station (with more charging sessions, the effect of fixed price on the price of the charging session is logically lower and more affordable for final user)."

- **How many EVs are registered in your system?**

"We have around 750 registered customers."

- **What is your market share in e-mobility? in terms of number of EVs registered in your system and also in terms of public charging stations you have?**

"Concerning the number of customers, we probably have something like 50% of the market, but this might be a bit misleading as the customers might be in parallel customers of others (such as PRE) as there is no functional roaming model. Concerning the public charging stations, we are the biggest charging stations operator by far, where the second biggest is PRE, then probably E.ON and the rest is pretty much fragmented… The point is that there is not yet a reliable statistic of the charging stations, so the numbers that can be found on the internet are mixing professional charging stations with more amateurish ones. I assume that in professional charging stations we might be somewhere around 40-50%, but this is rather my guess…"

- **How are the charging stations treated by the Distribution Operator? Are they treated as separate households or businesses? Or CEZ whole charging stations in a city are treated as aggregated customer? For example, in Prague, is PRE applying C tariff or D tariff for CEZ charging stations?**

"In case the charger has a separate grid connection, it is treated as a separate "consumption" point and its operator has to select a respective tariff. As the operation of public chargers is a commercial activity, C tariffs should be used. There is no aggregation possible, so each charger (or group of chargers, if connected to a single grid connection) has to choose its tariff and is treated separately."

APPENDIX B: TARIFF DECISION OF ELECTRICITY USAGE PAYMENT TO DSOs IN CASE OF HV GRID CONNECTION:

To compare C01d, C02d and C03d, the total costs caused by using them are compared. Firstly, the total kWh consumed from one charging station is calculated:

kWh consumed from 1 station/year= number of charging events/year*kWh consumed/charging (510 charging events/per station * 20kWh + 5,1 overtime charging events*5kWh) 510 is the number of charging events occurred in year 2020	10 455	kWh
total kWh consumed from 250 charging stations / year	2 613 750	kWh
total MWh consumed from 250 charging stations / year	2 613,8	MWh

The tariff prices are gotten from [53]. Total prices are calculated by considering the distribution market share of DSOs. For example, for C03d: Total Distribution Cost is calculated from 1162,01*24% + 1017,36*65% + 1132,86*11% = 1065,13

Distribution rate	**3 x 125A**	**C03d**		**C02d**		**C01d**	
Distribution area	Percentage of stations in DSO's region respectively	Permanent payment for the circuit breaker [CZK / year]	Cost per Distributed Quantity [CZK / MWh]	Permanent payment for the circuit breaker [CZK / year]	Cost per Distributed Quantity [CZK / MWh]	Permanent payment for the circuit breaker [CZK / year]	Cost per Distributed Quantity [CZK / MWh]
E.ON Distribuce	24%	81 312	1 162	7 692	2 852,2	1 536	3 511,1
CEZ Distribuce	65%	68 712	1 017,4	7 020	2 140,4	1 980	2 672,5
PRE Distribuce	11%	77 268	1 132,9	7 296	2 400,2	2 076	3 105,2
Total	100%	72 710,5	1 065,1	7 213,8	2 342,1	1 882	2 923,8
Total price for the consumed amount, CZK		72 710,5 + 1 065,1 * 2 613,8 = **= 2 856 690**		7 213,8 + 2342,1*2613,8 = = 6 128 975		1 882+ 2923,8 * 2 613,8= = 7 644 005	

As can be seen from the calculations, the total amount from C03d is the cheapest, that's why C03d is considered for the HV grid connection case.

APPENDIX C: ELECTRICITY COST INPUTS FOR HV AND LV CONNECTIONS

	C03d (HV connection Case)			C27d (LV connection Case)		
DSO	**CEZ**	**EON**	**PRE**	**CEZ**	**EON**	**PRE**
Monthly price per year booked capacity	171 705	143 903	193 631	-	-	
	2 060	1 727	2 324	-	-	-
assume	2 060	1 727	2 324	-	-	-
	309 000	259 050	348 600	-	-	-
			301 089			-
1) price for electricity supply, same for all DSOs, commercial part of price	1 148	1 148	1 148	1124	1124	1124
2) price for electricity supply, same for all DSOs, commercial part of price	-	-	-			
3) price for electricity supply, same for all DSOs, permanent payment	450	450	450	450	450	450
4) Electricity Tax Rate	28,3	28,3	28,3	28,3	28,3	28,3
5) Permanent payment for the reserve power per circuit breaker above 3x100 A to 3x125 A incl.	5 726	6 776	6 439	1 324	1 571	1 534
6) Renewable Energy Surcharge, 3-phase connection, according to the circuit breaker	45,15	45,15	45,15	45,15	45,15	45,15
7) Renewable Energy Surcharge, according to consumption	495	495	495	495	495	495
8) PRICE OF SYSTEM SERVICES	93,63	93,63	93,63	93,63	93,63	93,63
10) OTE's activities	5,4	5,4	5,4	5,4	5,4	5,4
11) price for electricity distribution	1 017,36	1 162,01	1 132,9	1 790,15	2 031,8	2 081,1
the total unit price for electricity (1+11) per MWh	2 165,36	2 310,01	2 280,9	2 914,15	3 155,8	3 205,1
Total unit price for electricity per kWh	2,17	2,31	2,28	2,91	3,16	3,21
Average unit price for electricity per kWh			**2,21**			**3,00**
fixed permanent (3+5+6*125A+10)	11 825,2	[CZK/month]		7 423,2	[CZK/month]	
	141 901,8	[CZK/year]		**89 077,8**	[CZK/year]	
variable permanent (4+7+8)	616,9	[CZK/MWh]		616,9	[CZK/MWh]	
	0,62	[CZK/kWh]		**0,62**	[CZK/kWh]	

