LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Business and Management
Strategic Finance and Business Analytics (MSF)

Master’s Thesis

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REAL OPTION APPROACH TO EV CHARGING INFRASTRUCTURE IN FINLAND: INVESTMENT DECISION-MAKING UNDER UNCERTAINTY

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ABSTRACT

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2018

81 pages, 21 figures, 13 tables

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Keywords: electric vehicles, EV, charging infrastructure, real options, real option valuation, ROV, fuzzy pay-off, public infrastructure, uncertainty, decision-making.

Today the transport sector contributes the majority of greenhouse gas emissions that stimulates the global community to support the rapid adoption of Electric Vehicles (EV). The development of the charging infrastructure is identified as one of the driving forces of the EV adoption that, however, requires significant initial investments and is characterized with uncertainty and irreversibility. Finland introduced ambitious long-term targets on the EV adoption, therefore the thesis examines the charging infrastructure in Finland as an example of an investment project under uncertainty. The aim of the study is to elaborate on how uncertainty affects investment decision-making and how policy regulations reflect uncertainty and support investment decision-making. To cope with uncertainty, the fuzzy pay-off method as a real option valuation approach is applied on the project in this study and considers future managerial flexibility in investment decision-making. In additions, this study considers a growth option for the project and based on that, suggests the step-by-step decision-making.

The findings of the thesis have significant theoretical and practical implications for the research in infrastructure investments as well as for the investment decision-making under uncertainty. The two-fold structure of the findings allows decision and policy makers use the results as a basis or a model for practical decision-making. In overall, the thesis is considered as an initial step for the investigation of the charging infrastructure in Finland as a real option or an opportunity for follow-on investments with the use of the fuzzy logic and the fuzzy pay-off method.

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LIST OF SYMBOLS AND ABBREVIATIONS

CF	Cash Flows
CI	Charging Infrastructure
CNS	Carbon-Neutral Scenario
CS	Charging Stations
CSO	Charging stations operator
DCF	Discounted Cash Flow
DR	Discount Rare
DTA	Decision Tree Analysis
EMSP	Electro Mobility Service Provider
EV	Electric Vehicle
FCF	Future Cash Flows
FCS	Fast-charging stations
FPOM	Fuzzy Pay-off method
GHG	Greenhouse gas
MO	Marketplace operator
NPE	German National Platform for Electric Mobility
NPV	Net Present Value
OR	Operational Revenue
PPP	Private-public partnership
PV	Present Value
ROI	Return on Investment
ROV	Real Option Valuation
RRR	Required Rate of Return

1 INTRODUCTION

In this chapter, the motivation and background of the study are defined. Subsequently, the research problem, questions and objectives are stated. On the basis of the research objectives relevant methods are selected as well as the entire master thesis is structured and designed accordingly.

1.1 Motivation and background

The transport sector has the major impact on the environment that causes climate change. It is *"the second largest contributor to greenhouse gas emissions in the European Union (EU) after the energy sector"* (Serradilla et al, 2017). Furthermore, it contributes almost the quarter of GHG emissions (23%) globally. By 2050 one-fifth (18%) of global GHG emissions reduction must be contributed by transport electrification (IEA, 2016). In this regard, large-scale adoption of **Electric Vehicles (EV)** has a significant impact on the establishment of the carbon-neutral society. The key drivers of large-scale EV adoption are a regulatory government policy, accessible **EV charging infrastructure (CI)** and an introduction of local incentives (Bakker and Jacob Trip, 2013). While the introduction of the regulatory policy and local incentives has been approached successfully in some countries, for example, Norway (Nørbech, 2013), the establishment of CI has raised a lot of questions that evolved to the "chicken-egg problem" (Markkula et al., 2013) that cannot define what should come first: a sufficient amount of EV on the roads to support building of CI or vice versa. In reality, these two aspects go together hand in hand. Large-scale EV adoption requires available network of public and private **charging stations (CS)** (Bakker and Jacob Trip, 2013). As an infrastructure project, CI is subject to project-specific risks, future uncertainties regarding market conditions and irreversibility of investments (Dixit and Pindyck, 1995) that also makes it financially unviable in the beginning of its lifetime (Poole et al., 2014). A more flexible approach such as **Real Option Valuation (ROV)** allows to address these issues in an investment analysis and contribute to investment decision-making under uncertainty.

This research considers the CI project in Finland as a numerical example. By 2030 Finnish government plans to introduce 250 000 EV, which is considered as an ambitious goal in given circumstances of a relatively low EV market share and limited CI facilities in Finland (Ministry of Economic Affairs and Employment, 2016). It indicates that building of sufficient CI would allow to achieve this target and therefore make it reasonable project for an investigation in this master thesis. Consequently, this study aims to elaborate on decision-making under uncertainty of infrastructure projects and consider investments in the CI project as a real option for follow-on investments.

1.1.1 Global adoption of Electric Vehicles

Since 1990s voluntary international agreements for energy efficiency improvements and GHG emissions reduction have been developed. Voluntary agreement is a contract between a government and an industry that is implemented for a long-term period according to certain commitments and timeline focusing on energy efficiency and emission reduction goals. These agreements are characterized with an introduction of energy efficient technologies and governmental support in financial incentives and policy regulations (Price, 2005). One of the examples of such nation-wide agreements is the Paris Climate Agreement that has been announced in 2015 for the purpose of decreasing global average temperature by reducing GHG emissions from both energy and non-energy industries. The Paris Climate Agreement has united 195 countries, including Finland, that now are committed to the GHG emissions reduction goal (IEA, 2016).

Nowadays, the world leader in EV share is Norway that has 150 000 (29% market share) and aims to reach 400 000 EV (nearly 70% market share). In the overall scope, Nordic countries are trying to reach the same level by following **Carbon-Neutral Scenario (CNS)** that sets climate issues resolving targets and focuses on shifting the policies to enhance renewable energy and E-mobility facilities. CNS enables to fulfill the vision of the Paris Climate Agreement and integrates aspects of energy policy and electrification strategy that focus on 85% GHG emissions reduction by 2050 in Nordic region (Figure 1). The flexibility and interconnection of electric systems and low-carbon technologies are key drivers of the future carbon-neutral society that is expected to be approached by 2050 (NETP, 2016).

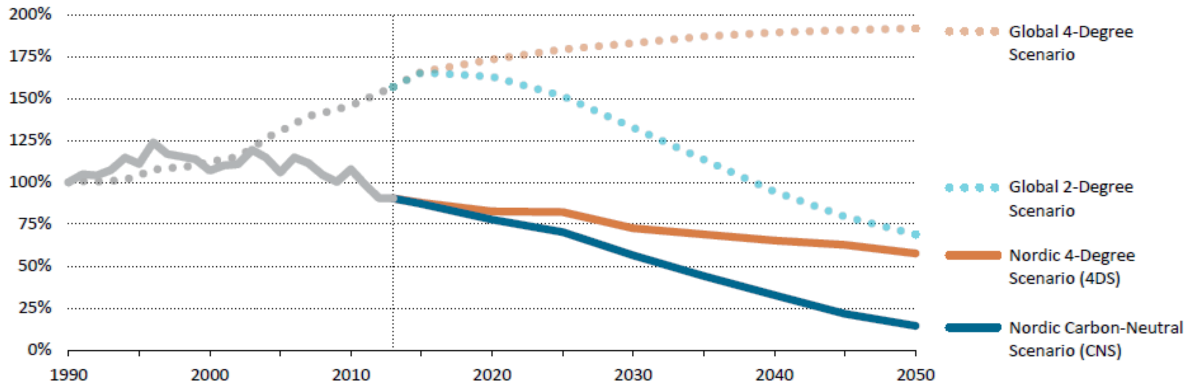

Figure 1. Nordic and global CO2 emissions
Source: Nordic Energy Technology Perspectives (NETP), 2016

Today EV takes 0.1% market share globally. The United States, Norway, the Netherland and China are the leaders in EV penetration that approached a rapid growth of sustainable vehicles for the last five years. In Europe, the number of EV from a thousand of units in 2010 reached the number of nearly 100 000 today (Transport & Environment, 2016). The global sales of EV reached 1.26 million for the period of 2010-2015 (Figure 2) that demonstrates significant change in government policy and E-mobility developments (IEA, 2016).

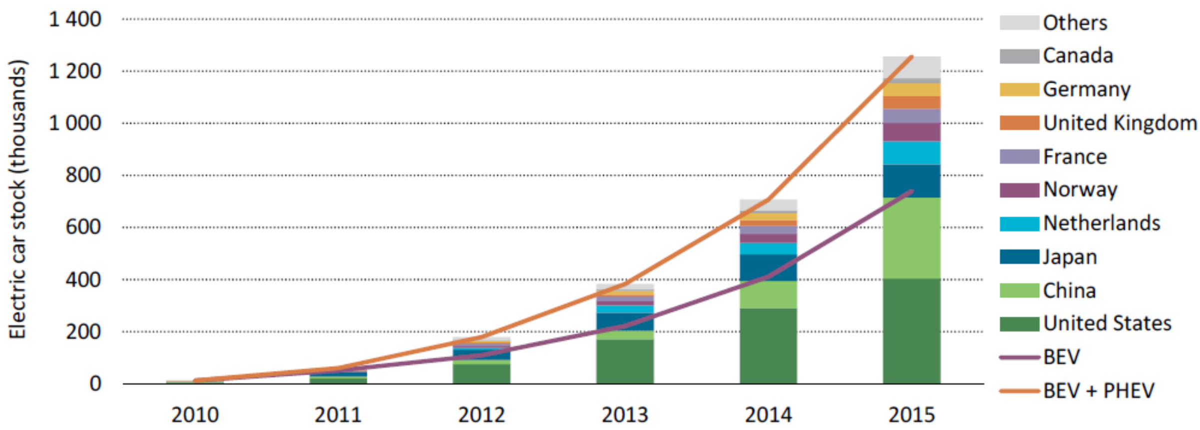

Figure 2. Evolution of global EV stock, 2010-2015
Source: IEA analysis based on EVI country submissions, complemented by EAFO (2016), IHS Polk (2014), MarkLines (2016), ACEA (2016a), EEA (2015) and IA-HEV (2015)

In 2015, 90% of car sales were witnessed in eight markets (Figure 3) that are China, the United States, the Netherlands, Norway, the United Kingdom, Japan, Germany and France where EV sales growth exceeded 75% (IEA, 2016).

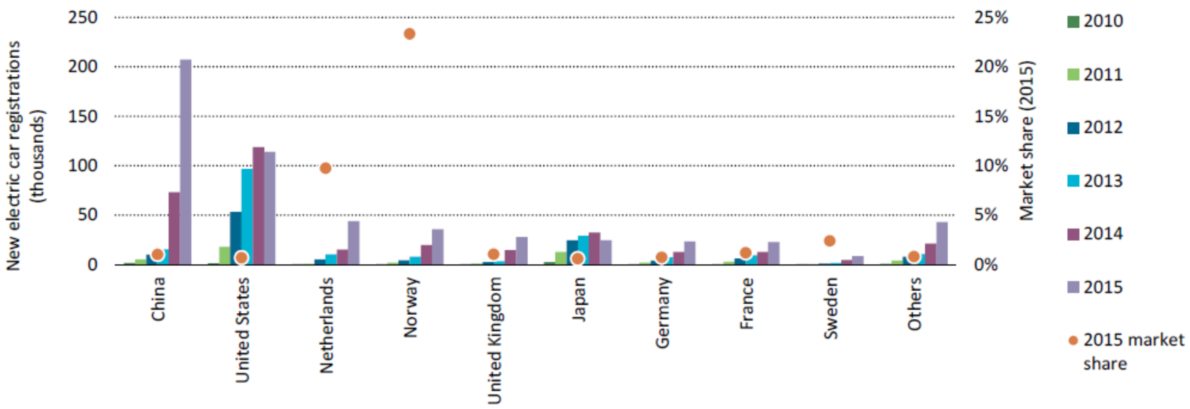

Figure 3. EV sales and market share in a selection of countries, 2015
Source: IEA analysis based on EVI country submissions, complemented by EAFO (2016), IHS Polk (2014), MarkLines (2016), ACEA (2016a), EEA (2015) and IA-HEV (2015)

In the context of agreements and national strategies, significant forces are focused on the development and introduction of the sustainable transport and required facilities such as CI. Globally, countries are committed to EV adoption and target to establish a wide network of CS. For instance, to achieve GHG emissions reduction goal, UK targets to adopt 15.9 million EV by 2030 that includes an introduction of private and public CS (Element Energy, 2009). In fact, the current situation in the CI development demonstrates (Figure 4) that the UK has the biggest concentration of **fast-charging stations (FCS)**. Figure 4 also demonstrates a wide distribution of FCS in Germany. A close cooperation between four German energy companies and automotive manufacturers allowed to establish around 24 000 CS and 100 FCS in 2 400 different locations (NPE, 2014). In Israel, the government takes full responsibility for the establishment of EV charging and battery replacing stations that has already brought 200 battery-replacing stations and 500 000 charging poles (Quantu et al., 2012). Finland demonstrates a poor performance in the FCS development compared to other countries in the EU that highlights an urgent need to build private and public CI to achieve large-scale EV adoption by 2030.

Figure 4. Distribution of EV rapid CS (>40kWh) in EU (2017)
Source: European Commission (2017)

On the global scale, another example is the Japanese infrastructure of FCS that has been built in a partnership between the government of Japan, automotive companies and Tokyo Electric Power Company, which is the biggest power company in Japan. The continuous establishment of the large-scale FCS infrastructure in highways and cosmopolitan areas shortens charging time enormously (Quantu et al., 2012). China builds charging and replacing facilities with the support of power grid enterprises. By 2011, there were around 250 battery charging-replacing stations and around 13 300 charging poles. Widely spread throughout the country there are intelligent charging-replacing stations for E-mobility that combine automatic charging, high power capacity for small passenger cars as well as for the public transport such as buses. The strategic plan of China is to build a network power supply system that consists of more than 40 000 charging poles and 200 CS in more than 20 cities in

China by 2020. In the United States, there are more than 20 500 CS along the highways and public parking lots (Quantu et al., 2012).

Norway is an example of the extremely rapid development of CI. Norway's capital city Oslo is the world leader in EV deployment. In 2009, Norway had less than 200 public CS. In 2016 only in the capital city Oslo, 1 996 public EV charging points were established for every 330 residents in the city. More than the half of GHG emissions in Oslo were accounted to the transport and therefore for the recent years there is a rapid growth of EV and large-scale rollout of the CI. One of the key drivers of the large-scale EV adoption in Norway is local incentives and financial subsidies (Nørbech, 2013). Generous public policy incentives facilitated the promotion of E-mobility, which contributed to the large-scale EV adoption and establishment of the CI. The collaboration between the government and private or municipal authorities has been a good model for building of CI in Norway (Nørbech, 2013; NETP, 2016).

In 2016, Norway opened the largest fast charging network in Europe by Tesla developed in the partnership with Fortum, which is the significant contribution to the development of the global E-mobility. The FCS network can charge 28 EV simultaneously delivering 2 000 kWh of electricity and ensuring a comfort long-distance E-driving experience[1].

Overall, global experience in EV adoption demonstrates that joined forces in a form of governmental subsidies and incentives, regulatory measures, financial support and cooperation with, for example, power grid enterprises and energy companies, can significantly affect rapid development of E-mobility.

1.1.2 Electric Vehicle adoption targets in Finland

With the commitment to the Paris Climate Agreement, Finland targets the efforts towards 80% GHG emissions reduction through E-mobility by 2050 (NETP, 2016). In 2016, there were 1.2% registered EV of total registered vehicles in Finland that doubled from 0.6% in 2015[2]. These numbers indicate that E-mobility has not been a major part of transportation facilities in Finland. However, according to Ministry of Economic Affairs and Employment (2016), the government of Finland takes the initiative to introduce a minimum of 250 000

[1] Newatlas. World's largest EV charging station opens in Norway. Available at https://newatlas.com/fortum-charge-and-drive-tesla-supercharger-nebbenes-norway/45284/.
[2] Virta. EV's in Finland slowly gaining prominent market share [infographic] (2017) Available at: http://www.virta.global/news/evs-in-finland-slowly-gaining-prominent-market-share-infographic

EV by 2030. To approach the goal successfully, the government of Finland allocates financial support in forms of subsidies for private investors and tax exemptions for EV owners. In 2017-2019, Finland plans to invest 4.8 million Euros to the CI and targets to triple the amount of current charging facilities. In total, it will result in 1.1 billion investment costs by 2030 (Ministry of Economic Affairs and Employment, 2016). Finland focuses 30% subsidy rate for conventional charging stations and 35% subsidy rate for smart charging solutions that is a system that establish data connection between a charging device and a charging operator. The half of the 4.8 million Euros investments is accounted to the smart CS. Overall, this initiative will support Finland to become a forerunner in the progressive establishment of the CI (Ministry of Economic Affairs and Employment, 2016).

Ministry of Transport and Communications (2011) revealed that investments and implementation of a public CI should be done already now to ensure large-scale EV adoption in the future. What is more, it highlights that even with the accessible public CI it is expected that there will not be an immediate change from conventional vehicle to EV thus rapid drop in GHG emissions reduction. Therefore by 2020 Finland will not be able to meet the commitments of the Paris Climate Agreement. The timeline is set for 2030 when the EV adoption rate would be enough to contribute to the GHG emissions reduction goal. Apart from the CI development, contribution to the large-scale EV adoption should be done through incentives. In Finland, incentives packages for EV owners are on the initial stage of development. Finland provides **(1) purchase subsidies** such as purchase-related tax, exemptions or reductions, registration and import tax and other financial purchase support; **(2) ownership benefits** such as annual tax exemption, reduction of electricity or energy costs; **(3) business and infrastructure support**. There is a lack of local incentives such as free parking, access to bus lanes, no toll fees, access to restricted areas in city center areas (EEA, 2016).

Overall, considered E-mobility situation in Finland shows that there is a need for structured recommendations regarding investment decision-making that this master thesis aims to provide. The consideration of different aspects of investment decision-making, which are risks and uncertainties, possibilities for future investments, policy recommendations would create a sound foundation for further investigation of E-mobility development and investment in CI in Finland for research community and initial recommendations for policy and decision makers. Consequently, next part of this research demonstrates a structured representation of the research problem, questions and objectives.

1.2 Research problem, questions and objectives

To achieve the GHG emissions reduction goal and large-scale EV adoption in Finland, accessible CI is required to promote E-mobility. The CI project is a long-term investment opportunity (Collan, 2012), which has an important implication for the future socio-economic and environmental development (Poole et al., 2014). Current low the EV adoption rate and limited infrastructure facilities in Finland indicate that significant investments and governmental regulatory measures are required to support the implementation of large-scale build up CI and EV adoption. Irreversibility of infrastructure investments (Dixit and Pindyck, 1995) and uncertain demand, investment costs, electricity prices and revenue affect **Future Cash Flows (FCF)** of the project. Given circumstances lead decision and policy makers to consider possibilities and real options that would allow to maximize benefits and minimize risks and uncertainties. Therefore, this research aims to apply an approach that accounts future managerial flexibilities in investment decision-making uncertainty and answer further research question:

(1) How does uncertainty towards large-scale EV adoption in Finland affect investment decision-making on CI project?

In fact, since investment decision in CI project in Finland has been already approved, investment analysis does not target to answer the question *"invest or do not invest?"* but it aims to elaborate on how investments can be done more efficiently in terms government regulatory measures. Therefore, the second research question states:

(2) How can regulatory policy minimize uncertainty in large CI projects?

This research aims to address these two questions by accomplishing the following research objectives:

1) Investigation of previous research experiences and data collection;
2) Conventional investment analysis of the CI project as a basis for ROV;
3) Application of real option thinking to the CI investment project;
4) Real option approach to the investment analysis of the CI project;
5) Investment decision-making on the CI project with inherent managerial flexibility;
6) Introduction of policy recommendations on investment decision-making on the CI.

Subsequently, methodology and structure are defined according to research objectives.

1.3 Methodology and design

Appropriate methods are selected on the basis of every research objective that also defines the structure and design of the master thesis. The following procedure is defined. The first research objective is achieved with the research of scientific literature based on three main pillars. (1) Investigation of a CI project model presented in previous scientific papers. (2) Theoretical background of ROV and the FPOM methodology. (3) Application of ROV and the FPOM to infrastructure projects in previous researches. This method of literature reviews allows to examine the topic of the thesis from three main perspectives, collect qualitative and quantitative data for the CI project and identify research gap.

The second research objective is achieved with the conventional **Discounted Cash Flow (DCF**) and further calculation of **Net Present Value (NPV)**. This method is perceived as a basis for further valuation of investment opportunities of CI project and therefore is necessary to conduct beforehand.

The third research objective identifies another method applied in this study. **Real option thinking** that helps to evaluate potential of the CI project, investments as "real-life" investment opportunities (Collan et al., 2016; Mills et al., 2006) and identify what types of real options can be applied to the CI project (Van Rhee et al., 2008).

The fuzzy pay-off method (FPOM) helps to address the fourth research objective and apply ROV approach as an innovative investment analysis to the CI project. The methodology is based on the book "The Pay-Off Method: Re-Inventing Investment Analysis" by M. Collan (2012). Reasoning of this research method is explained by its advantages for an investigation of a project under uncertainty. First, because it treats uncertainty with a probability theory, it identifies possible outcomes of a project with different probabilities (Collan et al., 2009). Second, applying different **discount rates (DR)** to revenues and costs, the fuzzy pay-off method accounts different risk factors and values managerial flexibility as a real option (Collan, 2011). Third, even though the concept of ROV is derived from the concept of financial option valuation, application of the models such as classic Black-Scholes Option Pricing Model, Monte-Carlo Simulation, Binominal Tree Method, would give better valuation results for financial securities, not real investments (Collan et al., 2009). Fourth, this method avoids sharp imprecise single estimation with a "human reasoning" behind as NPV (Collan et al., 2009) and instead obtains the distribution of possible outcomes (maximum, best guess and minimum) with the probability of occurrence of each of them (Collan, 2012). Possible outcomes (maximum, best guess and minimum) are identified with **Scenario Analysis** is conducted with **Scenario Manager tool in MS Excel.**

The fifth research objective is accomplished with a combination of three methods. (1) Real option thinking presented before that helped to identify potential real options for investment decision-making. (2) **Sensitivity Analysis** performed with Data Table tool in MS Excel is a method for investigation of NPV's sensitivity to several factors of uncertainty. Subsequently, results of sensitivity analysis suggest several factors that affect NPV most that are further analyzed in investment decision-making with the help of Decision Tree approach. (3) Decision Tree maps step-by-step decision-making managerial actions towards follow-on investment opportunities (Magee, 1964; Yao and Jaafari, 2003; De Reyck et al., 2008) depending on market conditions evaluated by benchmarks and decision rules suggested by the author of this study.

Finally, the last research objective, which is an introduction of policy recommendations for decision and policy makers allowed to address the second research questions in this master thesis. It presents an analysis of public-private partnership toward public infrastructure projects (Adetunji and Owolabi, 2015; Poole et al., 2014) and demonstrates interpretation of key findings applied to the CI project in Finland.

Table 1. Research design

N	Research objectives	Method
1	Investigation of previous research experiences and data collection	Literature review
2	Conventional investment analysis as a basis for ROV	Net Present Value (NPV)
	• Influence of uncertain factors on NPV	Sensitivity Analysis
3	Application of real option thinking to the CI project	Analytical approach
4	Real option approach to investment analysis of CI project;	The fuzzy pay-off method
	• Three cash-flow scenarios	Scenario analysis
5	Investment decision-making on CI project with inherent managerial flexibility;	Step-by-step Decision Tree
6	Introduction of policy recommendations	-

1.4 Structure

The structure of the master thesis is organized in the following order represented by Figure 5. Chapter 2 represents the theoretical background of the investment analysis of CI projects under uncertainty and application of ROV. Based on the findings and collected quantitative data, the conventional investment analysis and sensitivity analysis of NPV is represented in Chapter 3. In Chapter 4 real option thinking and the FPOM as ROV is applied to the CI project. Chapter 5 demonstrates key results of this master thesis that present investment decision-making and policy recommendations for the CI project in Finland. Furthermore, discussion of the study is presented in Chapter 6 including theoretical and practical implications. Finally, Chapter 7 is the conclusion of the master thesis that contains summary, research limitations and recommendations for further research.

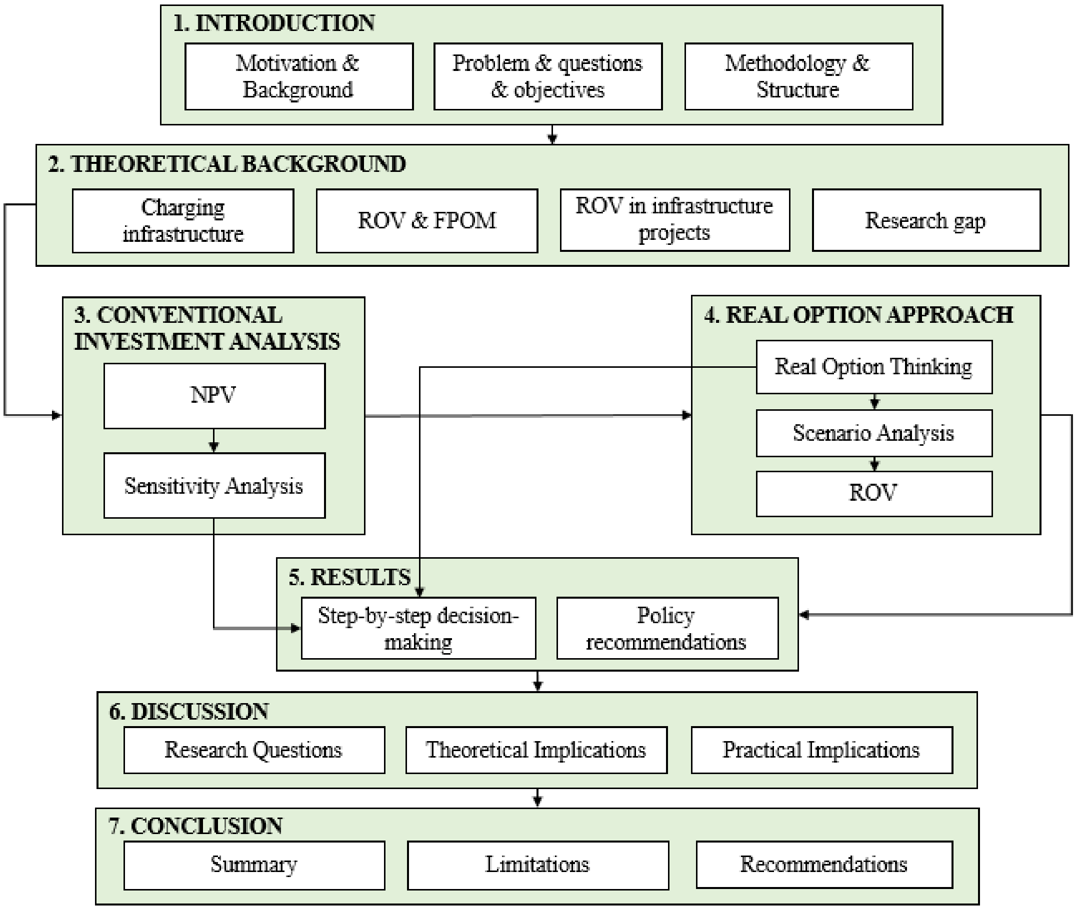

Figure 5. Structure and design of the thesis

2 THEORETICAL BACKGROUND

In this chapter, an overview of previous investigations on public infrastructure projects including CI projects. It contributes to the quantitative data collection applied further to a CF projection and calculation of NPV. In addition, it provides a theoretical background on ROV methods, including the FPOM and subsequently, shows how real option valuation approach has been used for an investment analysis of infrastructure projects. This chapter represents scientific literature that merges data and key findings from the sources performed from different markets such as China, Japan, Israel (Qiantu et al., 2012), Germany (Gnann et al., 2015), Norway (Nørbech, 2013), United States (Schroeder and Traber, 2012), Sweden (Xylia et al., 2017), Spain and the Netherlands (Madina et al., 2016), Denmark (Chesbrough et al., 2002), Finland (Markkula et al., 2013).

2.1 Charging infrastructure project business model

Large-scale adoption of new technologies such as E-mobility and CI depends on a successful business model, which provides value for both investors and customers. Bakker and Jacob Trip (2013) in their study highlighted that a CI business model can be "difficult" due to low margin, especially on the initial investment phase. In previous studies some business models for CI were suggested focusing on customer value and stakeholders' revenue (Kley et al, 2011), economic feasibility and investment decision-making (Madina et al., 2016; Serradilla et al, 2017). (Magretta, 2002) states that a business model identifies a value creation strategy for customers and stakeholders. Moreover, it has been investigated that "new-to-market" projects such as CI that are focused on the socio-economic and environmental development, have specific characteristics and requirements that existing business models cannot execute thus fail in "economic value creation" (Chesbrough and Rosenbloom, 2002; Budde Christensen et al., 2012).

The roles of stakeholders in CI business models are divided according to responsibilities. For example, Qiantu (2012) defines the "electricity supplier-oriented model" for CI models, where the rights belong to a EV infrastructure constructor while operation rights can be given to the same constructor or a specialized unit. In addition, the role of the government is to be responsible for a land provision and introduction of the policies and financial incentives. Poole et al. (2014) in the paper Public Infrastructure: A Framework for Decision-making

(2014) raised a deeper discussion regarding the role of the government in public infrastructure projects that bring social and economic benefit to the community. The study states that public infrastructure is *"an investment where the government has the primary role in, and responsibility for, deciding on whether and how infrastructure is provided in the interests of the broader community and on the source of the revenue streams to pay for the infrastructure over its life"* (Poole et al., 2014). It clearly states that the government is a major stakeholder in infrastructure projects that can transfer some responsibilities such as investments, construction, maintenance, operations to a private party, which has been also introduced in the study of Madina et al. (2016). However, the role of a regulator and a policy maker belongs to the government. In fact, most papers constantly highlight the importance of financial subsidies and incentives in EV adoption. For example, the UK introduced high fiscal incentives, but resulted in a relatively low EV market share (Mock and Yang, 2014) in spite of the biggest concentration of FCS (Figure 4). It proves that a sound government policy should be provided together with the sufficient CI to achieve large-scale EV adoption.

Furthermore, Madina et al., (2016) introduced a business model for CI projects including the main stakeholders. The stakeholders in the establishment and maintenance of CS are connected though business relationships that are illustrated by Figure 6. (1) B2C relationship is the relationship between E-mobility service provider (EMSP) that provides charging and related services to end customers (EV drivers) in both public and private CS. (2) B2B relationship is between EMSP and a charging stations operator (CSO) that is responsible for CI equipment supply and related management, monitoring and controlling including access to CI and electricity. (3) In a virtual B2B environment, a marketplace operator (MO) that provides services such as CI reservation and EV charging through the Internet and cloud services to CSO and EMSP. The presented distribution of responsibilities influences a cooperation between the government and public companies involved to CI projects as well as CS maintenance and operation.

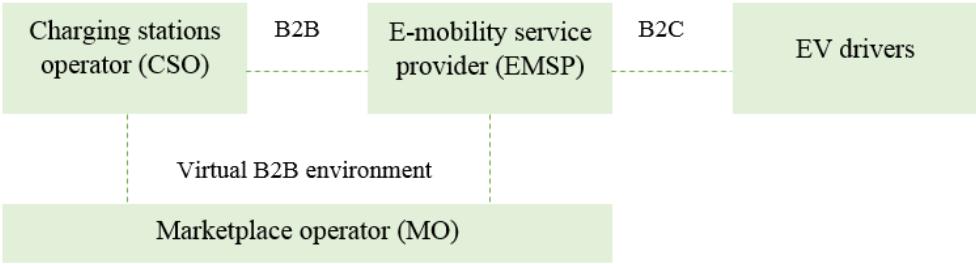

Figure 6. Stakeholders roles in EV CI business model
Source: (Madina et al., 2016)

Furthermore, CI can be private pf public. Madina et al. (2016) presents the classification of three types of CS listed below. In addition, NPE (2014) specifies investment and operational costs for each of them (Table 2). These types are traffic hotspot charging, highway charging (both public) and private home charging.

1) Traffic hotspot charging is a **public network of CS on private property** with medium power AC charging (22 kW);
2) Highway charging is a **public network of CS on private property** with high power DC charging (50 kW);
3) Private home charging is a **private property with a restricted access** with low power AC charging (3.7 kW).

Depending on the type of CS, customer demand varies. Private home CS are mainly preferred by EV users because of the convenience. Besides, 50% of conventional vehicles drivers would prefer EV only with an available private home CS (Madina et al., 2016). In fact, a few studies claimed that the major payoff from investment in CS can be reached only through private home CS. Bakker and Jacob Trip (2013) mentioned that some cities have a focus mainly on private CI to ensure low traffic pressure on the roads, while others are confident that public CI ensures high visibility of CI and creates a better environment for EV use. In spite of that, public CS are necessary to ensure comfort driving experience (Schroeder and Traber, 2012; Madina et al., 2016; Kley et al., 2011). Therefore, by investing in both public and private CS, stakeholders and investors will be able to reach large-scale EV adoption and financial viability of CI in the long-run (Markkula et al., 2013).

In addition, CS are divided into medium (low) power (AC) and high power (DC) that has an impact on driving experience as well as investment efficient and comfortable use of CS and

EV. Zhang et al. (2013) states that high power CS minimize charging time and maximize EV functionality, that creates a more convenient EV driving and charging experience. Gharbaoui et al., (2014) highlights that to ensure a comfort driving experience, CS should be operated in a “fair-sharing charging mode” that reduces power demand with a minimum impact on EV charging efficiency and time.

Scientific literature introduces CI model parameters that define cost and revenue structure. Electricity purchase cost, energy demand, maintenance costs, discount rate and charger availability rate (charger annual capacity, kWh/year) (Serradilla et al, 2017). On average full-charge of EV battery requires 20 kWh (Schroeder and Traber, 2012; Markkula et al., 2013). However, the average charging demand is expected to be lower, for example, 10 kWh that can be charged in 27 min (Madina et al., 2016). Another important parameter is EV efficiency that depends on the characteristics of a certain EV model and driving behavior. In previous literature, it has been estimated that EV efficiency that varies from 0.150 kWh/km (Schroeder and Traber, 2012) to 0.200 kWh/km (Markkula et al., 2013).

Overall, German National Platform for Electric Mobility (NPE) (2014) presents CI model parameters for public and private CS that are represented in (Table 2). The parameters for private CS are estimated does not include metering, billing and communication costs because of the private use (Schroeder and Traber, 2012).