APPENDIX D: CALCULATING THE TOTAL COST PER kWh

year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	Avg.
per station O&M, rental costs	330 515 000	330 515 000	330 515 000	330 515 000	330 515 000	330 463 970	330 463 970	330 463 970	330 463 970	330 463 970	
per EV O&M, rental cost	**78 844,2**	**40 613,8**	**26 807,9**	**20 616**	**16 343,5**	**13 516,5**	**10 420,5**	**7 503,4**	**6 254,9**	**3 262,6**	
cost per charging	2 592,1	1 335,2	881,4	677,8	537,3	444,4	342,6	246,7	205,6	107,3	
cost per kWh	129,6	66,8	44,1	33,9	26,9	22,2	17,1	12,3	10,3	5,4	
capacity booking cost	37 636 125	37 636 125	37 636 125	37 636 125	37 636 125	37 636 125	3 7636 125	37 636 125	37 636 125	37 636 125	
fixed cost	28 872 450	28 872 450	28 872 450	28 872 450	28 872 450	28 872 450	28 872 450	28 872 450	28 872 450	28 872 450	
fixed cost total per CS	66 508 575	66 508 575	66 508 575	66 508 575	66 508 575	66 508 575	66 508 575	66 508 575	66 508 575	66 508 575	
per EV fixed cost	**15 866**	**8 173**	**5 394**	**4 148**	**3 289**	**2 720**	**2 097**	**1 510**	**1 259**	**657**	
cost per charging	522	269	177	136	108	89	69	50	41	22	
cost per kWh	26	13	9	7	5	4	3	2	2	1	
annual O&M, rental, capacity, fixed cost per EV	**94 709,8**	**48 786,4**	**32 202,4**	**24 764,4**	**19 632,3**	**16 236,8**	**12 517,7**	**9 013,5**	**7 513,7**	**3 919,3**	
per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 061,8	92 951 940,1	109 333 730,6	137 795 712,4	150 138 444,6	261 671 754,4	
per subscription revenue (flat rate) per EV	6 258,8	5 658,9	5 119,0	4 632,9	4 195,5	3 801,9	3 447,6	3 128,7	2 841,8	2 583,5	
annual O&M, capacity, fixed cost per EV after subtracting subscription fee	88 451	43 127,4	27 083,5	20 131,5	15 4367	12 435	9 070,1	5 885	4 672	1 335,8	**22 762,8**
cost per charging	2 908	1 417,9	890,4	661,9	507,5	408,8	298,2	193,5	153,6	43,9	**748,4**
cost per kWh	145,4	70,9	44,5	33,1	25,4	20,4	14,9	9,7	7,7	2,2	**37,4**
									kWh dependent cost		**4,23**
									kWh total cost		**41,6**
									kWh cost per charging		**833**

APPENDIX E: Financial Analysis Inputs for considering only DC charging events

HV GRID CONNECTION INPUTS

	Total	CEZ	EON	PRE	Funded stations
Number of public DC charger estimated to be constructed by 2020	250	162	61	27	105
	Utilities' shares on electricity distribution in CZ	65%	35%		
		0,65	0,24	0,11	

	1	2	1	4	5	6	7	8	9	10
year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
number of EVs estimated	4 192	8 138	12 329	16 032	20 223	24 449	31 713	44 042	52 833	101 287
estimated number of EV's which are registered in other providers	1 808	3 512	5 321	6 918	8727	10 551	13 687	19 008	22 802	43 713
number of average charging events per year in total	127 507	247 531	375 007	487 640	615 116	743 657	964 604	1 339 611	1 607 004	3 080 813
number of average charging events per year in one charging station	510	990	1 500	1 951	2 460	2 975	3 858	5 358	6 428	12 323
number of average charging events per month in one charging station	42,5	82,5	125	162,6	205	248	321,5	446,5	535,7	1 027
number of average charging events per day in one charging station	1,42	2,75	4,17	5,42	6,83	8,3	10,7	14,9	17,9	34,2
kWh consumed from 1 station/year= number of chargings/year*kWh consumed/charging	10 201	19 802	30 001	39 011	49 209	59 493	77 168	107 169	128 560	246 465
kWh consumed from 1 station/year additional (10% of charging events occur overtime)	255	495,1	750	975,3	1 230,2	1 487,3	1 929,2	2 679,2	3 214	6 161,6
total extra minutes per station (30min*number of charging events*10%)	1 530,1	2 970,4	4 500,1	5 851,7	7 381,4	8 924	11 575,2	16 075,3	19 284	36 969,8
electricity commodity price (CZK/per charging station)	10 455,5	20 298	30 750,6	39 986,5	50 439,5	60 980	79 097,5	109 848,1	131 774,3	252 626,7
capacity booking cost (CZK/per charging station)	301 089	301 089	301 089	301 089	301 089	301 089	301 089	301 089	301 089	301 089
fixed regulated electricity cost (CZK per charging station)	141 902	141 902	141 902	141 902	141 902	141 902	141 902	141 902	141 902	141 902
variable regulated electricity cost (CZK per charging station)	6 450,3	12 522,2	18 971	24 669	31 117,7	37 620,3	48 797,6	67 768,6	81 296	155 853
total electricity cost (CZK per charging station)	**459 897**	**475 811**	**492 712,3**	**507 646,1**	**524 548**	**541 591**	**570 885,9**	**620 607,5**	**656 061**	**851 470,4**