Table 2. Business model parameters for private and public types of CS

Model Parameter	**Public**		**Private**
Type of EV CI	Traffic hotspot	Highway charging	Home charging
Power facility	Medium power AC	Fast power DC	Low power AC
Charging facility	22 kWh	50 kWh	3.7 kW
Investment costs	10500 EUR	27150 EUR	1500 EUR
Operation and maintenance costs	1150 EUR	2500 EUR	50 EUR
Metering and billing cost	375 EUR	375 EUR	-
Communication cost	200 EUR	200 EUR	-
Expected lifetime	7.5 years	7.5 years	12 years
Discount rate	7%	7 %	7%

Source: Operational and investment costs assumptions (Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012)

The cost structure for CI includes capital expenditures (CAPEX) and operating expenditures (OPEX). The structure of CAPEX are charger purchase and delivery, installation, power connection, preparation works and commissioning. OPEX structure includes electricity costs, land rent or purchase, management costs and maintenance costs (Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012). The major revenues come only from the sales of electricity to EV drivers. In fact, previous literature discusses that the major problem of infrastructure investments is to minimize uncertainty of investment costs and future demand (Alvarez, 1999; Herder et al., 2010) and maximize customers' willingness to pay. Therefore, one of the significant factors for investment decision-making are electricity re-sale price and the estimated amount of energy to be sold.

The markup or margin value that is included in the re-sale price takes a considerable part in the revenues that are come only from customers' electricity purchase. Schroeder and Traber (2012) state that customers' willingness to pay a minimum markup for EV CI service leads to an increase in ROI and a possibility to cover capital expenditures of investments. However, customers' willingness to pay depends on many factors such as EV purchase prices, electricity costs, charging prices and availability of a standardized CI (Miao et al, 2014). In addition, Guo et al. (2016) claims that large-scale development of CI in urban and suburban areas with the regard to traffic conditions will maximize customers' willingness to pay.

Furthermore, Christensen et al. (2012) presents the CI business model in a Danish market and highlights that in average 20% of charging EV will require full EV charge capacity which is 1-2 hours per day. The key point of that business model that it offers numerous packages to customers' that include fixed number of kilometers per year that is connected to an identity card (ID) of each customer. The contract includes a subscription fee of 1340 EUR that partly covers CS installation costs that can be in public or private places. The capital expenditures require for CS may depend on distance to the electric grid and soil characteristics, however the study suggests an estimated price of 2680 EUR (Christensen et al., 2012). This study suggests another perspective for decision and policy makers in CI business model.

Besides, while the CI project implementation, it is important to follow regulations regarding the E-mobility development strategy. According to the European Commission directive towards Electric Vehicles in Europe (2016), the amount of charging stations should cover the amount of registered EV at least twice, where at least 10% should be public CS.

Consequently, these findings are considered as basis for further conventional investment analysis and are used as major data for CF projection. Subsequently, results of previous investigations in CI model practices are applied on investment decision-making and policy recommendations.

2.2 Real option valuation and the fuzzy pay-off method

Ho and Liao (2011) discussed that in circumstances of hardly predictable market conditions, decision makers evaluate managerial flexibilities in investment projects as **"real options"** or **"strategic options"**. Chatterjee and Ramesh (1999) presented a similar concept from the perspective of innovation projects, that real options are valued as opportunities for investments in a current project with a strategic possibility of adoption of another innovation in the future.

Furthermore, Yao and Jaafari (2003) in their research highlighted that investment projects might be classified from the perspective of inherent complexity and market uncertainties. Inherent project complexity is a type of diversified risks when a management has a power to put a solution in practice to eliminate these risks. Market uncertainties are non-diversified risks because they are not under the management's control. Collan et al., 2016 distinguishes risk and uncertainty from each other. The concept of risk assumes that the probabilities of future events are **"objectively known"** thus it facilitates a decision-making process and estimation of FCF and NPV. Also, independence of those probabilities from choices and actions of a decision maker, creates an environment, where the entire decision-making process has a certain structure and relies on available information regarding future market conditions. In contrast, uncertainty is interpreted differently. It is a state where knowledge of future events is based on **"subjective assumptions"** and when a decision maker is unable to find out the probabilities of future events (Collan et al., 2016) and need to react proactively according to future upcoming changes (Leslie and Michaels, 1997).

Because the emphasis of the master thesis is a decision-making process of a complex infrastructure project exposed to high market uncertainty, a traditional DCF method as an investment analysis is not enough. In many scientific studies, conventional NPV and DCF have been criticized due to the methods' limitations. Yao and Jaafari, (2003) discussed that DCF method has been applied often to evaluate a project in reasonable and predictable market uncertainty, in other circumstances this approach does not give successful results. Projects with more complexity and uncertainty require a more flexible approach in decision-making. Ho and Liao, 2011; Van Rhee et al. (2008) in their studies discussed that DCF assumes that no contingencies are expected during the lifetime of an investment project that lead to the fixed CF scenario and disregard of maximum and minimum future values. Dixit and Pindyck, 1995; Van Rhee et al., 2008 highlighted that another issue with DCF method is use of constant discount rate that incorporates general risks of industry or a company with the weighted average cost of capital that do not account specific risks for a single project. Consequently, it does not consider project flexibility, limits strategic management of investment and results in biased FCF (Trigeorgis, 1996). As a result, strategic investment decisions towards complex large-scale infrastructure projects such as new airports, roads and production plants with inherent risks from uncertain market demand, construction costs and technology development, should be valued as a real option.

However, Trigeorgis (1993b) highlights that by using real option valuation techniques, NPV is not completely excluded but expanded to the strategic NPV that combines passive NPV of expected CF and value of a real option from active management. Correctly applied NPV to the option valuation techniques discovers investment opportunities beyond the limits of passive NPV (Trigeorgis, 1993a; De Reyck et al., 2008).

$$Expanded\ (strategic)\ NPV = Passive\ (Static)\ NPV + Option\ Value\ (Active)$$

The term of a real option has been developed by Stewart Myers (1977) and referred to the application of the option pricing theory to the valuation of financial assets (Mills et al., 2006; Miller and Waller, 2003). The idea of the theory is to value a portfolio of financial assets as an option to buy (call option) or sell (put option) that hedge against financial risks (Trigeorgis, 1996). Previous literature examined several methods of analyzing real options. Valuation of real options, originated from financial options valuations, uses methods such as the Black-Scholes Option Pricing Model, Monte-Carlo Simulation, Binominal method, the Fuzzy Pay-Off Method (Collan et al., 2009).

Van Rhee et al. (2008) emphasized that applying real options analysis to infrastructure project, numerous opportunities or options can be obtained to minimize losses in uncertain future situations. It provides decision makers with a better view on future investment opportunities. In fact, Trigeorgis (1993b) states that real options can occur naturally in the context of current market situations, for instance, option to defer or abandon. In some other cases, they can be incorporated as strategically planned such as an option to expand.

Valuation of investment opportunities (options) is performed with a real option valuation (ROV) approach that is strategic investment decision-making method. Collan (2012) discussed that ROV allows decision makers to incorporate managerial flexibility maximizing the benefits and minimizing the uncertainties that traditional DCF method ignores. Managerial flexibility represents managers' opportunity to undertake a decision based on a variety of choices. Real options provide this opportunity and give the right but not an obligation to choose whether to use the opportunity or not depending on market conditions.

One of the traditional methods is the binominal tree approach that values real option of underlying project and present possible FCF scenarios according to their probabilities. Besides, the **decision tree analysis (DTA)** captures flexible decision-making evaluating FCF and each opportunity on every stage before proceeding to the next one. It models strategic management of investments and provides a decision-making framework (De Reyck et al., 2008). However, there have been more groundbreaking methods developed for ROV. For example, Ho and Liao (2011) applied the fuzzy binominal tree as a ROV method in an investment project, where fuzzy numbers are used as parameters in the expanded NPV valuation.

One of the innovative and methods is the **fuzzy pay-off method (FPOM)** introduced by M. Collan and presented in his book *"The Pay-Off Method: Re-Inventing Investment Analysis*" (2012) as well as other several articles (Collan et al., 2009; Collan et al., 2016). The underlying concept of the FPOM is the fuzzy pay-off distribution of future value of investments that is mapped based on NPV CF scenarios (Collan et al., 2016). Based on the fuzzy logic, decision-makers can obtain the probability distribution of FCF scenarios and estimate the value of the future investment opportunity (Collan, 2012). One of the key advantages of the fuzzy pay-off method is that it can be applied on highly complex investment projects with a limited information under high uncertainty (Collan et al., 2016) such as large-scale industrial and infrastructure projects so called *"giga investments"* (Collan, 2012). These types of investments are characterized with a long-term investment opportunity, important of it socio-economic and environmental status and significant contribution to the development of other industries. Such investments impossible to reverse when an investment decision has been done and predicts its FCF because of high uncertainty (Collan, 2012).

Consequently, the introduced theoretical background of ROV and the FPOM is further used for the real option valuation as an investment analysis for the CI project. In addition, it elaborates on the methodology and demonstrates the FPOM as a relevant method for valuation of the CI project as a real option.

2.3 Application of real option valuation on infrastructure project

There are several studies that applied ROV approach to infrastructure projects. One of the important observations is noted by Poole et al. (2014) that an investment analysis with embedded real options and further decision-making does not answer the question whether to invest or not, but how to invest in the opportunities (options) more effectively to benefit in the long-run when a decision has been already done in favor of building infrastructure.

Poole et al. (2014) in the paper Public Infrastructure: A Framework for Decision-making discussed major characteristics of public infrastructure projects, which are (1) long-term; (2) significant amount of initial capital expenditures is required; (3) costs and revenues exposed to uncertainty and project-specific risks; (4) irreversibility and illiquidity of investments. Dixit and Pindyck (1995) emphasized that irreversibility, uncertainty and timing are key issues in infrastructure projects thus to proactively manage risk and uncertainty, real options should be incorporated. Infrastructure projects such as transportation, energy, telecommunications are exposed to high uncertainty that makes investors to estimate flexibility, future growth options and consider "mid-course strategy corrections" (Adetunji and Owolabi, 2016).

Adetunji and Owolabi (2016) state that investments in infrastructure projects create new investment opportunities in forms of real options. Moreover, Trigeorgis (1993b) investigated ROV applied on infrastructure projects and noted that in reality such projects are more complex, therefore might involve multiple real options embedded in investments. It has been discovered that use of multiple options provides a greater value than use of a single option because of giving more flexibilities and opportunities for further decision-making (Ho and Liao, 2011; Rose, 1998, Triegorgis, 1993a). Furthermore, nature of the multiple real option interaction in infrastructure projects (railroad, tollroads, highway) has been actively investigated in the research community. Yao and Jaafari (2003) also highlighted in the study that one project can incorporate up to seven different real options that guarantees management having a high probability of obtaining a positive outcome than negative. A range of researchers discovered a real option interaction impact on a project value. Adetunji and Owolabi (2016) analyzed how interacted time-to-build and growth options affect value of infrastructure projects. Rose (1998) conducted valuation of combined a real option to terminate and a real option to defer in tollroards investments. Trigeorgis (1993a) examined investments with embedded multiple real options to defer, to abandon, to expand, to contract and to switch. Adetunji and Owolabi (2016) pointed out that valuation of infrastructure projects with embedded multiple real option is a complex method. The more real options are incorporated into an investment project, the more complex the valuation gets.

The overall scope of the scientific literature on the application of real options on infrastructure projects demonstrates that it is a relevant method due to irreversibility and uncertainty. Subsequently, limited investigations on ROV approach applied on CI projects leads to an introduction of the research gap for this study.

2.4 Research gap

The literature review has shown that the adoption of EV and subsequent construction of the CI has been investigated from the point of economic value (Schroeder and Traber, 2012; Madina et al., 2016; Kley et al., 2011; Markkula et al., 2013), which involves CI specifications such as charging facility, power facility, type of CS and business model parameters such as cost structure, expected lifetime, revenue streams, discount rates with the regard to technical EV characteristics such as EV efficiency. Furthermore, studies that focus on the decision-making analysis on investments in CI have a very limited presence in the scientific literature.

From the methodological perspective, there are several studies that investigated investments in infrastructure projects under uncertainty and in most cases, applied the Binominal Tree as a ROV method (Adetunji and Owolabi 2016; Triegorgis, 1993a; Triegorgis, 1993b). To achieve a broader advancement in ROV, this master thesis attempts to elaborate on decision-making under uncertainty using the FPOM by Collan (2012) based on the CI project in Finland.

From the market perspective, the major contribution is made by the studies that examined investments in CI in Germany, Spain and the Netherlands (Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012). Based on these researches, all qualitative data is collected for a conventional investment analysis. Only one research investigated the CI in Finland (Markkula et al., 2013) that is limited to conventional NPV analysis with rough data assumptions and ignorance of market uncertainties and managerial flexibility.

Consequently, previous literature investigated investments in infrastructure projects under uncertainty, presented the analysis of incorporated managerial flexibility as a real option. However, there is scarce presence of studies related to an investment analysis of the CI project as a real option based on the FPOM. This master thesis aims to fulfill this research gap and present investment decision-making on the CI project and policy recommendations.

3 CONVENTIONAL INVESTMENT ANALYSIS

In this chapter, the conventional investment analysis uses classic DCF and NPV analysis as a basis for ROV, which will be shown and explained in detail further in this master thesis. It calculates NPV best guess scenario that will be used further as a basis in the scenario analysis and as a most possible outcome in the fuzzy pay-off distribution. The CF projection is based on CI data assumptions introduced in the literature review. Demand, costs structure and revenues are the components of the CF model and each of them has a detailed representation with the main assumptions. To facilitate an overall understanding of the calculation process, the cost model, revenue model and other accompanying calculations are provided. In addition, sensitivity analysis of NPV is conducted.

3.1 Net Present Value

This part demonstrates how CF model is designed based on data assumptions (Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012). Projection of CF is conducted for the period of 2017-2030 (14 years) where 2016 is considered as period 0 with initial (current) data.

The CF model consist of three main elements, which are (1) customer demand or a forecasted sufficient number of CS according to number of registered EVs; (2) revenue structure that shows the main source of revenue for the project and calculates charging price based on the revenue function; (3) costs structure (CAPEX and OPEX) with the cost function.

3.1.1 Customer demand

Customer demand is identified as the amount of CS needed to be constructed in Finland according to the registered amount of EV. In 2016, number of registered EV in Finland was 3285 EVs (2016)[3]. The goal of Finland is to adopt 250 000 EV by 2030 that identifies 36.27% EV adoption rate as an annual compound growth rate. Figure 7 illustrates demonstrates a forecasted EVs growth in Finland for 2016 – 2030. Calculation of the EV adoption rate has been performed with the following formula (1).

$$EV\ adoption\ rate = \frac{Current\ number\ of\ EV_{(2016)}}{Expected\ number\ of\ EV_{(2030)}}^{\left(\frac{1}{15-1}\right)-1} \tag{1}$$

[3] Virta. EV's in Finland slowly gaining prominent market share [infographic] Available at: http://www.virta.global/news/evs-in-finland-slowly-gaining-prominent-market-share-infographic

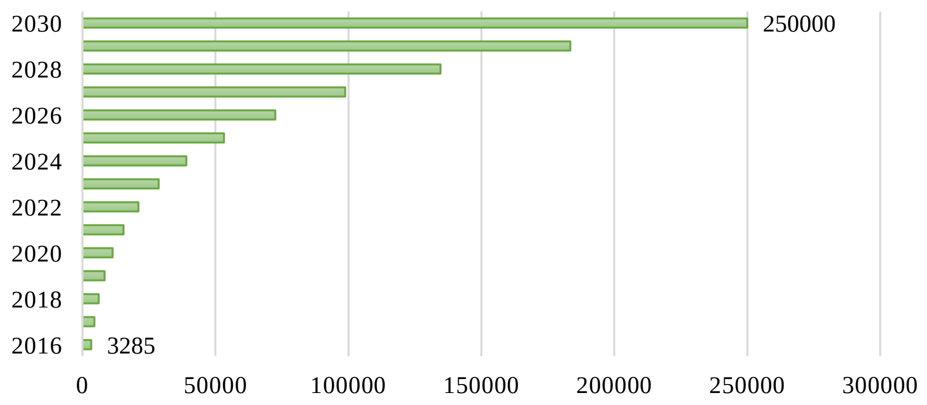

Figure 7. Number of EV in Finland 2016-2030
Source: CF projection made by the author based on number of EV (2016)[4] and applied 36.27% annual compound growth rate (1)

Based on previous findings of Madina et al., (2016), most of the potential EV drivers would prefer private CS because of comfort use. However, public CI is essential to ensure a better E-driving experience. Therefore, there are two types of CS are considered in this research, which are **public** (medium power 22 kWh and fast power 50 kWh) and **private or home charging** (low power 3.6 kWh). To achieve a steady growth of CS by 2030, 15% share for public and 85% share of private are assumed for this research (Figure 8).

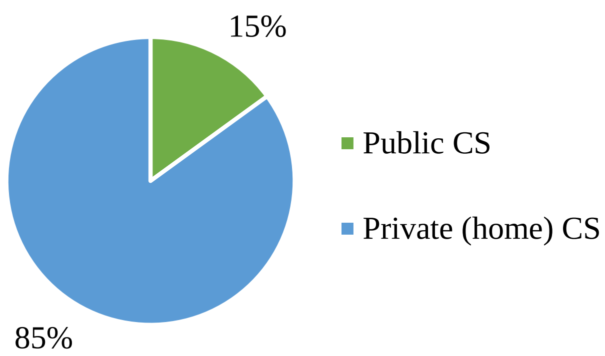

Figure 8. Private and Public CS share

According to the European Commission directive towards Electric Vehicles in Europe (2016), the amount of charging stations should cover the amount of registered EV at least

[4] Virta. EV's in Finland slowly gaining prominent market share [infographic] Available at: http://www.virta.global/news/evs-in-finland-slowly-gaining-prominent-market-share-infographic

twice, where at least 10% should be public CS. Therefore, this assumption gives a more concrete prediction of how large CI should be according to the regulations thus the factor called **Cover ratio** is introduced by the author for this research (2).

$$Cover\ ratio = \frac{Number\ of\ charging\ stations}{Number\ of\ EV} = 2 \quad (2)$$

Based on this equation, in Finland the total amount of existing CS covered the amount or registered EV by 1.2 times (122% cover ratio) in 2016. To further estimate a number of CS, Cover ratio is set as a constant value of 2 (200%) that means that the amount of all types of charging stations is twice more than the amount of registered EV. However, as a notice it is a very rough estimation and taken as an assumption for CF projection based on the Directive of European Commission (2016).

Schuman and Brent (2005) researched asset performance topic and claimed that lifecycle of an asset must be taken into consideration. It allows to identify the lifetime of a real asset and predict next reinvestment, which allows to manage investments more efficiently. Therefore, one of the key parameters in the CF model is a charging station lifetime introduced in Table 2 (Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012). It is considered as a number of years when CS is in operation and able to charge EV. In the end of every CS's lifetime, the reinvestment is needed that is taken into account in the CF model. For the public CI the lifetime is 7.5 years and for the private (home charging), it is 12 years.

The lifetime factor is accounted in the CF model, that is why there are two separate blocks that calculates the number of existing CS and newly constructed CS by type annually (Table 3):

- **The number of existing CS by type** is the amount of required CS to construct according to registered EV annually.
- **The number of new constructed CS by type** that is the amount of new stations for the construction when lifetime of excising ones has expired, and it is necessary to build new ones to keep cover ratio stable at 2.

Table 3. Forecasted number of CS for the best guess scenario

Year	**2016**	**2017**	**2018**	**2019**	**2020**	**…**	**2030**
	0	1	2	3	4	…	14
Number of registered EVs	3285	4476	6100	8312	11326	…	250000
Adoption rate = 36,27%							
Number of existing charging stations by type							
PUBLIC	1000	1331	1830	2494	3398	…	75000
Fast charging	400	532	732	997	1359	…	30000
Medium charging	600	798	1098	1496	2039	…	45000
PRIVATE	3000	7540	10369	14130	19254	…	425000
Total existing charging stations	*4000*	*8871*	*12199*	*16624*	*22652*	…	*500000*
Cover ratio (%)	**122%**	**200%**	200%	200%	200%	…	200%
Number of new constructed by type							
PUBLIC (8 years lifetime)							
End of service life		0	0	0	0	…	1679
Public charging stations		331	499	664	904	…	21640
PRIVATE (12 years lifetime)							
End of service life		0	0	0	0	…	2829
Home charging stations		4540	2829	3761	5124	…	115938

Source: CF projection performed by the author based on data assumptions from Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012.

Figure 9 illustrates public and private CI growth in 2017 – 2030.

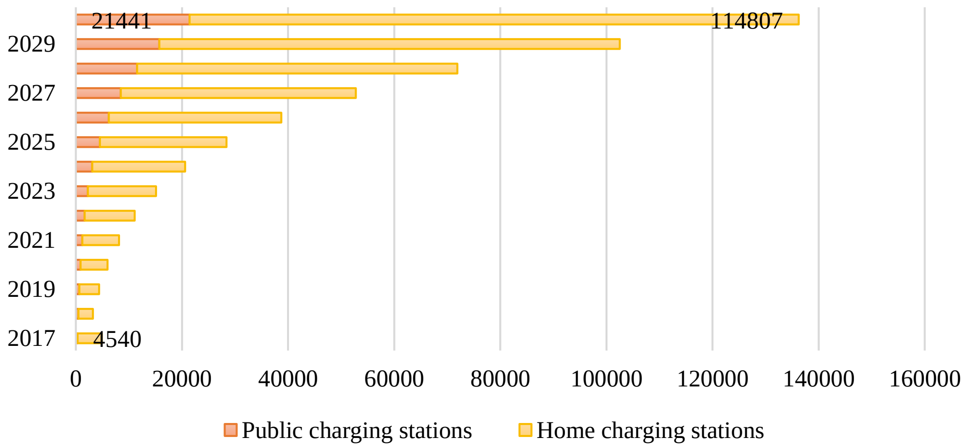

Figure 9. New constructed charging stations by type 2017-2030
Source: created by the author based on a Table 3

It shows that a dramatic growth of CS is estimated in Finland by 2030. It means that significant financial and technical forces should be accumulated in order to meet the goal of 250 000 EV by 2030 and fulfill electricity demand coming from potential EV drivers.

3.1.2 Cost structure

The cost structure of the CI project consists of two elements (1) Investment costs (CAPEX) and (2) operational costs (OPEX). Both CAPEX and OPEX are separated for every type of the CI (public and private) depending on the power capability (Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012).

Total CAPEX for the public infrastructure is accumulated from subsidies given by Finnish government and private investments. According to Ministry of Economic Affairs and Employment (2016), 4.8 million Euros subsidies are planned to be allocated for 2017-2019. In total public and private investments public CI in total will reach 1.1 billion by 2030.

Private investments in infrastructure projects are mainly justified with a commercial interest, therefore cost efficiency is one of the important variables that identifies frequency and timing of private investments such as maintenance or operation (Rouse and Chiu; 2009). Therefore, CAPEX and OPEX efficiency rate are key input variable in the cost model that minimizes costs per one CS. (Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012).

CAPEX efficiency rate is 9% and OPEX efficiency rate is 3%. By applying these rates, investments in the CI reach positive operational CF and overall 1.1 billion CAPEX for public infrastructure. Furthermore, the CAPEX cost model is presented with a detailed CF model in the Table 4 below.

First CAPEX per one charger for year (t) annually is calculated for each type of charging stations (public and private home charging), that accounts efficiency rate (E) for CAPEX (3):

$$CAPEX_{per\ 1\ (t)} = (1 - E) \times CAPEX_{per\ 1(t-1)} \qquad (3)$$

E – efficiency rate, %

$CAPEX_{per\ 1\ (t-1)}$ – CAPEX per one charger in previous year (t-1)

The cost function for the private investment costs $CAPEX_{private}$ is demonstrated as formula (4) that shows that building of new charging stations is included to CAPEX after the end of the lifetime of existing charging points:

$$CAPEX_{private} = CAPEX_{per\ 1\ (t)} \times (15\% \times N_{p\ new(t)} + 85\% \times N_{h\ new(t)}) \tag{4}$$

$N_{p\ new\ (t)}$ – total number of newly constructed public charging stations in year t

$N_{h\ new\ (t)}$ – total amount of newly constructed home charging stations in year t

Where number of newly constructed charging stations $N_{new\ (t)}$ is cumulative calculated by formula (5) for both public and home charging stations:

$$N_{new\ (t)} = N_{(t)} + N_{end(t)} + N_{(t-1)} \tag{5}$$

$N_{(t)}$ – total number of charging stations in year (t)

$N_{end\ (t)}$ – total amount of charging stations with end of their lifetime in year (t)

$N_{(t-1)}$ – total amount of charging stations in previous year (t-1)

Finally, $CAPEX_{total\ (t)}$ is a total amount of investment costs for building new charging stations every year and they accumulate both public and private investment costs (6)

$$CAPEX_{total\ (t)} = CAPEX_{private(t)} + CAPEX_{public(t)} \tag{6}$$

Where $CAPEX_{public}$ is a total amount of investments required for public infrastructure (7) accounted subsidies from Finland $CAPEX_{subsidies\ (t)}$: 4.8 million for 2017-2019:

$$CAPEX_{public(t)} = CAPEX_{pubic\ (t)} - CAPEX_{subsidies\ (t)} \tag{7}$$

The overall representation of the CAPEX CF model is presented in Table 4.

Table 4. Forecasted CAPEX in CF model (thousand Euros)

Year	**2016**	**2017**	**2018**	**2019**	**2020**	**…**	**2030**
Period	0	1	2	3	4	…	14
CAPEX efficiency rate = 9 %							
CAPEX (CS 1 unit)							
PUBLIC	37,65	34,26	31,18	28,37	25,82	…	10,05
Fast charging	27,15	24,71	22,48	20,46	18,62	…	7,25
Medium charging	10,50	9,56	8,70	7,91	7,20	…	2,80
PRIVATE	1,50	1,37	1,24	1,13	1,03	…	0,40
CAPEX (total)							
PUBLIC total:	-	*11326,63*	*15567,54*	*18828,34*	*23347,45*	...	*217566,57*
- Subsidies	-	1600,00	1600,00	1600,00	-	…	-
- PUBLIC	-	9726,63	13967,54	17228,34	23347,45	…	217566,57
PRIVATE total	*4500,00*	*6197,14*	*3514,58*	*4250,75*	*5271,00*	...	*46440,63*
TOTAL CAPEX	**-**	***15923,77***	***17482,12***	***21479,09***	***28618,46***	**…**	***264007,20***

Source: CF projection performed by the author based on data assumptions from on Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012

Furthermore, the OPEX cost function is calculated and is presented with the CF model structure in Table 5.

The $OPEX_{total\,(t)}$ cost function has a similar concept, but the function calculates annual OPEX for the total amount $N_{(t)}$ of charging stations annually (8):

$$OPEX_{total\,(t)} = OPEX_{per\,1\,(t)} \times (15\% \times N_{p(t)} + 85\% \times N_{h(t)}) \quad (8)$$

N_p – total number of public charging stations in year t

N_h – total amount of home charging stations in year t

Where OPEX per one CS for year (t) annually is calculated for each type of charging stations (public and home charging), that accounts efficiency rate (E) for OPEX (9):

$$OPEX_{per\,1\,(t)} = (1 - E) \times CAPEX_{per\,1(t-1)} \quad (9)$$

E – efficiency rate, %

$OPEX_{per\,1\,(t-1)}$ – OPEX per one charger in previous year (t-1)

Table 5. Forecasted OPEX in CF model (thousand Euros)

Year	2016	2017	2018	2019	2020	…	2030
Period	0	1	2	3	4	…	14
OPEX efficiency rate = 3%							
OPEX (CS 1 unit)							
PUBLIC	4,70	4,56	4,42	4,29	4,16	…	3,07
Fast charging	2,98	2,89	2,80	2,72	2,63	…	1,94
Medium charging	1,73	1,67	1,62	1,57	1,53	…	1,13
PRIVATE	0,05	0,05	0,05	0,05	0,04	…	0,03
OPEX (total)							
PUBLIC total	0,00	2871,75	3830,91	5063,61	6692,95	…	108942,05
Fast charging	1190,00	1535,90	2048,89	2708,18	3579,60	…	58265,64
Medium charging	1035,00	1335,85	1782,02	2355,43	3113,35	…	50676,42
PRIVATE total	150,00	365,69	487,83	644,80	852,29	…	13872,77
TOTAL OPEX	***2375,00***	***3237,45***	***4318,74***	***5708,41***	***7545,24***	**…**	***122814,82***

Source: CF projection performed by the author based on based data assumptions from Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012

3.1.3 Revenue structure

The source of income for this investment project is operational revenue that come from the markup, which is a margin over total electricity costs included fees and taxes (Schroeder and Traber, 2012). In other words, selling electricity to EV drivers ("electricity sell" – "electricity buy") brings the operational revenue from the investments. The estimation of a charging price for the public and private CS is an optimization problem that holds many assumptions such as investment and operational costs, marketing and customers' willingness to pay (Markkula et al., 2013). Because at starting stage of EV penetration, charging stations are produced in small numbers thus the building of extensive charging network requires high CAPEX and OPEX (NPE, 2014).

To approximately estimate the margin that could bring positive operational revenue, many technical factors should be considered: electricity price (Eur/kWh), charging price (Eur/kWh), average battery full power per EVs (kWh), the power facility of charging station (fast, medium, low), charging facility (kWh), EV efficiency (kWh/km). In average full-charge of EV battery requires 20 kWh (Schroeder and Traber, 2012; Markkula et al., 2013), 10 kWh that can be charged in 27 min (Madina et al., 2016). According to charging facility for each type of charging stations (Table 6), to charge battery full, with medium charging (22 kWh) it would take 60 minutes, with fast charging (50 kWh) - 25 minutes and with home charging station (3.6 kWh) - approximately 6 hours.

Table 6. Charging stations power and charging facility by type

Model Parameter	**Public**		**Private**
Type of EV CI	Traffic hotspot	Highway charging	Home charging
Power facility	Medium power AC	Fast power DC	Low power AC
Charging facility	22 kWh	50 kWh	3.7 kW

Source: Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012.

For the assumption of a charging price, Fortum Charge & Drive charging prices are taken. Depending on the CS type and power capability, the charging price for medium power is approximately 0.30 Euros per kWh or 0.04 per minute (2.4 Euros per hour). For the fast powers CS, the price is 0.20 Euros per minute (12 Euros per hour). Therefore, to charge 20 kWh depending on the power type of a CS, on average would costs 6 Euros for both medium power (AC) and fast power (DC) or 0.30 Euros per kWh[5].

Furthermore, depending on the characteristics of a certain EV model and driving experience, EV efficiency is different. For this research, 0.200 kWh/km EV efficiency is assumed (Schroeder and Traber, 2012). This assumption leads to the conclusion that using a medium power charging station to charge 20kWh for full battery allowing to drive the distance of 100 km, EV driver should pay 6 Euros. While fuel consumption is 0.049 liter/km for diesel powered cars. In average, the price for diesel in Finland is 1.25 Euros per liter[6] that would require paying approximately 7 EUR for 100 km driving range.

Besides, for estimating future electricity prices in Finland, the base price of 2016 (0.0861 Eur/ kWh) for electricity price for industrial consumers including VAT and other levies is taken. In the Figure 10, there is a graphical representation of historical electricity prices in Finland.

[5] Fortum. Forum Charge & Drive map. Available at: https://map.chargedrive.com/.
[6] Global Petrol Prices. Finland Diesel Prices (2017). Available at: http://www.globalpetrolprices.com/Finland/diesel_prices/.

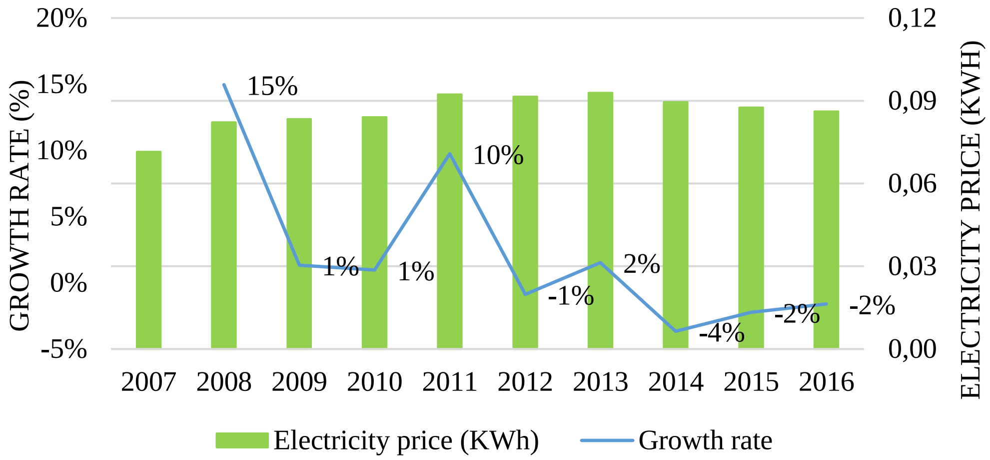

Figure 10. Electricity prices for industrial consumers including VAT and other levies in Finland (2007-2016)
Source: Eurostat Database[7]

Large-scale EV adoptions will dramatically affect electricity consumption and electricity power system in Finland. The total amount of electricity consumption is expected to rise by 3TWh in case of 50% growth adopted EVs in Finland (Koreneff et al., 2009). Therefore, the charging process should be designed so that it does not create momentary surges in electricity consumption or require additional power. Electricity production capacity in itself does limit adoption of electric cars (Ministry of Transport and Communications, 2011).

For this research, annual electricity demand is estimated according to the daily average electricity consumption per EV annually and total number of EV in Finland. The estimated future electricity demand in Finland is illustrated by Figure 11.

[7] Eurostat Database. Available at http://ec.europa.eu/eurostat/data/database.