LV GRID CONNECTION INPUTS

	Total	CEZ	EON	PRE	Funded stations						
Number of public DC charger estimated to be constructed by 2020	250	162	61	27	105						
	Utilities' shares on electricity distribution in CZ	65%	35%								
		0,65	0,24	0,11							
		1	**2**	**1**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
number of EVs estimated		4 192	8 138	12 329	16 032	20 223	24 449	31 713	44 042	52 833	101 287
estimated number of EV's which are registered in other providers		1 808	3 512	5 321	6 918	8 727	10 551	13 687	19 008	22 802	43 713
number of average charging events per year in total		127 507	247 531	375 007	487 640	615 116	743 657	964 604	1 339 611	1 607 004	3 080 813
number of average charging events per year in one charging station		510	990	1 500	1 951	2 460	2 975	3 858	5 358	6 428	12 323
number of average charging events per month in one charging station		42,5	82,5	125	162,6	205	248	321,5	446,5	535,7	1 027
number of average charging events per day in one charging station		1,42	2,75	4,17	5,42	6,83	8,3	10,7	14,9	17,9	34,2
kWh consumed from 1 station/year= number of charging/year*kWh consumed/charging		10 201	19 802	30 001	39 011	49 209	59 493	77 168	107 169	128 560	246 465
kWh consumed from 1 station/year additional (10% of charging events occur 60min)		255	495,1	750	975,3	1 230,2	1 487,3	1 929,2	2 679,2	3 214	6 161,6
total extra minutes per station (30min*number of charging events*10%)		1 530,1	2 970,4	4 500,1	5 851,7	7 381,4	8 924	11 575,2	16 075,3	19 284	36 969,8
electricity commodity price (CZK/per charging station)		10 455,5	20 298	30 750,6	39 986,5	50 439,5	60 980	79 097,5	109 848,1	131 774,3	252 626,7
capacity booking cost (CZK/per charging station)		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
fixed regulated electricity cost (CZK per charging station)		89 078	89 078	89 078	89 078	89 078	89 078	89 078	89 078	89 078	89 078
variable regulated electricity cost (CZK per charging station)		6 450,3	12 522,2	18 971,0	24 669	31 118	37 620,3	48 797,6	67 768,6	81 295,5	155 853
total electricity cost (CZK per charging station)		**105 984**	**121 898**	**138 799,3**	**153 733,1**	**170 635**	**187 678**	**216 973**	**266 694,5**	**302 147,6**	**497 557,4**

APPENDIX F: Financial Analysis Inputs for considering 95% DC + 5% AC Charging Events

HV GRID CONNECTION INPUTS

	Total	CEZ	EON	PRE	Funded stations					
Number of public DC charger estimated to be constructed by 2020	250	162	61	27	105					
Utilities' shares on electricity distribution in CZ		65%	35%							
		0,65	0,24	0,11						
		1	**2**	**1**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
number of EVs estimated		4 192	8 138	12 329	16 032	20 223	24 449	31 713	44 042	52 833	101 287
estimated number of EV's which are registered in other providers		1 808	3 512	5 321	6 918	8 727	10 551	13 687	19 008	22 802	43 713
number of average charging events per year in total		127 507	247 531	375 007	487 640	615 116	743 657	964 604	1 339 611	1 607 004	3 080 813
number of average charging events per year in one charging station		510	990	1 500	1 951	2 460	2 975	3 858	5 358	6 428	12 323
number of average DC charging events per year in one charging station		485	941	1425	1 853	2 337	2 826	3 665	5 091	6 107	11 707
number of average AC charging events per year in one charging station		26	50	75	98	123	149	193	268	321	616
number of average charging events per month in one charging station		42,5	82,5	125	162,6	205	248	321,5	446,5	535,7	1 027
number of average charging events per day in one charging station		1,42	2,75	4,17	5,42	6,83	8,26	10,72	14,88	17,86	34,23
kWh consumed from 1 station/year= number of charging/year*kWh consumed/charging		10 201	19 802	30 001	39 011	49 209	59 493	77 168	107 169	128 560	246 465
kWh consumed from 1 station/year additional (10% of charging events overtime)		255	495,1	750	975,3	1 230,2	1 487,3	1 929,2	2 679,2	3 214	6 161,6
total normal charging event minutes at 1 DC charger=#of charging/year*30min		14 535,8	28 218,5	42 750,8	55 591	70 123,3	84 776,9	109 965	152 715,6	183 198,4	351213
total normal charging event minutes at 1 AC charger=#of charging/year*60min		1 530,1	2 970,4	4 500,1	5 851,7	7 381,4	8 924	11 575,2	16 075,3	19 284	36 969,8
DC, total extra minutes per station (30min*number of charging events*10%)		1 453,6	2 821,9	4 275,1	5 559,1	7 012,3	8 477,7	10 996,5	15 271,6	18 319,8	35 121,3
AC, total extra minutes per station (60min*number of charging events*10%)		153,0	297,0	450,0	585,2	738,1	892,4	1 157,5	1 607,5	1 928,4	3 697
electricity commodity price (CZK/per charging station)		10 455,5	20 298	30 750,6	39 986,5	50 439,5	60 980	79 097,5	109 848,1	131 774,3	252 626,7
capacity booking cost (CZK/per charging station)		301 089	301 089	301 089	301 089	301 089	301 089	301 089	301 089	301 089	301 089
fixed regulated electricity cost (CZK per charging station)		141 902	141 902	141 902	141 902	141 902	141 902	141 902	141 902	141 902	141 902
variable regulated electricity cost (CZK per charging station)		6 450,3	12 522,2	18 971	24 669	31 117,7	37 620,3	48 797,6	67 768,6	81 296	155 853
total electricity cost (CZK per charging station)		**459 897**	**475 811**	**492 712,3**	**507 646,1**	**524 548**	**541 591**	**570 885,9**	**620 607,5**	**656 061**	**851 470,4**

LV GRID CONNECTION INPUTS

	Total	CEZ	EON	PRE	Funded stations						
Number of public DC charger estimated to be constructed by 2020	250	162	61	27	105						
Utilities' shares on electricity distribution in CZ		65%	35%								
		0,65	0,24	0,11							
		1	**2**	**1**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
number of EVs estimated		4 192	8 138	12 329	16 032	20 223	24 449	31 713	44 042	52 833	101 287
estimated number of EV's which are registered in other providers		1 808	3 512	5 321	6 918	8 727	10 551	13 687	19 008	22 802	43 713
number of average charging events per year in total		127 507	247 531	375 007	487 640	615 116	743 657	964 604	1 339 611	1 607 004	3 080 813
number of average charging events per year in one charging station		510	990	1 500	1 951	2 460	2 975	3 858	5 358	6 428	12 323
number of average DC charging events per year in one charging station		485	941	1425	1 853	2 337	2 826	3 665	5 091	6 107	11 707
number of average AC charging events per year in one charging station		26	50	75	98	123	149	193	268	321	616
number of average charging events per month in one charging station		42,5	82,5	125	162,6	205	248	321,5	446,5	535,7	1 027
number of average charging events per day in one charging station		1,42	2,75	4,17	5,42	6,83	8,26	10,72	14,88	17,86	34,23
kWh consumed from 1 station/year= number of charging/year*kWh consumed/charging		10 201	19 802	30 001	39 011	49 209	59 493	77 168	107 169	128 560	246 465
kWh consumed from 1 station/year additional (10% of charging events occur 60min)		255	495,1	750	975,3	1 230,2	1 487,3	1 929,2	2 679,2	3 214	6 161,6
total normal charging event minutes at 1 DC charger=#of charging/year*30min		14 535,8	28 218,5	42 750,8	55 591	70 123,3	84 776,9	109 965	152 715,6	183 198,4	351213
total normal charging event minutes at 1 AC charger=#of charging/year*60min		1 530,1	2 970,4	4 500,1	5 851,7	7 381,4	8 924	11 575,2	16 075,3	19 284	36 969,8
DC, total extra minutes per station (30min*number of charging events*10%)		1 453,6	2 821,9	4 275,1	5 559,1	7 012,3	8 477,7	10 996,5	15 271,6	18 319,8	35 121,3
AC, total extra minutes per station (60min*number of charging events*10%)		153,0	297,0	450,0	585,2	738,1	892,4	1 157,5	1 607,5	1 928,4	3 697
electricity commodity price (CZK/per charging station)		10 455,5	20 298	30 750,6	39 986,5	50 439,5	60 980	79 097,5	109 848,1	131 774,3	252 626,7
capacity booking cost (CZK/per charging station)		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
fixed regulated electricity cost (CZK per charging station)		89 078	89 078	89 078	89 078	89 078	89 078	89 078	89 078	89 078	89 078
variable regulated electricity cost (CZK per charging station)		6 450,3	12 522,2	18 971,0	24 669	31 118	37 620,3	48 797,6	67 768,6	81 295,5	155 853
total electricity cost (CZK per charging station)		**105 984**	**121 898**	**138 799,3**	**153 733,1**	**170 635**	**187 678**	**216 973**	**266 694,5**	**302 147,6**	**497 557,4**

APPENDIX G: FINANCIAL ANALYSIS FOR CASE 1: HV-GRID CONNECTION & COMBINED CASE

COSTS											
total electricity cost regulated + commodity		-114 974 172	-118 952 621	-123 178 084	-126 911 535	-131 136 998	-135 397 750	-142 721 483	-155 151 867	-164 015 158	-212 867 606
electricity price paid to DSO		-5 784 867	-11 230 260	-17 013 747	-22 123 806	-27 907 293	-33 739 080	-43 763 239	-60 776 986	-72 908 372	-139 773 821
operations and IT costs		-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000
maintenance		0	0	0	0	0	-51 030	-51 030	-51 030	-51 030	-51 030
parking space rent		-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000
depreciation		-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503
TOTAL OPERATING COSTS		-470 414 542	-479 838 383	-489 847 334	-498 690 843	-508 699 794	-518 843 362	-536 191 255	-565 635 386	-586 630 062	-702 347 960
TOTAL OPERATING COSTS (50% HV + 50% LV)	0,5	-427 209 733	-437 607 195	-448 650 216	-458 407 388	-469 450 409	-480 636 682	-499 776 865	-532 263 003	-555 426 735	-683 099 972

REVENUES										
per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 062	92 951 940	109 333 731	137 795 712	150 138 445	261 671 754
kWh variable price (CZK)	60 119 393	116 710 788	176 815 840	229 922 260	290 027 312	350 634 315	454 810 668	631 626 508	757 702 268	1 452 603 290
minutes variable price (CZK)	3 825 200	7 425 925	11 250 213	14 629 200	18 453 488	22 309 713	28 938 113	40 188 325	48 210 113	92 424 388
total operating revenue	90 181 393	170 189 113	251 177 592	318 826 228	393 326 861	465 895 967	593 082 511	809 610 545	956 050 825	1 806 699 432
total operating revenue (50% HV + 50% LV)	90 181 393	170 189 113	251 177 592	318 826 228	393 326 861	465 895 967	593 082 511	809 610 545	956 050 825	1 806 699 432