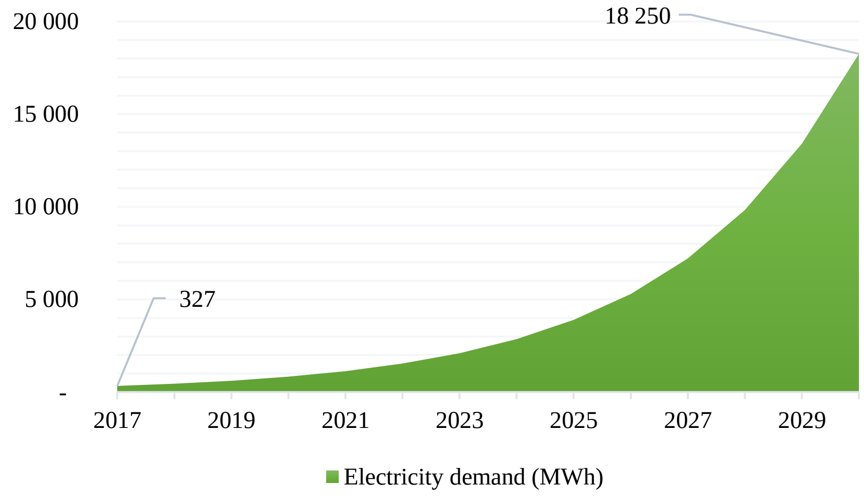

Figure 11. Electricity demand (MWh) for EV in Finland for 2017-2030

Therefore, by estimating an annual compound growth rate for electricity prices (2.086%) based on the historical electricity price, the future trends in electricity prices are obtained. What is more, taking a generic assumption of an average charging price (0.30 Euro/kWh) for every type of the CS, it is subject to 0.5% annual growth. This allows to follow the growth of electricity prices annual and keep the margin at a constant level (0.2 Euro/kWh). Figure 12 demonstrates the future estimated growth of electricity and charging prices in Finland for 2017-2030.

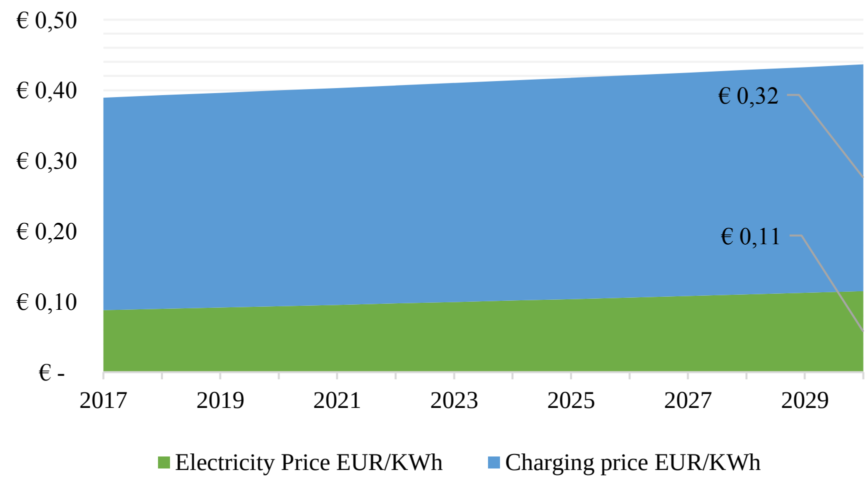

Figure 12. Electricity prices and charging prices in Finland for 2017-2030

The overall CF model for the operational revenue is structured in the Table 7. Operational revenue OR $_{(t)}$ function is represented as a formula (10):

$$OR_{(t)} = El_{demand(t)} \times (CP_{(t)} - El_{Price\ (t)}) \qquad (10)$$

$El_{demand\ (t)}$ – electricity demand in year (t)

$CP_{(t)}$ – charging price in year (t)

$El_{price\ (t)}$ – electricity price in year (t)

Where electricity demand is calculated with the formula (11) annually (365 days in a year):

$$El_{demand\ (t)} = N_{EV\ (t)} \times AvC_{(t)} \times 365 \qquad (11)$$

$N_{EV\ (t)}$ – number of registered EVs in year (t)

$AvC_{(t)}$ – average charge per 1 EV in year (t) that is constant variable 20kWh

Table 7. Forecasted operational revenue in thousand Euros

Year	**2016**	**2017**	**2018**	**…**	**2030**
Period	0	1	2	…	14
Electricity price annual growth rate = 2,00%					
Charging price annual growth rate = 1,00%					
Markup (margin), Eur = 0,21					
Electricity demand (KWh)		32677158,10	44527706,33	…	1825000000,00
Electricity price Eur/KWh	0,0861	0,09	0,09	…	0,11
Charging price Eur/KWh	0,3	0,30	0,30	…	0,32
Operational revenues	**-**	**6979,97**	**9511,29**	**…**	**389827,16**

Source: CF projection performed by the author based on historical electricity prices in Finland (Eurostat Database) and Fortum Charge & Drive pricing tariffs

To further calculate NPV, CF are divided into the operational CF and investment costs CF. Also, the discount rate is different for the operational CF and investment costs CF, because each of them are subjected to different risks (Collan, 2012). Since the discount rates for the profitability analysis can be selected by the analyst (Collan, 2011), discount rates were chosen according to previous investigations of financial analysis of infrastructure projects for EV (Madina et al., 2016; NPE, 2014) and Guidelines for the Assessment of Transport Infrastructure Projects in Finland (2013).

Operational CF are calculated as operational revenue subtracting operational costs (Collan, 2012). From the previous demonstration of the costs function, the operational costs are

OPEX $_{total(t)}$ for each year (t). Taking previous assumption for the operational revenue and operational costs, the operational CF are calculated with the formula (12):

$$Operational\ CF_{(t)} = OR_{(t)} - OPEX_{total(t)} \tag{12}$$

Investment cost CF is the sum of $CAPEX_{total}$ from public (subsidies) and private investments calculated with the formula (13):

$$Investment\ costs\ CF_{(t)} = \sum_{t=1}^{n} CAPEX_{total\ (t)} \tag{13}$$

To further calculate NPV for the best guess scenario, present value (PV) (14) of the operational CF and investments cost CF are calculated separately with the different discount rates. The discount rate for the operational CF (5%) is taken from Guidelines for the Assessment of Transport Infrastructure Projects in Finland (2013). Discount rate (r) for the investment cost CF (7%) is taken from data findings in literature review (Madina et al., 2016)

$$PV_t = \frac{CF_t}{(1+r)^t} \tag{14}$$

The NPV for the project is estimated by calculating the cumulative NPV (15) value adding all the present values together (Collan, 2012).

$$NPV_{(t+1)} = PV_{Operational\ CF\ (t)} - PV_{Investment\ CF\ (t)} + PV_{Investement\ CF\ (t+1)} \tag{15}$$

Finally, the obtained best guess NPV is negative **- 89 091 thousand Euros** (Table 8) that in the traditional investment analysis would indicate do not to invest further because of the clear unprofitability of building charging infrastructure in Finland for charging operators and energy companies by 2030, because of ambitious governmental targets to deploy 250 000 EV by 2030. However, as the conventional NPV ignores managerial flexibility, in this research the NPV value does not answer the question: *"invest or not to invest?"* but is considered as a basis for the further scenario analysis, where maximum and minimum NPVs are obtained for ROV that incorporates managerial flexibility – real option.

Table 8. Present Value and NPV best guess

Year	2016	2017	2018	2019	2020	…	2030
Period	0	1	2	3	4	…	14
Discount rate for operational CF=5,00%							
Discount rate for Investment CF= 7,00%							
PRESENT VALUE							
Operational CF	-	3742,52	5192,55	7252,20	10115,61	…	267012,33
Investment cost CF	-	15923,77	17482,12	21479,09	28618,46	…	264007,20
PV of Operational CF	-	3564,31	4709,79	6264,73	8322,14	…	134859,37
PV of Investment cost CF	-	14882,03	15269,56	17533,34	21832,88	…	102386,54
Cumulative PV	-	-11317,72	-21877,49	-33146,10	-46656,85	…	**-89091,37**
NPV best guess = -89 091,37 thousand Euros							

Source: CF projection performed by the author based on the results from Tables 4,5 and 7

In the next section, the sensitivity analysis is performed for the risk assessment and evaluation of best guess NPV's responsiveness to possible future uncertainty of key parameters in the CF model.

3.2 Sensitivity analysis

In this research, the aim of the sensitivity analysis is to estimate what factors of uncertainty influence NPV of the CI project. Furthermore, the most influential factors are used as a basis for the analysis of uncertainty of the CI projects, real option thinking and investment decision-making.

The sensitivity analysis as a process that identifies key parameters that has the biggest impact on NPV. On the one hand, due to the methods' limitations, results can be biased. It analyses the impact on NPV of changes in a single variable at a time while the others are constant thus ignoring the combination of changes in a range of variables simultaneously. On the other hand, the sensitivity analysis allows to examine key variable that can affect investment uncertainty (Yao and Jaafari, 2003) as well as to evaluate reliability of CF model by providing with an information what variables are the most influential (Briš, 2007).

This study performs the sensitivity analysis of NPV to the major variables of the CI project, that are under uncertainty. The function includes a **dependent variable:** NPV best guess and seven **independent variables**: (1) EV adoption rate; (2) markup; (3) electricity price annual growth rate; (4) charging price annual growth rate; (5) cover ratio; (6) OPEX efficiency rate (%); (7) CAPEX efficiency rate (%) illustrates by Figure 13.

The sensitivity analysis is performed with the **Data Table tool in MS Excel** based on independent variables change, which is +/- 20%.

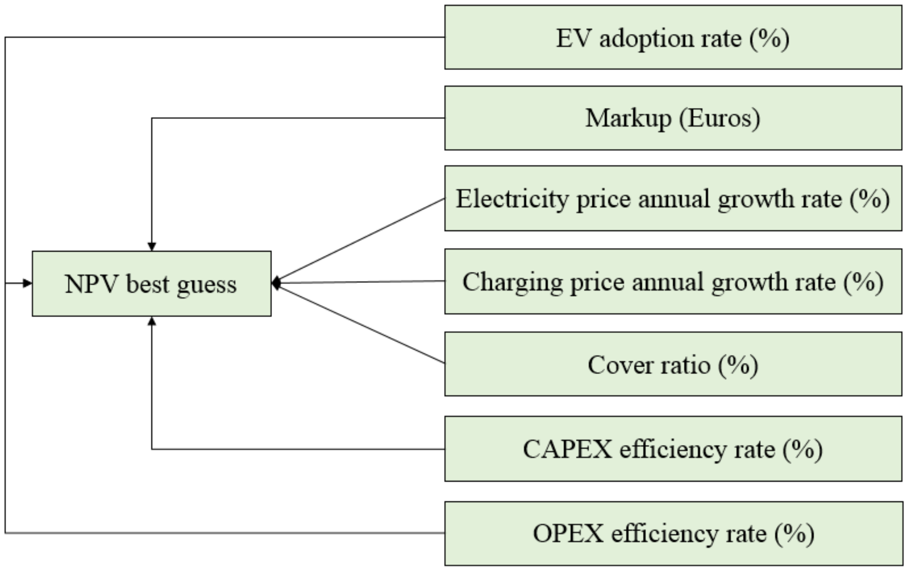

Figure 13. Sensitivity analysis dependent and independent variables

The results are represented by the tornado diagram (Figure 14). It illustrates that NPV is highly sensitive to the 20% change in four input parameters that are EV adoption rate, markup, cover ratio and CAPEX efficiency rate. Practically for decision makers it means that it is essential to consider these indicators in the risk and uncertainty management.

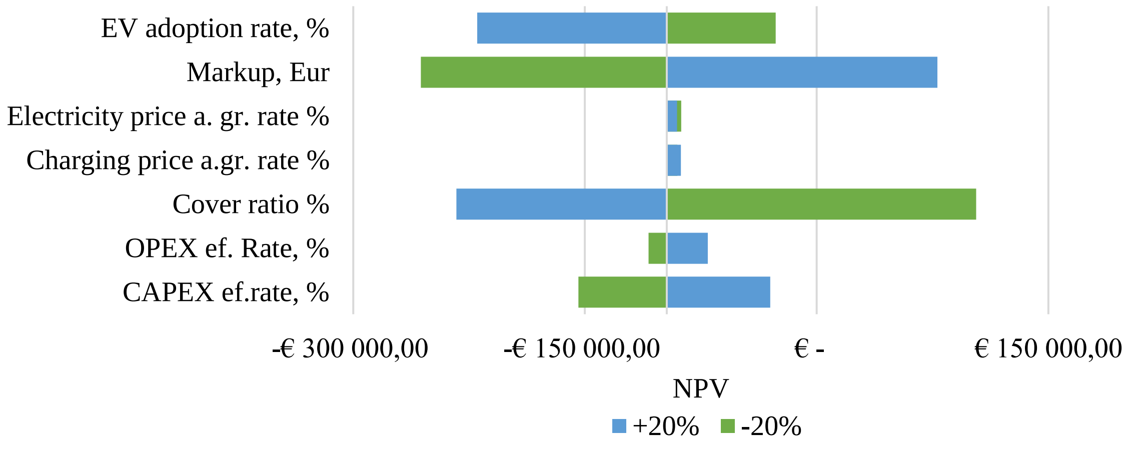

Figure 14. Sensitivity analysis of NPV (+/-20% risk factor change)
Source: performed by the author based on NPV best guess (Table 8)

First, the **EV adoption** rate would significantly affect NPV in 20% change. It is unidentified as a factor of uncertainty, because of future unpredictability in EV purchase trends, and therefore should be considered in investment decision-making. In fact, the EV adoption rate should be positive (stable or growing), because it identifies how many EV are adopted annually in Finland.

Second, **cover ratio** is related to the EV adoption rate and therefore is an influential factor in the sensitivity analysis of NPV. The higher the cover ratio, the higher the amount of adopted EV thus demand for electricity supply. Considering that Finland is targeting large-scale EV deployment, it is reasonable to assume that cover ratio should increase in the future, because every EV driver prefers the private home CS as well as additionally charge EV with the public CS. As a cover ratio is considered as a guiding factor that measures a number of CS in relation to number of EVs in the country (European Commission, 2016), it is important for policy makers to actively measure amount of adopted EV annually to provide the CI.

Third, future investment costs for the CI project are associated with high uncertainty. Changes in **CAPEX efficiency rate** would significantly affect NPV, because the largest share of costs is related to CAPEX in the CF. That is why, cost efficiency has a significant contribution to the CF projection. Therefore, it is one of the key factors in managerial flexibility to maximize benefits and minimize any extra costs and financial risks.

Fourth, **markup** has a significant influence on NPV because it is the only source of revenue in the CI project and therefore affects the operational revenue CF. However, this factor does not create uncertainty because in this research it is considered as a constant variable. Markup variability might be affected by significant changes in future electricity prices.

Overall, the findings from the sensitivity analysis provide a foundation for further investment decision-making and policy recommendations that will be considered in more detail further in this study. Due to limitations of the sensitivity analyses, the obtained results can be biased, however it allowed to analyze NPV's sensitivity to the key parameters of uncertainty in the CF of the CI project.

4 REAL OPTION APPROACH

In this chapter, the investment analysis using ROV approach is performed based on the results obtained in the conventional investment analysis using NPV. Real option thinking is applied to identify future investment opportunities of the CI project and presents types of real options that can be applied further for decision-making. The FPOM as ROV approach is selected for this study as it is a relevant method for the valuation of investments in real assets (Collan et al., 2009).

4.1 Real option thinking to charging infrastructure project

To further perform the decision-making analysis, real option thinking is applied on the CI project that analyses investment opportunities. It allows to consider the CI project as a real option for follow-on investments. Real options are "real-life" investment opportunities that "provide managers with strategic flexibility" (Collan et al., 2016). In addition, real options are considered as contracts with inherent opportunities (Mills et al., 2006) that decision makers value as opportunities to realize and reach an optimal payoff (Leslie and Michaels, 1997).

Ability to think strategically and manage investments proactively is the **real option thinking** concept. It is an initial step for strategic decision-making in capital investments and is defined as managerial analytical skills that enable them to recognize real options, incorporate them to investment strategies accordingly, and respond to environmental changes, that are **"reactive kinds of flexibilities"**. There are also **"proactive kinds of flexibilities"** that mean managerial capability to increase the value of a real option before exercising it (Leslie and Michaels, 1997). Luehrman (1998) considers business strategies as series of several options that gives managers flexibility to make decisions immediately or defer them and act as circumstances change.

The application of real option thinking requires understanding of the projects' uncertainty that is analyzed. First, the CI is a long-term investment project with the period of over 10 years that indicates that the project is under uncertainty due to limited information available about future circumstances (Collan et al., 2016). Second, the CI project is an irreversible "giga investments" (Collan, 2012) infrastructure project therefore a real option is incorporated in real market investments, minimizing managers' obligations (Leslie and Michaels, 1997). Furthermore, real options such as to stage investments, to expand, to defer, to phase (Van Rhee et al., 2008), to apply timing actions (Collan, 2012) to investments should be incorporated to the investment planning and analysis. Third, the current situation in the E-mobility in Finland demonstrates a very low number of EV on its roads that indicates low EV adoption rate thus insufficient demand for a large-scale CI. In fact, in the light of conventional investment analysis the CI project is unprofitable. The obtained NPV is - 89 091 thousand Euros (Table 8) that based on this method would suggest do not invest. However, the CI project has socio-economic and environmental benefits that primary has a goal to contribute to the large-scale EV adoption thus reduce GHG emissions. Based on that, this project has a potential in the long-run and by applying ROV, is the strategically attractive investment in the future. Because the major revenue comes from re-sale of electricity to EV (charging price), (Madina et al., 2016), electricity prices fluctuation is a critical factor of uncertainty that affects investment NPV. Fourth, the results of the sensitivity analysis demonstrate that several factors determine uncertainty of the CI project's NPV (investment costs, customer demand, EV adoption rate, electricity price). Finally, the governmental programme of the investments in the CI just has been planned and therefore the whole investment in the CI project can be considered as a real option (Collan, 2012).

The results of the real option thinking showed that the CI project is exposed to the high complexity and uncertainty. Figure 15 illustrates the positioning the CI project from the perspective of uncertainty and complexity (Yao and Jaafari, 2003).

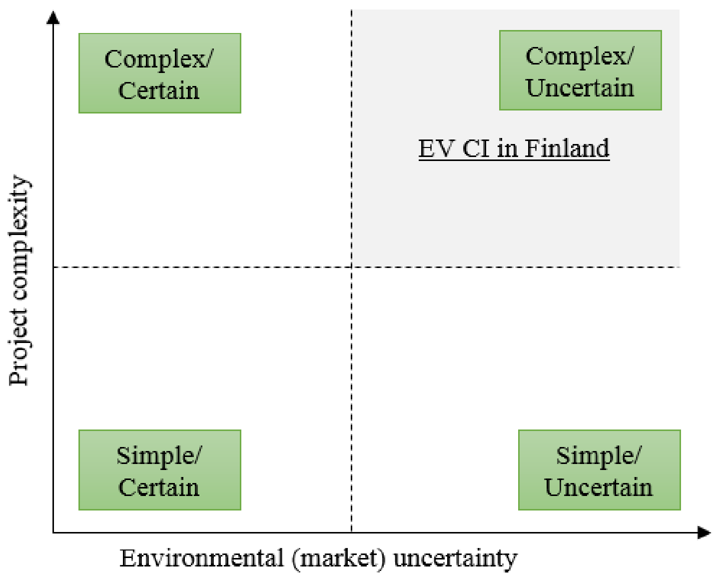

Figure 15. Project complexity and market uncertainty positioning of the CI project
Source: created by the author based on the method of Yao and Jaafari (2003)

Practically it means that the CI is exposed to high uncertainty that would suggest to analyze the project based on a ROV method. Applying real option thinking, the author of the current research suggests three types of real options that could be possibly incorporated separately or altogether to the investment analysis of the CI project in Finland (Table 9).

Table 9. Types of real options applied to the CI project

Type of real option	Description
to grow or to expand	The real option **to grow or to expand** (Van Rhee et al., 2008) enables decision makers to scale the number of CS depending on the amount of registered EV in Finland. Currently, a share of registered EV in Finland is relatively low (1.2%)[8] that is reflected in a low number of CS. Extending the CI, an option to grow or to expand is incorporated in the further investment decision. As time passes, the EV adoption rate grows, a real option to expand the CI can be exercised according to terms, for example *"if the EV adoption rate grows, additional lands in public areas are guaranteed to be reserved to build additional CS"*.
to defer	The real option **to defer** (Van Rhee et al., 2008) enables decision makers to put construction of the CI on hold because of the low EV adoption rate and hardly predictable uncertainty. If the amount of EV on Finnish roads is stable, a real option to defer can be exercised according to the terms, for example *"if the EV adoption rate is stable and current amount of CS is sufficient, construction of EV CI can deferred until the number of registered EV starts to grow again"*. This flexibility allows to control investments in the CI and avoid premature decisions.
time-to-build option	The real option **to phase** or **time-to-build option** (Van Rhee et al., 2008) enables to undertake *"timing of actions"* (Collan, 2012) in investment decision-making. As time passes, expected

[8] Virta. EV's in Finland slowly gaining prominent market share [infographic] Available at: http://www.virta.global/news/evs-in-finland-slowly-gaining-prominent-market-share-infographic.

	customer demand can change thus planned investment resources can be scheduled for certain periods of time / regions in Finland. Therefore, investments in the CI can be divided into several phases depending on these factors. It adds value to this investment project for example, *"if CS are planned to be built in a certain region of Finland or a district in a city such as Helsinki depending on EV traffic at a certain period of time, time-to-build option is exercised".*

Source: representation of real option thinking for the IC project performed by the author based on Van Rhee et al., 2008; Collan, 2012

Overall, these examples of real options demonstrate how real option thinking can be applied to the CI project in Finland. To further examine investments in the CI according to the terminology of call and put options, the following is suggested.

As originated from financial options, call option (buy) and put (sell option) define similar actions – having the right *"to act with regards to an underlying asset at a given future time, or during a given future period"* (Collan et al., 2016). In the case of capital investments, it can be the right to invest in an opportunity. In the CI project, there are a few major sources of uncertainty: investment and operational costs, EV adoption rate and future electricity price over the period of 10 years. Considering several real options (to grow, to defer, to phase) that can be applied to the investments in the CI project, decision makers can purchase a **call option** that is the **right to invest in CI** within the period when there is a certain number of EV adopted. The opportunities to make changes in the CI investments would add value to the project by mitigating risks (Collan et all., 2016).

To further incorporate managerial flexibility to the CI project, the representation of three NPV scenarios is preformed based on the scenario analysis of NPV.

4.2 Scenario analysis

The goal of the scenario analysis is to analyze different alternatives and present possible outcomes. These alternatives do not forecast but provide a picture of what could happen in the future based on different outcomes (Piyatrapoomi et al., 2004). The scenario analysis is the facilitator of decision-making under uncertainty. It helps to identify and anticipate contingences and uncertain events in the future. In real-life decision-making input factors of the analysis are estimated by project managers and decision makers. (Miller and Waller, 2003). The results from the scenario analysis are considered as a basis for the fuzzy pay-off distribution presented further in this study for the valuation of the CI project investment as a real option based on the FPOM.

Three NPV scenarios are required (maximum, best guess and minimum) for the triangular fuzzy pay-off distribution. Best guess scenario represents the most probable scenario that could happen in the future. Minimum and maximum scenarios picture possible changes in the CF operations and investment costs. The scenario approach enables decision makers to consider the full range of possibilities and allows to conduct a more comprehensive analysis of an investment project and apply the FPOM as ROV (Collan, 2012).

M. Collan (2012) states that in the scenario analysis, upside and downside NPV changes are *"never symmetric"* and usually are 10% or 20%. In fact, to estimate maximum or minimum PV, the possible changes in future operational CF and investment costs CF should be considered independently. For a maximum scenario, minimum investment costs (-) and maximum operational CF (+) (Collan, 2012). Based on that approach, (1) CAPEX efficiency rate and (2) OPEX efficiency rate are used to generate minimum and maximum scenarios for the operational CF and investment cost CF that further influenced the NPV results (Table 10).

Table 10. Scenario analysis assumptions and NPV results (maximum, best guess, minimum)

Factor in CF model	**Maximum NPV**	**Best guess NPV**	**Minimum NPV**
CAPEX efficiency rate	11%	9%	8%
OPEX efficiency rate	5%	3%	2%
NPV (thousand Euros)	***91 839***	***- 89 091***	***- 195 825***

Source: performed by the author with Scenario Manager tool in MS Excel based on "The Pay-Off Method: Re-Inventing Investment Analysis" (Collan, 2012)

For all three scenarios margin is a constant value 0.21 EUR/kWh. With the charging price growing annually at 0.5% growth rate for all three scenarios, it allows investors to reach positive operational revenues and CF. Cover ratio is constant as well and equals to 2.00.

In the minimum NPV scenario, OPEX less cost-efficient with the rate of 2%. The forecasted total CAPEX for the public infrastructure (1.1 billion Euros) slightly increases based on 8% CAPEX efficiency rate. In the maximum NPV scenario, cost efficiency for both OPEX and

CAPEX is expected to be higher because of the larger scale of the CI. In the result, efficiency rate for CAPEX is 12% and for OPEX is 5%. It means that CAPEX for public infrastructure is slightly less than forecasted 1.1 billion Euros by the Finnish government. Besides, OPEX efficiency rate leads to a more efficient maintenance of the CI thus more cost-efficient investments.

Figure 16 illustrates the proportion OPEX/CAPEX for three different scenarios, that demonstrates that CAPEX takes the biggest share in the cost structure of the CI project.

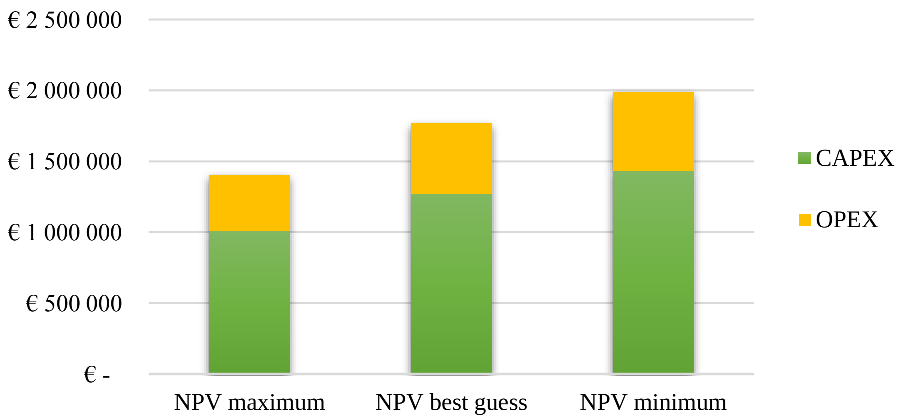

Figure 16. CAPEX and OPEX for max. best guess, min scenario (thousand Euros)

Based in the three generated scenarios, discounted cumulative CF for maximum, best guess, minimum CF scenarios are illustrated by Figure 17. It shows that the distance between maximum and minimum scenarios is wide that indicates high level of inaccuracy (Collan, 2012). The figure demonstrates that by the end of the investment period discounted cumulative CF are starting to grow. It shows that as long as the EV adoption rate continues to grow, and investments are efficiency performed, the project may expect be profitable in the long-run.

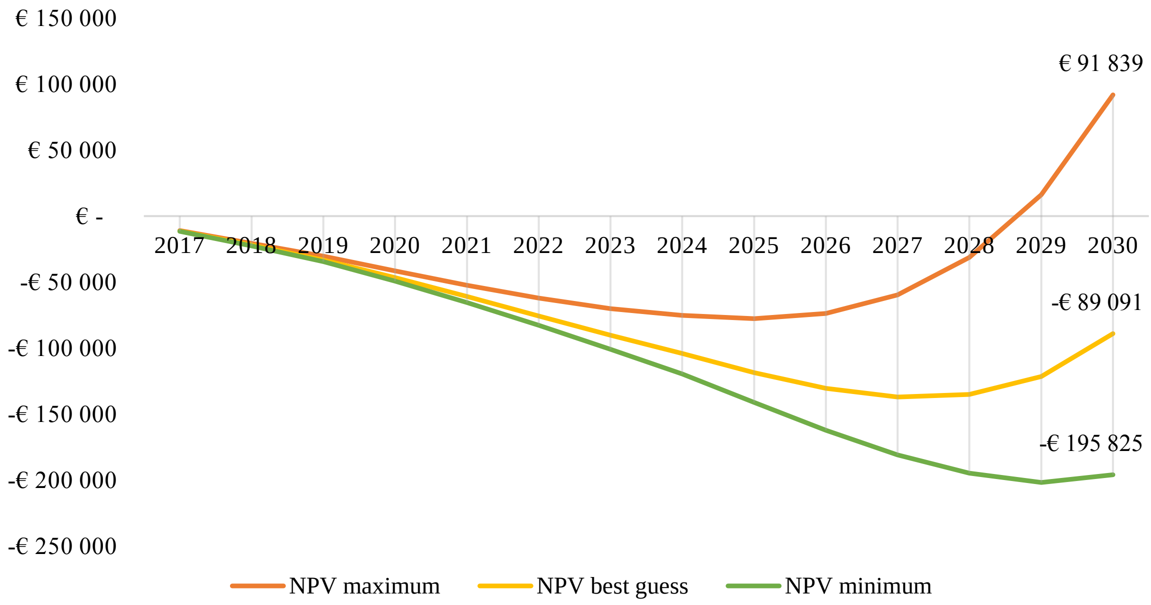

Figure 17. Cumulative NPV for min, best guess and max scenarios (thousand Euros)
Source: generated by the author based on NPV (Table 8) and Scenario Analysis (Table 10)

Considering the whole investment in the CI as a real option, the distribution of possible future NPV values is built. Based on the FPOM an option has a range of possible values that might happen in the future with certain probability. ROV considers only positive values while negative values are zeros, because managers exercise an option exclusively in the favorable conditions that would bring positive value to their investments (Collan, 2012). Under these assumptions, the triangular distribution of possible expected values is built based on based on NPV scenarios (maximum, best guess and minimum) and illustrated by Figure 18, that is mapping all the expected values with assigned probabilities from 0.0 to 1.0. The next step is to calculate probability weighted mean of the fuzzy pay-off distribution that will demonstrate an expected option value distribution (Collan, 2012).

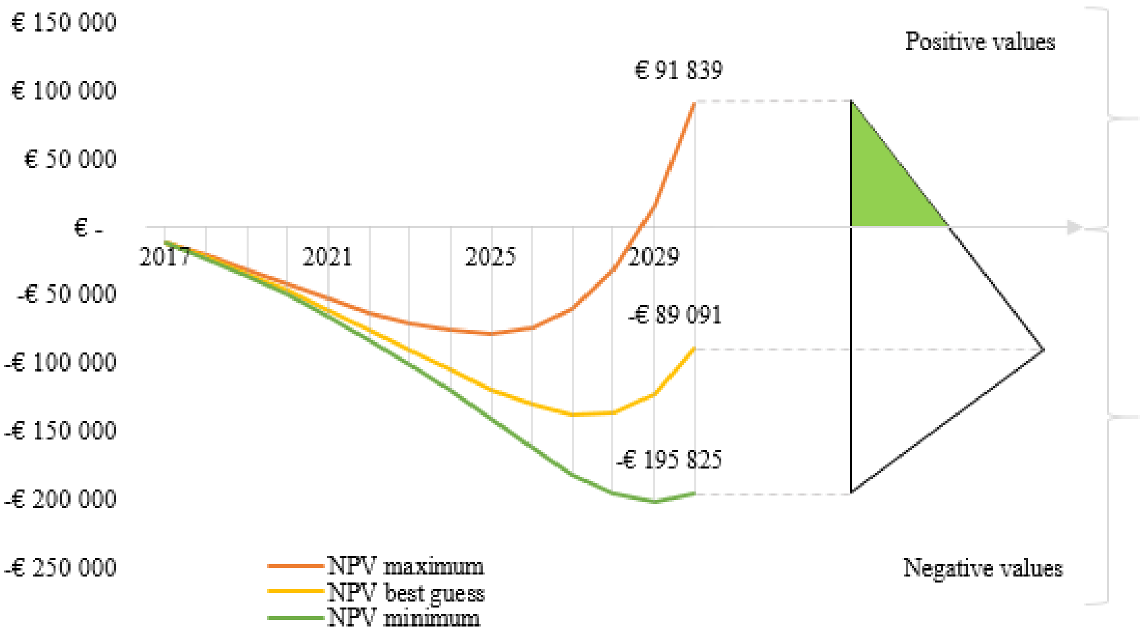

Figure 18. Creation of the triangular fuzzy pay-off distribution
Source: created by the author based on Collan M. (2012). The Pay-Off Method: Re-Inventing Investment Analysis

4.3 Real option valuation

The foundation of the FPOM is the fuzzy pay-off distribution that is defined as the fuzzy number (Collan, 2012). The fuzzy number illustrated by Figure 19, has a triangular shape and is defined by three points that represent three different scenarios of NPV of the project (Collan et al., 2009). The minimum, best guess and maximum possible NPVs are represented by the points “a-α”, “a”, “a+β”, respectively, where “α” and “β” are distances between best guess and minimum and maximum scenarios. The height of this triangular distribution is the degree of membership (from 0.0 to 1.0) that defines the possibility of occurrence of each value in the pay-off distribution (Collan, 2012). For example, the best guess scenario has a membership degree of 1 that refers to the most possible outcome.

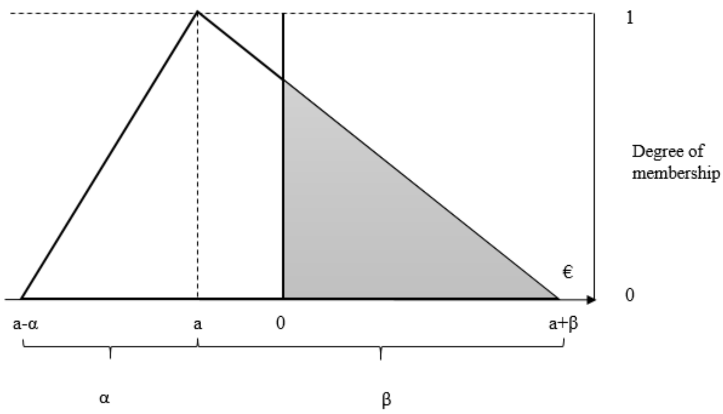

Figure 19. The triangular fuzzy number
Source: the illustration of the fuzzy pay-off distribution is based on "The Pay-Off Method: Re-Inventing Investment Analysis" (Collan, 2012)

Based on the fuzzy logic, valuation of a real option is performed according to the formula (16) (Collan et al., 2009). Because real option is a right but not an obligation, a decision maker would exercise an option only in beneficial conditions that are represented in the area above zero in the fuzzy pay-off distribution (Figure 19). Accordingly, ROV is the weighted average of positive outcomes of the fuzzy pay-off distribution where negative values are mapped as zero (Collan, 2011).

$$ROV = \frac{\int_0^\infty A(x)dx}{\int_{-\infty}^\infty A(x)dx} \times E(A_+) \quad (16)$$

where,

$E(A_+)$ is a possibilistic mean of a positive area of the fuzzy pay-off distribution.