INCOME		-380 233 148	-309 649 270	-238 669 742	-179 8646 15	-115 372 933	-52 947 394	56 891 257	243 975 159	369 420 763	1 104 351 472
INCOME FOR (50% HV + 50% LV)		-337 028 340	-267 418 082	-197 472 624	-139 581 160	-76 123 547	-14 740 715	93 305 646	277 347 542	400 624 091	1 123 599 460
Capital Expenditures											
charger costs (105 stations)	-71 442 000										
installation cost (105 stations)	-53 581 500										
charger costs (145 stations)	-98 658 000										
installation cost (145 stations)	-73 993 500										
financing											
loan amount (85% installation cost funded)	106 269 975										
85%											
free cash flow	-191 405 025	-361 092 646	-290 508 768	-219 529 239	-160 724 112	-96 232 430	-33 806 892	76 031 759	263 115 662	388 561 265	112 349 1975
(1+inflation)		1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
real cash flow	-191 405 025	-354 012 398	-279 227 958	-206 867 305	-148 484 236	-87 160 677	-30 019 553	66 190 222	224 566 684	325 130 685	921 654 732
IRR	2,37%										
NPV with inflation	-249 946 834										
cash flow for mixed case	-191 405 025	-317 887 838	-248 277 579	-178 332 121	-120 440 657	-56 983 045	4 399 787	112 446 149	296 488 045	419 764 593	1 142 739 962
real cash flow for mixed case	-191 405 025	-311 654 743	-238 636 658	-168 046 341	-111 268 550	-51 611 299	3 906 885	97 891 139	253 049 691	351 240 234	937 444 785
NPV of LV and HV together	3 682 166,3										
IRR of LV and HV together	5,89%										

APPENDIX H: FINANCIAL ANALYSIS FOR CASE 1 CONTINUED: LV-GRID CONNECTION

COSTS

total electricity cost regulated + commodity	-26 495 922	-30 474 371	-34 699 834	-38 433 285	-42 658 748	-46 919 500	-54 243 233	-66 673 617	-75 536 908	-124 389 356
electricity price paid to DSO	-7 853 501	-15 246 133	-23 097 761	-30 035 145	-37 886 773	-45 803 971	-59 412 709	-82 510 470	-98 979 966	-189 756 097
operations and IT costs	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000
maintenance	0	0	0	0	0	-51 030	-51 030	-51 030	-51 030	-51 030
parking space rent	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000
depreciation	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503
TOTAL OPERATING COSTS	-384 004 925	-395 376 007	-407 453 098	-418 123 932	-430 201 024	-442 430 003	-463 362 475	-498 890 620	-524 223 407	-663 851 985

REVENUES

per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 062	92 951 940	109 333 731	137 795 712	150 138 445	261 671 754
kWh variable price (CZK)	60 119 393	116 710 788	176 815 840	229 922 260	290 027 312	350 634 315	454 810 668	631 626 508	757 702 268	1 452 603 290
minutes variable price (CZK)	3 825 200	7 425 925	11 250 213	14 629 200	18 453 488	22 309 713	28 938 113	40 188 325	48 210 113	92 424 388
total operating revenue	90 181 393	170 189 113	251 177 592	318 826 228	393 326 861	465 895 967	593 082 511	809 610 545	956 050 825	1 806 699 432

INCOME	-293 823 532	-225 186 894	-156 275 505	-99 297 704	-36 874 162	23 465 964	129 720 036	310 719 925	431 827 419	1 142 847 447

capital expenditures											
charger costs (105 stations)	-71 442 000										
installation cost (105 stations)	-53 581 500										
charger costs (145 stations)	-98 658 000										
installation cost (145 stations)	-73 993 500										
financing											
loan amount (85% installation cost funded)	106 269 975										
85%											
free cash flow	-191 405 025	-274 683 029	-206 046 391	-137 135 003	-80 157 202	-17 733 660	42 606 467	148 860 539	329 860 428	450 967 921	1 161 987 950
(1+inflation)		1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
real cash flow	-191 405 025	-269 297 088	-198 045 359	-129 225 376	-74 052 864	-16 061 922	37 833 323	129 592 057	281 532 699	377 349 783	953 234 839
IRR	10%										
NPV with inflation	257 311 167										

APPENDIX I: FINANCIAL ANALYSIS FOR CASE 2: HV-GRID CONNECTION & COMBINED CASE

COSTS										
total electricity cost regulated + commodity	-114 974 172	-118 952 621	-123 178 084	-126 911 535	-131 136 998	-135 397 750	-142 721 483	-155 151 867	-164 015 158	-212 867 606
electricity price paid to DSO	-5 784 867	-11 230 260	-17 013 747	-22 123 806	-27 907 293	-33 739 080	-43 763 239	-60 776 986	-72 908 372	-139 773 821
operations and IT costs	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000
maintenance	0	0	0	0	0	-51 030	-51 030	-51 030	-51 030	-51 030
parking space rent	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000
depreciation	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503
Total Operating Costs	-470 414 542	-479 838 383	-489 847 334	-498 690 843	-508 699 794	-518 843 362	-536 191 255	-565 635 386	-586 630 062	-702 347 960