$\int_0^\infty A(x)dx$ is a positive area of the pay-off distribution.

$\int_{-\infty}^\infty A(x)dx$ is a negative area of the pay-off distribution.

Depending on a location of a positive area (above zero, partly above zero, below zero), a possibilistic mean $E(A_+)$ is computed differently (Table 11) (Collan, 2011).

Table 11. Possibilistic mean formula according to a pay-off distribution location

N	Pay-off distribution	Possibilistic mean formula
1	Above zero, 0<(a- α)	$E(A_{+}) = \alpha + \frac{\beta - \alpha}{6}$
2	Partly above zero, (a- α)<0<a	$E(A_{+}) = \alpha + \frac{\beta - \alpha}{6} + \frac{(\alpha - a)^3}{6\alpha^2}$
3	Partly above zero, a<0<(a + β)	$E(A_{+}) = \frac{(\alpha + \beta)^3}{6 \times \beta^2}$
4	Below zero	$E(A_{+}) = 0$

Source: "The Pay-Off Method: Re-Inventing Investment Analysis" (Collan, 2012)

For this research the fuzzy pay-off distribution is build based on the fuzzy number. It is a simplified triangular shape that demonstrates the possible reality that is a forecasted value is *"good enough"* (Collan, 2012). Figure 20 demonstrates that negative NPV will happened with the highest possibility 1. NPV = 0 would be possible with a probability a bit higher than 0.5 that factually is a very good result in given circumstances of future uncertainties in investment costs, electricity prices and EV adoption rate. The small triangle (shaded area) is a value of real option that is estimated further with the FPOM.

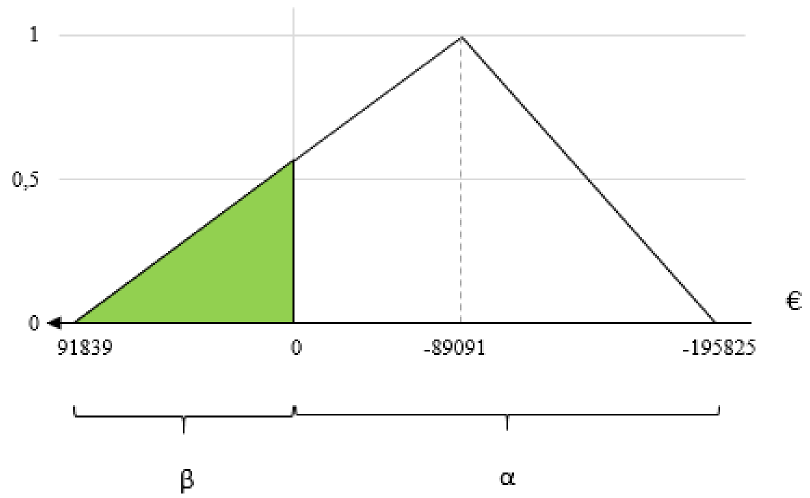

Figure 20. Horizontal representation of the fuzzy pay-off distribution for a real option for the CI
Source: calculations of the author based on the FPOM (Collan, 2012)

As is it shown on the Figure 20, the pay-off distribution of investments in the CI project is located above zero between the best guess NPV and maximum possible NPV (a < 0 < a+β), which is the case number 2 presented in the Table 11. Therefore, further calculations of a possibilistic mean and ROV are performed according to the formula for that specific case.

In this research, the ROV calculation procedure is based on "The Pay-Off Method: Re-Inventing Investment Analysis" (Collan, 2012).

To calculate a possibilistic mean of a positive area E(A_+), for the case where a positive area is partly above zero (a < 0 < a+β), the following formula (17) is used:

$$E(A_+) = \frac{(\alpha + \beta)^3}{6 \times \beta^2} \tag{17}$$

To calculate the positive area (A_+) of the triangular the fuzzy pay-off distribution, first the area of the whole distribution (A) is calculated. As the positive are of the fuzzy pay-off distribution is a triangle, the simple mathematical formula (18) is applied for calculation the area of A that is the fuzzy NPV (Collan et al., 2009).

$$A = \frac{1}{2} \times height \times width \tag{18}$$

Furthermore, the FPOM is applied for the valuation of CI project as a real option. Fuzzy numbers are calculated and presented in Table 12.

Table 12. Max, best guess, min NPV scenarios and fuzzy numbers (thousand Euros)

Scenario	Thousand Euros	Fuzzy number
Maximum scenario NPV	**91 839**	a+β
Best guess scenario NPV	**-89 091**	a
Minimum scenario NPV	**-195 825**	a-α
Distance between best guess scenario NPV and maximum scenario NPV	|**91 839**-(**-89 091**)| = **180 930**	β
Distance between the best guess scenario NPV and minimum scenario NPV	|**-195 825**-(**-89 091**)| = **106 744**	α

Source: performed by the author based on "The Pay-Off Method: Re-Inventing Investment Analysis" (Collan, 2012)

Subsequently, applying the formula (19) the mean of positive area of the fuzzy pay-off distribution is:

$$E(A_+) = \frac{(\alpha + \beta)^3}{6 \times \beta^2} = \frac{(106\,744 + 180\,930)^3}{6 \times 180\,930^2} = \mathbf{121\,195} \qquad (19)$$

To further calculate the value of a real option $ROV = \frac{A_+}{A} \times E(A_+)$, it is necessary to obtain the values of positive area (A_+) and the area of the entire triangular distribution (A). Using the following formula (20), with the simple calculations, the whole area of a triangular is obtained:

$$A = \frac{1}{2} \times height \times width = \frac{1}{2} \times 1 \times (91\,839 + 195\,825) = \mathbf{143\,832} \qquad (20)$$

To further calculate the area of a positive side using the same formula for A, first the "height at zero" (Collan, 2012) should be found. Knowing that the height is linearly proportional to the distance between "height at zero" and maximum NPV, with the following proportion "height at zero" is obtained (21):

$$\frac{\text{"}height\ at\ zero\text{"}}{91\,839} = \frac{1.00}{180930} \rightarrow \text{"height at zero"} = \frac{1.00}{180930} \times 91\,839 = \mathbf{0.5} \qquad (21)$$

Consequently, the positive area (A_+) is obtained (22):

$$A_+ = \frac{1}{2} \times 0.5 \times 91839 = \mathbf{23308} \qquad (22)$$

Finally, based on the previous calculations, it is easy to estimate ROV for the investigated EV CI project (23):

$$ROV = \frac{A_+}{A} \times E(A_+) = \frac{23308}{143832} \times 121195 = \mathbf{19\,640}\ (\boldsymbol{thousand\ Euros}) \qquad (23)$$

Overall, the obtained result indicates that the value of the real option for investments in the CI in Finland is **19 640 thousand Euros.** According to Collan (2012), if the cost of a project is less than ROV, an investment project should be approved and therefore a decision maker should make a positive investment decision. Based on that rule, it is sensible to invest in the CI project using real options and, for example with a growth option to invest in a timely manner as market changes are more beneficial.

$$\begin{gathered} Expanded\ NPV = Passive\ NPV + ROV = \mathbf{-89\ 091 + 19\ 640} \\ \boldsymbol{Expanded\ NPV = -69451}\ (\boldsymbol{thousand\ Euros}) \end{gathered} \tag{24}$$

In conclusion, passive NPV results is a negative value that in a traditional DCF analysis would suggest abandoning the project because of neglecting potential investment opportunities in the long-run (Yao and Jaafari, 2003; Trigeorgis, 1996). The equation (24) shows that a real option added a value to passive NPV, even though the expended NPV is still negative, it is justified by the nature of the CI as a long-term investment project that aims to meet large demand in the future. The limited investments costs and a lack of current demand makes the CI project unprofitable now, but potentially attractive in the future. The investments in the CI project are evaluated as a real option, which showed a positive result. The empirical study proved that a practical application of a real option allows to discover managerial flexibilities that could be used by decision and policy makers in order to achieve maximum investment efficiency and minimum project-specific risks and market uncertainties.

5 RESULTS

In this chapter, the findings and results of the investment analysis of the CI project based on the FPOM are presented. These are divided into two sections and each them addresses each research questions of this study.

5.1 Step-by-step decision-making

This section presents the investment decision-making based on the step-by-step decision tree. The results allow to address the first research questions, which is *"How does uncertainty towards large-scale EV adoption in Finland affect investment decision-making on CI project?"*. The possibility to expand investments in CS across Finland could be considered as a growth option. In case of such a large-scale infrastructure project under uncertainty, the management cannot make one-time investments. Therefore, for the CI project it is reasonable to make decisions in a timely manner with the incorporated growth option. The growth option allows to expand infrastructure in a timely manner depending on upcoming market conditions based on a decision **"invest or wait".** The expansion of the CI in Finland is an important part of the overall goal to bring more EV, ideally replace conventional vehicles, and contribute to the reduction of GHG emissions. Moreover, this investment project is already ongoing and there are many private companies that provide infrastructure facilities and participate in a variety of partnerships to support this initiative.

The decision tree method allows to perform the analysis of managerial flexibility in the CI project and at the same time suggest structured decision-making process. Many researches such as Magee, (1964), Yao and Jaafari (2003), De Reyck et al. (2008) agreed on a decision tree as method that illustrates managerial actions, which a decision maker has a flexibility to undertake in response to current market conditions and uncertainty. That is why, a simplified three-step decision tree that suggest how uncertainty affect investment decision-making.

The foundation of a step-by-step decision-making is decision rules that guide a decision maker at each stage of an investment opportunity evaluation according to pre-determined benchmarks suggested by the author based on the results of the sensitivity analysis and real option thinking. The actual values are set according to minimum values of the best guess scenario of a CF model and presented in Table 13. In real-life, benchmarks can be set by decision makers, experts or policy makers. The benchmarks can be modified or adjusted according to, for example, project performance and its goals, policy regulations, legislation, market conditions, financial recourses and other conditions that determine success of a project. Additionally, decision rules help to understand how uncertainties influence a decision-making process and the outcome based on market conditions (EV adoption rate, electricity price growth rate) and a project condition (CAPEX efficiency rate).

Table 13. Benchmarks for the factors of uncertainty

Factor of uncertainty	Benchmarks
EV adoption rate	≥ 25%
Electricity price volatility	≈ 2%
CAPEX efficiency rate	≥ 9%

Source: set by the author based on CF model of this research.

The logic behind the decision tree model is to analyze every factor of uncertainty and compare to the pre-determined benchmarks (Table 13), current market conditions, project development stage and other relevant point and further decide to **"invest or wait"**. Overall, it has a stepwise approach that contributes to the development of a systematic analysis and helps to discover how uncertainty affects an investment decision-making process. Figure 21 represents a step-by-step decision tree suggested for investment decision making on the CI project. To get a better understanding of the suggested decision tree, every factor and step is considered further in more detail.

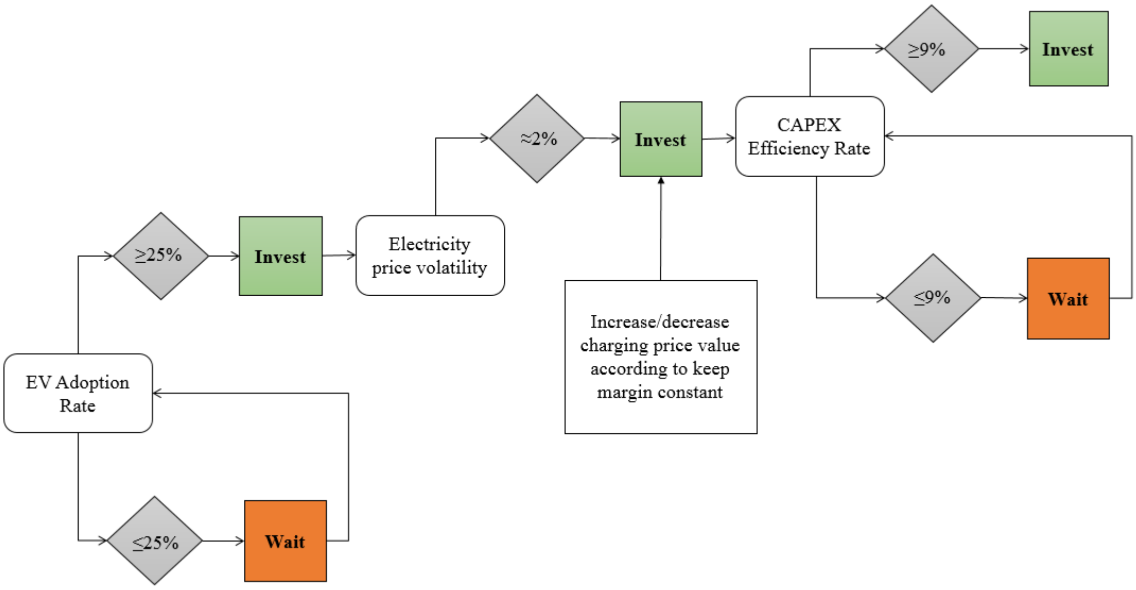

Figure 21. Step-by-step decision-making (growth option)
Source: performed by the author based on growth option and benchmarks (Table 13).

This research does not aim to provide a strict guideline for investment decision-making but to suggest the decision-making model and analyze how uncertainty affects it. All the numerical values are provided exclusively based on the empirical analysis of this research and can be different from the reality.

EV adoption rate: The problem of an investment decision-making in the CI has been always considered as a "chicken-egg problem" (Markkula et al., 2013). On the one hand, the more CS are available, the more drivers tend to purchase EV. On the other hand, to build an infrastructure a decision maker expects a sufficient demand for the CI. Therefore, the first factor that should be analyzed in investment decision-making is customer demand represented as the EV adoption rate. In the best guess scenario, 36.27% annual growth rate is considered as the EV adoption rate that should be achieved to adopt 250 000 EV by 2030. For the first step of a decision tree, the benchmark is recommended to be 25% in order to balance between the present demand for CS and a strategic long-term goal to invest in the CI in order to attract more EV regardless the current demand.

Decision rule #1: if the EV adoption rate is more than 25%, the decision is to invest. If it is less than 25%, it is recommended to wait and promote E-mobility by, for example financial incentives such as purchase inventive or road tax rebate (European Commission, 2013). In addition to incentives, it would be recommended to comply with EU legislation and keep the cover ratio stable to comply with EU directive (European Commission, 2017).

Electricity price volatility: When the EV adoption rate shows that minimum required demand is on the market, further investment analysis requires to estimate volatility of electricity prices, because electricity re-sale is the only source of income thus may affect outcome of the CI irreversible project dramatically. In a decision-making process it is always the invest decision regardless electricity price volatility. However, a decision maker should reflect these changes in the charging price for consumers to keep margin constant. The benchmark for electricity purchase price deviation is approximately 2% because this is the level when the margin starts to change significantly and influence the overall operational income.

Decision rule#2: if electricity price volatility is approximately 2%, then a decision maker should adjust the charging price for consumers to keep margin positive.

CAPEX efficiency rate: According to the sensitivity analysis, CAPEX efficiency rate has a significant impact on decision-making because of its high influence on the overall profitability. In the best guess scenario 9% CAPEX efficiency rate keeps overall investment costs on the expected level according to the strategy of Finnish Ministry of Economic Affairs and Employment (2016). Therefore, the next decision rule is suggested.

Decision rule#3: If CAPEX efficiency rate is more than 9%, then a decision maker invests in an expansion of infrastructure. If it is less than 9%, the recommendation would be to improve costs management and cost control to maximize CAPEX efficiency.

5.2 Public-private partnership

This section discusses major aspects of public infrastructure investments from the public-private cooperation perspective and identifies the role of the government. The findings of this part address the second research question *"How can regulatory policy minimize uncertainty in large CI projects?".* Based on that and previous findings introduced in literature review, the author suggest final recommendations regarding government support initiatives and policy, what flexibilities and options could be introduced and how cooperation with private sector may be considered for the public CI in Finland.

5.2.1 Description and best practices

Adetunji and Owolabi (2015) discussed that traditionally, infrastructure investments have been executed by the government due to low financial viability that comes from ignorance of managerial flexibility in an investment analysis. (Poole et al., 2014) highlighted that a very important role of the government is to make sure that within such unfractured projects all services focused on socio-economic benefits, are provided to a broader community. That is why, discussion and introduction of recommendations deserves special attention in this master thesis.

Today, the preferred model of public infrastructure investments is a co-financing that involves public companies' investments and governmental subsidies or funding (Bakker and Jacob Trip, 2013). Usually if private sector participates in public infrastructure projects, such cooperation is performed through a public-private partnership (PPP) (Adetunji and Owolabi, 2015). This is a form of a public-private cooperation characterized with a mutual exchange of possibilities and opportunities. It has become a very widespread method of executing infrastructure investments, especially in developing countries that pursue economic growth (Adetunji and Owolabi, 2016). In PPP, government's role is a facilitator of private investments execution and support. (Poole et al., 2014) claimed that such a role should be strengthened with policy regulations. The financial viability of infrastructure projects highly depends on a clear and structured government policy that is able to efficiently regulate private investments and anticipate risks and uncertainties. Besides, (Poole et al., 2014) also mentioned that overinvestment and underinvestment are results of a poor regulation policy that causes different project-specific risks and uncertainty. Therefore, policy makers should clearly support private investment with an introduction of a sound and clear regulatory policy, for example to provide pricing or regulatory requirements for efficient electricity supply. In fact, Finnish government subsidizes investments in the CI to encourage private investments thus constant development of sound regulations can attract more private investment and significantly contribute to a faster development of the CI.