REVENUES										
per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 062	92 951 940	109 333 731	137 795 712	150 138 445	261 671 754
kWh variable price (CZK)	61 164 948	118 740 541	179 890 898	233 920 908	295 071 265	356 732 303	462 720 419	642 611 317	770 879 699	1 477 865 956
minutes variable price (CZK)	2 983 656	5 792 222	8 775 166	11 410 776	14 393 720	17 401 576	22 571 728	31 346 894	37 603 888	72 091 022
Total Operating Revenues	90 385 404	170 585 162	251 777 604	319 606 452	394 311 047	467 085 819	594 625 877	811 753 923	958 622 031	1 811 628 733

INCOME	-380 029 138	-309 253 221	-238 069 731	-179 084 391	-114 388 747	-51 757 543	58 434 623	246 118 536	371 991 969	1 109 280 773
income for 50% case (50% * (HV income + LV income))	-336 824 329	-267 022 033	-196 872 612	-138 800 936	-75 139 362	-13 550 864	94 849 012	279 490 919	403 195 297	1 128 528 760

capital expenditures											
charger costs (105 stations)	-71 442 000										
installation cost (105 stations)	-53 581 500										
charger costs (145 stations)	-98 658 000										
installation cost (145 stations)	-73 993 500										
financing											
loan amount (85% installation cost funded)	106 269 975										
85%											
free cash flow	-191 405 025	-360 888 635	-290 112 719	-218 929 228	-159 943 888	-95 248 244	-32 617 041	77 575 125	265 259 039	391 132 471	1 128 421 276
(1+inflation)		1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
real cash flow	-191 405 025	-353 812 387	-278 847 288	-206 301 901	-147 763 430	-86 269 269	-28 962 999	67 533 815	226 396 036	327 282 155	925 698 475
IRR	2,49%										
NPV with inflation	-241 292 583										
cash flow for mixed case	-191 405 025	-317 683 827	-247 881 530	-177 732 110	-119 660 433	-55 998 859	5 589 639	113 989 515	298 631 422	422 335 799	1147 669 263
real cash flow for mixed case	-191 405 025	-311 454 732	-238 255 988	-167 480 937	-110 547 744	-50 719 892	4 963 439	99 234 732	254 879 043	353 391 704	941 488 529
NPV of LV and HV together	12 336 418										
IRR of LV and HV together	6,01%										

APPENDIX J: FINANCIAL ANALYSIS FOR CASE 2 CONTINUED: LV-GRID CONNECTION

COSTS										
total electricity cost regulated + commodity	-26 495 922	-30 474 371	-34 699 834	-38 433 285	-42 658 748	-46 919 500	-54 243 233	-66 673 617	-75 536 908	-124 389 356
electricity price paid to DSO	-7 853 501	-15 246 133	-23 097 761	-30 035 145	-37 886 773	-45 803 971	-59 412 709	-82 510 470	-98 979 966	-189 756 097
operations and IT costs	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000
maintenance	0	0	0	0	0	-51 030	-51 030	-51 030	-51 030	-51 030
parking space rent	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000
depreciation	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503
Total Operating Costs	-384 004 925	-395 376 007	-407 453 098	-418 123 932	-430 201 024	-442 430 003	-463 362 475	-498 890 620	-524 223 407	-663 851 985

REVENUES										
per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 062	92 951 940	109 333 731	137 795 712	150 138 445	261 671 754
kWh variable price (CZK)	61 164 948	118 740 541	179 890 898	233 920 908	295 071 265	356 732 303	462 720 419	642 611 317	770 879 699	1 477 865 956
minutes variable price (CZK)	2 983 656	5 792 222	8 775 166	11 410 776	14 393 720	17 401 576	22 571 728	31 346 894	37 603 888	72 091 022
Total Operating Revenues	90 385 404	170 585 162	251 777 604	319 606 452	394 311 047	467 085 819	594 625 877	811 753 923	958 622 031	1 811 628 733

INCOME	-293 619 521	-224 790 844	-155 675 494	-98 517 480	-35 889 976	24 655 816	131 263 402	312 863 303	434 398 625	1 147 776 748

capital expenditures	
charger costs (105 stations)	-71 442 000
installation cost (105 stations)	-53 581 500
charger costs (145 stations)	-98 658 000
installation cost (145 stations)	-73 993 500
financing	
loan amount (85% installation cost funded)	106 269 975
85%	

free cash flow	-191 405 025	-274 479 019	-205 650 342	-136 534 992	-79 376 978	-16 749 474	43 796 318	150 403 905	332 003 805	453 539 127	1 166 917 250
(1+inflation)		1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
real cash flow	-191 405 025	-269 097 077	-197 664 688	-128 659 972	-73 332 058	-15 170 515	38 889 877	130 935 650	283 362 051	379 501 253	957 278 582
IRR	10%										
NPV with inflation	265 965 418										

APPENDIX K: FINANCIAL ANALYSIS FOR CASE 3: HV-GRID CONNECTION & COMBINED CASE

COSTS										
total electricity cost regulated + commodity	-114 974 172	-118 952 621	-123 178 084	-126 911 535	-131 136 998	-135 397 750	-142 721 483	-155 151 867	-164 015 158	-212 867 606
electricity price paid to DSO	-5 784 867	-11 230 260	-17 013 747	-22 123 806	-27 907 293	-33 739 080	-43 763 239	-60 776 986	-72 908 372	-139 773 821
operations and IT costs	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000
maintenance	0	0	0	0	0	-51 030	-51 030	-51 030	-51 030	-51 030
parking space rent	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000
depreciation	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503
TOTAL OPERATING COSTS	-470 414 542	-479 838 383	-489 847 334	-498 690 843	-508 699 794	-518 843 362	-536 191 255	-565 635 386	-586 630 062	-702 347 960

REVENUES										
per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 062	92 951 940	109 333 731	137 795 712	150 138 445	261 671 754
kWh variable price (CZK)	3 790 136	7 357 854	11 147 086	14 495 099	18 284 331	22 105 207	28 672 846	39 819 932	47 768 186	91 577 164
minutes variable price (CZK)	60 170 396	116 809 800	176 965 843	230 117 316	290 273 358	350 931 778	455 196 510	632 162 352	758 345 070	1 453 835 615
total operating revenue	90 197 332	170 220 054	251 224 468	318 887 183	393 403 751	465 988 924	593 203 087	809 777 997	956 251 701	1 807 084 534

INCOME		-380 217 210	-309 618 329	-238 622 866	-179 803 660	-115 296 043	-52 854 437	57 011 832	244 142 610	369 621 638	1 104 736 574
INCOME FOR (50% HV + 50% LV)	0,5	-337 012 402	-267 387 141	-197 425 748	-139 520 205	-76 046 658	-14 647 758	93 426 222	277 514 993	400 824 966	1 123 984 561

capital expenditures	
charger costs (105 stations)	-71 442 000
installation cost (105 stations)	-53 581 500
charger costs (145 stations)	-98 658 000
installation cost (145 stations)	-73 993 500
financing	
loan amount (85% installation cost funded for 105 stations)	106 269 975
85%	

free cash flow	-191 405 025	-361 076 707	-290 477 826	-219 482 363	-160 663 157	-96 155 541	-33 713 935	76 152 334	263 283 113	388 762 141	1 123 877 077
(1+inflation)		1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
real cash flow	-191 405 025	-353 996 772	-279 198 218	-206 823 133	-148 427 923	-87 091 036	-29 937 009	66 295 190	224 709 602	325 298 768	921 970 649
cash flow for mixed case	-191 405 025	-317 871 899	-248 246 638	-178 285 245	-120 379 702	-56 906 155	4 492 745	112 566 724	296 655 496	419 965 469	1 143 125 064
real cash flow for mixed case	-191 405 025	-311 639 117	-238 606 919	-168 002 168	-111 212 237	-51 541 658	3 989 429	97 996 108	253 192 609	351 408 317	937 760 703

IRR	2,38%
NPV with inflation	-249 270 721
NPV of (50% HV + 50% LV)	4 358 280
IRR of (50% HV + 50% LV)	5,90%

APPENDIX L: FINANCIAL ANALYSIS FOR CASE 3 CONTINUED: LV-GRID CONNECTION

COSTS										
total electricity cost regulated + commodity	-26 495 922	-30 474 371	-34 699 834	-38 433 285	-42 658 748	-46 919 500	-54 243 233	-66 673 617	-75 536 908	-124 389 356
electricity price paid to DSO	-7 853 501	-15 246 133	-23 097 761	-30 035 145	-37 886 773	-45 803 971	-59 412 709	-82 510 470	-98 979 966	-189 756 097
operations and IT costs	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000
maintenance	0	0	0	0	0	-51 030	-51 030	-51 030	-51 030	-51 030
parking space rent	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000
depreciation	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503
TOTAL OPERATING COSTS	-384 004 925	-395 376 007	-407 453 098	-418 123 932	-430 201 024	-442 430 003	-463 362 475	-498 890 620	-524 223 407	-663 851 985
REVENUES										
per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 062	92 951 940	109 333 731	137 795 712	150 138 445	261 671 754
kWh variable price (CZK)	3 790 136	7 357 854	11 147 086	14 495 099	18 284 331	22 105 207	28 672 846	39 819 932	47 768 186	91 577 164
minutes variable price (CZK)	60 170 396	116 809 800	176 965 843	230 117 316	290 273 358	350 931 778	455 196 510	632 162 352	758 345 070	1 453 835 615
total operating revenue	90 197 332	170 220 054	251 224 468	318 887 183	393 403 751	465 988 924	593 203 087	809 777 997	956 251 701	1 807 084 534
INCOME	-293 807 594	-225 155 952	-156 228 629	-99 236 749	-36 797 273	23 558 921	129 840 612	310 887 377	432 028 294	1 143 232 549

capital expenditures	
charger costs (105 stations)	-71 442 000
installation cost (105 stations)	-53 581 500
charger costs (145 stations)	-98 658 000
installation cost (145 stations)	-73 993 500
financing	
loan amount (85% installation cost funded for 105 stations)	106 269 975
85%	

free cash flow	-191 405 025	-274 667 091	-206 015 450	-137 088 127	-80 096 247	-17 656 770	42 699 424	148 981 114	330 027 879	451 168 797	1 162 373 051
(1+inflation)		1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
real cash flow	-191 405 025	-269 281 462	-198 015 619	-129 181 204	-73 996 551	-15 992 281	37915866	129 697 025	281 675 617	377 517 866	953 550 756
IRR	**9,80%**										
NPV with inflation	**257 987 280**										

APPENDIX M: FINANCIAL ANALYSIS FOR CASE 4: HV-GRID CONNECTION & COMBINED CASE

COSTS										
total electricity cost regulated + commodity	-114 974 172	-118 952 621	-123 178 084	-126 911 535	-131 136 998	-135 397 750	-142 721 483	-155 151 867	-164 015 158	-212 867 606
electricity price paid to DSO	-5 784 867	-11 230 260	-17 013 747	-22 123 806	-27 907 293	-33 739 080	-43 763 239	-60 776 986	-72 908 372	-139 773 821
operations and IT costs	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000
maintenance	0	0	0	0	0	-51 030	-51 030	-51 030	-51 030	-51 030
parking space rent	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000
depreciation	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503
Total Operating Costs	-470 414 542	-479 838 383	-489 847 334	-498 690 843	-508 699 794	-518 843 362	-536 191 255	-565 635 386	-586 630 062	-702 347 960

REVENUES										
per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 062	92 951 940	109 333 731	137 795 712	150 138 445	261 671 754
kWh variable price (CZK)	8 623 212	16 740 387	25 361 542	32 978 849	41 600 004	50 293 157	65 235 669	90 597 211	108 680 860	208 353 837
minutes variable price (CZK)	55 236 844	107 232 214	162 455 881	211 249 305	266 472 973	322 157 826	417 873 579	580 329 460	696 166 077	1 334 631 262
Total Operating Revenues	90 096 856	170 025 000	250 928 963	318 502 923	392 919 039	465 402 923	592 442 979	808 722 383	954 985 382	1 804 656 853

INCOME	-380 317 685	-309 813 383	-238 918 372	-180 187 920	-115 780 755	-53 440 439	56 251 724	243 086 997	368 355 319	1 102 308 894
income for 50% case (50% * (HV income + LV income))	-337 112 877	-267 582 195	-197 721 253	-139 904 465	-765 313 670	-15 233 760	92 666 114	276 459 380	399 558 647	1 121 556 881

capital expenditures	
charger costs (105 stations)	-71 442 000
installation cost (105 stations)	-53 581 500
charger costs (145 stations)	-98 658 000
installation cost (145 stations)	-73 993 500
financing	
loan amount (85% installation cost funded)	106 269 975
85%	

free cash flow	-191 405 025	-361 177 183	-290 672 881	-219 777 869	-161 047 418	-96 640 252	-34 299 937	75 392 227	262 227 500	387 495 822	1 121 449 396
(1+inflation)		1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
real cash flow	-191 405 025	-354 095 277	-279 385 699	-207 101 595	-148 782 920	-87 530 054	-30 457 362	65 633 470	223 808 646	324 239 169	919 979 105
IRR	2%										
NPV with inflation	-253 532 940										
cash flow for mixed case	-191 405 025	-317 972 375	-248 441 692	-178 580 751	-120 763 963	-57 390 867	3 906 743	111 806 617	295 599 883	418 699 150	1 140 697 383
real cash flow for mixed case	-191 405 025	-311 737 622	-238 794 399	-168 280 630	-111 567 234	-51 980 677	3 469 076	97 334 388	252 291 654	350 348 718	935 769 159
NPV of LV and HV together	96 060,83										
IRR of LV and HV together	5,84%										

APPENDIX N: FINANCIAL ANALYSIS FOR CASE 4 CONTINUED: LV-GRID CONNECTION

COSTS										
total electricity cost regulated + commodity	-26 495 922	-30 474 371	-34 699 834	-38 433 285	-42 658 748	-46 919 500	-54 243 233	-66 673 617	-75 536 908	-124 389 356
electricity price paid to DSO	-7 853 501	-15 246 133	-23 097 761	-30 035 145	-37 886 773	-45 803 971	-59 412 709	-82 510 470	-98 979 966	-189 756 097
operations and IT costs	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000	-329 265 000
maintenance	0	0	0	0	0	-51 030	-51 030	-51 030	-51 030	-51 030
parking space rent	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000	-1 250 000
depreciation	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503	-19 140 503
Total Operating Costs	-384 004 925	-395 376 007	-407 453 098	-418 123 932	-430 201 024	-442 430 003	-463 362 475	-498 890 620	-524 223 407	-663 851 985
REVENUES										
per subscription revenue (flat rate)	26 236 800	46 052 400	63 111 540	74 274 768	84 846 062	92 951 940	109 333 731	137 795 712	150 138 445	261 671 754
kWh variable price (CZK)	8 623 212	16 740 387	25 361 542	32 978 849	41 600 004	50 293 157	65 235 669	90 597 211	108 680 860	208 353 837
minutes variable price (CZK)	55 236 844	107 232 214	162 455 881	211 249 305	266 472 973	322 157 826	417 873 579	580 329 460	696 166 077	1 334 631 262
Total Operating Revenues	90 096 856	170 025 000	250 928 963	318 502 923	392 919 039	465 402 923	592 442 979	808 722 383	954 985 382	1 804 656 853
INCOME	-293 908 069	-225 351 007	-156 524 135	-99 621 010	-37 281 984	22 972 920	129 080 504	309 831 763	430 761 975	1 140 804 868

capital expenditures	
charger costs (105 stations)	-71 442 000
installation cost (105 stations)	-53 581 500
charger costs (145 stations)	-98 658 000
installation cost (145 stations)	-73 993 500
financing	
loan amount (85% installation cost funded)	106 269 975
85%	

free cash flow	-191 405 025	-274 767 566	-206 210 504	-137 383 633	-80 480 507	-18 141 482	42 113 422	148 221 006	328 972 266	449 902 478	1 159 945 371
(1+inflation)		1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02	1,02
real cash flow	-191 405 025	-269 379 967	-198 203 099	-129 459 665	-74 351 548	-16 431 299	37 395 514	129 035 306	280 774 661	376 458 267	951 559 213
IRR	10%										
NPV with inflation	253 725 061										