(Adetunji and Owolabi, 2015) discussed that under PPP private companies are interested in obtaining returns. In the discussion about trade-off between public and private parties in infrastructure decision-making Schraven and Hartmann (2017) highlighted that public companies pursue particularly a commercial interest therefore it is necessary to set up the right balance between financial and public interests for both parties.

Therefore, together with development of policy regulations, favorable PPP clauses that minimize losses and maximize profits for each party, would also increase private investments and minimize uncertainty. Such condition may include governmental guarantees, fixed payments and real options. On the one hand, the fact that infrastructure investments are not financially viable (Poole et al., 2014), as it also has been demonstrated with the investment analysis of the CI project, real options allow to enhance the value of investments, cope with uncertainty, reduce necessity of fixed governmental support and attract more private investments to the project (Adetunji and Owolabi, 2015). On the other hand of PPP, there are many risks associated with a such partnership. (Araújo and Sutherland, 2010) introduces two key aspects that PPP do not guarantee investments efficiency in infrastructure projects. First, the overall result depends on a variety of factors such as risk sharing, contract conditions between government and private companies. Second, fiscal policy and macroeconomics can be weakened due to large liabilities.

Participation of private investors in PPP can be short-term or long-term. Short-term period lasts from 1 to 5 years, when private companies operate, maintain and manage the infrastructure. Long-term partnership is from 10 to 30 years when private companies perform as owners of infrastructure designing, financing and operating it (Adetunji and Owolabi, 2015). To further develop recommendations for the project, the CI project under PPP is considered.

5.2.2 Policy recommendations

The CI project in Finland is a long-term PPP (2017-2030) with combined public and private investments. Under PPP, private parties may perform as owners of CS and perform as E-mobility service providers (EMSP) and charging stations operator (CSO) (Madina et al., 2016). To support private investments and minimize uncertainties, application of real options is suggested as well as several policy regulations are introduced and applied to the CI investments:

- Because of electricity price volatilities and uncertain future demand (demand risk), electricity supply can be negotiated and regulated by the government with the use of **call option** that would give the right to buy a certain amount of electricity at a pre-determined price. And can be exercised when the demand risk is minimized.

- Private companies that take the ownership for building, operating and providing services to end users can negotiate for expanding the infrastructure in specific areas and regions in Finland under favorable conditions. Applying a **call option** to the agreement would that give the right to a private company to expand a charging network, ensuring its right to expand when the EV adoption rate enhanced.

- **Fixed government payments, cash support, grants** (Adetunji and Owolabi, 2015) or direct **subsidies** that support private parties financially. In Finland, currently the government subsidizes private investments in the CI with a fixed 4.8 million Euros for 2017-2019. For the further PPP cooperation, the government might agree on providing more support in fixed payments to ensure faster adoption of EV.

- **Government guarantees** may include **revenue guarantee** as a type of governmental support for private companies that guarantees minimum annual revenues to private investors (Adetunji and Owolabi, 2015). Specifically, for the CI project, a markup (0.21 Euros per one charge) that is a suggested constant value for 2017-2030 in CF model is a minimum guaranteed revenue fixed for private companies that build and operate CS. Another type of the government guarantee can be ensured based on issued forecasts regarding uncertain factors such as traffic or EV adoption rate forecast generated by Finnish authorities responsible for that. If the forecast is different from the reality, the government provides payments to a private company. The terms and conditions are identified by both parties (Poole et al., 2014).

- **Availability payments** are provided by the government if certain KPIs and quality parameters are met by a private party. For example, the government of Finland may provide quarterly payments to E-mobility Service Provider (EMSP) if quarterly quota of amount or newly constructed CS is met (Poole et al., 2014).
- **Construction cost guarantee** deals with uncertainty in investments costs (Adetunji and Owolabi, 2015). This may be presented as a real option that sets limits on investments costs and ensures that if investments costs exceed the set cost limits, no loss is expected.
- Ministry of Transport and Communications of Finland (2011) mentioned that a special influential factor on the efficient development of EV CI may be included in **building regulations** for property developers by having an opportunity to build CS in publicly available locations such as shopping malls, business centers, newly build apartments. This maybe be an obligation (Bakker and Jacob Trip, 2013) or executed as a real option to expand.
- **Risks anticipation and diversification** is expected from PPP with private financing, when risks are transferred to private companies with a higher required rate of return (RRR). For example, a private company can minimize construction costs by controlling the whole process timeline, avoiding delays and by having experts in CS design and technical issues (Poole et al., 2014). In contrast, Araújo and Sutherland (2010) suggest that in case of unexpected future demand, demand risk should not be transferred to the private sector but should be under control of the government that "*can retain service and policy flexibility and responsiveness to service delivery*". Besides, the government of Finland should make sure that the CI is introduced gradually in the regions with the highest traffic demand and at the best locations that would ensure open accessibility to CS even during inter-city journeys.

Furthermore, through these contract conditions, a real option imbedded in the CI project increased the value of the project and created numerous managerial flexibilities that deal with future uncertainty. For the CI in Finland, the growth option and time-to-build option are the most suitable solutions to deal with uncertainty. Incorporating these types of real options, irreversible investments can be executed in a time manner and staged according to the favorable market conditions.

A variety of companies in Finland already build CS across Finland. For example, Fortum Charge & Drive charging network that drivers could already see on some areas in Finland. In 2017 Fortum and OP Financial Group announced a new partnership that aims to build 100 CS in 80 locations in Finland[9]. With this partnership CS will be in the areas close of OP banks. Despite the fact that it promotes E-mobility in Finland, the partnership creates a win-win situation for both parties. (1) OP will fulfill the goal of the service diversification promoting the OP Kulku service, introduced in 2016, which allows drivers to use EV at a monthly fee. (2) Fortum Charge & Drive as an owner and an operator of charging stations obtains the right to build charging stations in the OP banks locations. As a result of this partnership, more OP's customers would find it convenient to use EV with a mobility services by OP and facilities by Fortum. It is important to motivate and encourage companies, banks, funds and possible parties to participate in such partnerships to promote E-mobility and create EV friendly environment.

Another example is that, the world largest EV parking is expected to be operated in Varma's head office in Salmisaari, Helsinki. The facility is 250 parking spots with FCS and smart charging facilities. Varma's Commercial Property Director Toni Pekonen mentions that *"charging stations will be needed in places where they spend extended periods of time"*[10]. Consequently, the tendency of growing charging network is very strong and with growing number of EV on Finnish road, a need for CS will become urgent.

Apart from encouraging private investments to the CI project, local incentives are one of the driving forces of rapid EV adoption. One of such incentives is an offering of free parking

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[9] Fortum. Fortum Charge & Drive and OP increase electric car charging stations by a third in Finland. Available at: https://www.fortum.com/en/mediaroom/pages/fortum-charge-drive-and-op-increase-electric-car-charging-stations-by-a-third-in-finland.aspx.

[10]Varma is preparing for the coming of electric cars: 250 chargeable parking spots under construction in Salmisaari parking facility (2017) Available at: https://www.varma.fi/en/other/newsroom/news/2017-q2/varma-is-preparing-for-the-age-of-electric-cars/.

for EV. While this method proved to be highly efficient, for example in Norway (Nørbech, 2013), there are some issues that might be considered before implementing it. Bakker and Jacob Trip (2013) in their study highlighted that 50% of EV use CS spots for parking only because the actual charging they do in private home CS that causes a parking occupation problem. Therefore, usually free parking is a temporary measure and in fact, this study mentioned that EV parking should not be completely free because the governmental goal should reduce traffic occupation in general and ultimately promote public transport in the cities.

One of the highly influential measures is giving a permission to EV drives to use bus lanes and limited-access roads. Giving the idea that traffic times can be minimized or completely eliminated, adoption of EV could grow dramatically. However, in the long-run control measures would be necessary to avoid traffic on bus lanes.

Generally, promotion of EV should be visible and attractive for protentional EV users (Bakker and Jacob Trip, 2013). Ministry of Transport and Communications of Finland (2011) also highlighted that large-scale EV adoption requires increase of awareness in the community through development of an information system that could provide explicit information and up-to-date information of available CS as well as support a mobile use of EV CI. Bakker and Jacob Trip (2013) suggested that CS should be visible as much as possible in the open spaces on the roads with an attractive design. Another interesting recommendation is a co-operation with auto retailers on an arrangement of EV test drives to let people get the EV driving experience. Cooperation with automotive companies as it happens in Germany and Japan (Quantu et al., 2012) may bring valuable results to the CI project, because recent models developed by worldwide automotive companies for EV launch were more flexible to contingent events and included specific EV model components that are adjustable to changes (Bohnsack et al., 2014).

In conclusion, development of the CI in Finland requires a variety of consistent regulatory measures towards public-private investments, risk management and incentives. However, to influence people’s decision on EV usage requires a more strategic approach and a direct cooperation with potential customers to raise awareness and ensure safe EV driving experience.

6 DISCUSSION

This chapter represents a summary of answers to two research questions, discusses theoretical implications and present practical implications for decision makers and policy makers based on key findings in the previous Chapter 5.

6.1 Answers to the research questions

Uncertainty determines conditions of infrastructure projects thus affects decision-making process dramatically. The aim of the first research question is to identify uncertainties that the CI project is exposed to and understand how they affect an investment decision making. The combination of research objectives and results assists in answering to this research question and present key findings.

- The higher uncertainty, the more structured, complex and thoughtful a decision-making process should be. Uncertainty and irreversibility of the CI dictate the rules of decision-making enabling a careful consideration of all risks, available resources, current demand, strategic locations for building the CI and other decisive factors. In the environment with limited information, investment decision-making becomes more complex.

- The key findings of real option thinking demonstrate that different types of uncertainty can be minimized with different types of real option types. As the scientific literature states (Triegorgis, 1993a Rose, 1998; Ho and Liao, 2011) that the incorporation of multiple real options simultaneously allows to minimize uncertainty more effectively thus makes an investment analysis and decision-making more complex.

- This research shows that uncertainty require a more thorough analysis. The correct uncertainty identification and embedded real options makes investment decision-making more flexible. From a simple "yes or no" decision-making, it transforms to a more analytical and better justified process of how investments should be done efficiently and effectively. In fact, it may require more forces to join in the form of technical or financial experts, legal advisors, analysts, private companies, partners. I addition, investment decision-making with incorporated flexibility can use "mid-course strategy corrections" and adjusted according to market conditions with real options (Adetunji and Owolabi, 2016).

Despite the negative attitude towards risks and uncertainties, factually it creates a favorable situation from decision-making perspective providing decision makers with an opportunity to conduct a deeper analysis, evaluation of current conditions, use “mid-course strategy corrections” (Adetunji and Owolabi, 2016) and invest gradually as time passes without investing all resources at a time.

The findings from the policy recommendations allow to conclude that uncertainty can be reflected by introduction of governmental measures under the PPP. It allows to minimize uncertainty by the provision of flexible conditions, under which private companies could perform better investment decision-making. Regulatory policy that meet commercial interest of public parties stimulate private to participate in PPP and provide private investment that allow to minimize risks and uncertainty of the project. In fact, that uncertainty in infrastructure projects might be mitigated by the legislation or commercial partnerships with other parties participated in a project to transfer risks (Yao and Jaafari, 2003). Therefore, the policy development under PPP is a key initiative that should be highlighted by the government to achieve better investment decision-making and mitigation of uncertainty.

6.2 Theoretical implications

Literature review of this master thesis helps to understand the scope of the academic approach to investigation of infrastructure projects. Uncertainty and irreversibility are the major conditions of investments in infrastructure projects (Dixit and Pindyck, 1995). Unlike the traditional DCF and NPV analysis that ignores managerial flexibility (Ho and Liao, 2011; Van Rhee et al., 2008; Trigeorgis, 1996) and works best in a risk-predicted environment (Yao and Jaafari, 2003), ROV has been found as the most effective method for infrastructure projects investment analysis (Adetunji and Owolabi, 2016; Poole et al., 2014). Especially, the innovative FPOM applies to complex investment projects under uncertainties (Collan et al., 2016; Collan, 2012). Investment analysis of the CI in Finland applying the FPOM and further analysis of investment decision-making for this specific project and market has been identified as a research gap of the thesis.

The results of this study demonstrate three key theoretical implications. First, the master thesis highlights the importance of the FPOM as ROV approach that helps to perform an investment analysis of infrastructure projects with limited information. This research is considered as an initial step in the investment analysis of the CI project in Finland and therefore can be taken as a basis for further investigation and extension by subsequent researchers. Second, the results of the thesis prove that investments in infrastructure projects should be considered as real options. The findings of real option thinking demonstrate a spectrum of future investment opportunities for the CI project and suggest concrete examples of real options that may be further analyzed by subsequent researchers. Third, investment decision-making under uncertainty based on the example of a growth options demonstrates that benchmarks may be used as a useful tool for navigating an investment decision-making process by establishing a step-by-step guiding model. This suggested framework might be considered by future researchers as a model for investment decision-making under uncertainty, adjusted and applied to a different type of a real option.

The results of the study narrow the research gap. Investment analysis of the CI in Finland provides a significant contribution to the application of FPOM to infrastructure projects under uncertainty. The method is proved to be an effective ROV approach that allows to evaluate future investment opportunities and consequently contribute to the investment decision-making. Hence, research objectives of this master thesis are achieved.

6.3 Practical implications

Infrastructure project can be considered as a multidimensional research-related field in the financial analysis. It may cover a variety of specific topics such as uncertainty and risk management, investment analysis, timeline planning, geographical representation, regulatory measures and standards, sources of financing and others. This master thesis attempts to elaborate on investment decision-making under uncertainty of the CI project in Finland and present policy recommendations.

This research represents key findings that reveal practical implications for decision-makers and policy makers. Results from investment decision-making allow to solve such dilemmas as (1) building CS in different regions simultaneously or in the certain order depending on the demand, times and resources; (2) participate in a co-financing with private companies or independently fund the infrastructure build-up in a certain region; (3) give the obligation to private property developers to build CS in public spaces or establish a public-private partnership (PPP) to support the efficient establishment of the CI; (4) provide free parking for EV drivers as a local incentive or partly charge drivers to avoid parking occupation problem and enable another revenue stream. Such approach gives more flexibility, time and an opportunity to test what works best and in some cases, to take a small risk. The consideration of investments in the CI project as a real option or as an opportunity for follow-on investments, gives decision makers the flexibility to think strategically and take the most benefit out of it. Analyzed growth option in this research shows how decision makers may consider extension of their investments in the future depending on the demand or investments costs, possible the CI placement (roads, inside or outside parking lots in shopping malls, office buildings), the type of CS (fast or medium charging; full electric vehicle, hybrid electric vehicle or merged) and other technical issues, financing, revenue streams, electricity supply conditions, PPP regulations and other factors that influence the decision. Eventually, the quality of the CI improves because of the thorough consideration of outside environment and actual need that lead to the open, accessible and well-planned infrastructure. By creating and providing such EV-friendly conditions, it raises the awareness in the society that EV is an ordinary transport for everyday use.

6.3.1 Decision makers

The first research question allowed to develop investment decision-making framework that is based on the introduction of benchmarks and decision rules. The decision rules that identify benchmarks are the guiding standards that limit uncertainty thus allowing decision makers to make justified and reasonable decisions on future investments in the CI. This method can be taken by the analysts and decision makers as a foundation for developing a structured and more sophisticated investment decision-making guideline involving more factors and inside information related to the CI in Finland, which is not publicly available.

6.3.2 Policy makers

Results presented in the policy recommendations have two practical implications. First, it suggests how infrastructure investments can be performed through public-private partnership in Finland. With introduced financial incentives and contractual conditions, policy makers can acquire a common knowledge of how public and private investments can cooperate to achieve an efficient co-financing for the CI project. Second, the findings suggest policy makers how to raise awareness of E-mobility in Finland and create a convenient environment for driving EV through governmental measures and as well as how to motivate private companies to participate in PPP based on the experience of other countries.

7 CONCLUSION

In this chapter, the summary and critical evaluation of the master thesis is presented with the research limitations and recommendations.

7.1 Summary

This master thesis investigates how uncertainty affects investment decision-making based on the CI project in Finland and evaluates future investment opportunities of the project with the help of the FPOM by considering the whole investment as a real option. Research of global perspectives on E-mobility and support of EV adoption globally and in Finland helped to identify the research problem, questions and objectives. The data gathering has been performed based on the literature review from three main perspectives. (1) EV CI business model that was the main source of data for the CF model. (2) The consideration of the FPOM as a suitable ROV approach for this study. (3) The application of ROV to infrastructure projects. Based on the findings, research gap has been introduced. Regardless the criticism towards DCF and NPV, conventional investment analysis with NPV is an important step towards the FPOM implementation for the CI project.

Major findings of this master thesis lead to the conclusion that the CI project's inherent managerial flexibility perceived as a real option identifies high potential of the investments in the future. Indeed, the CI project contributes to the large-scale adoption of EV that in return enables the socio-economic and environmental development in Finland, contributes to the GHG emissions reduction goal, renewable energy industry development and, in overall, the successful execution of commitments of the Paris Climate Agreement. The implementation of such strategic projects is more complex, and this study proved that inherent project's irreversibility and uncertainty should be treated with a thorough investment decision-making. The growth option applied to the CI project allowed to implement the step-by-step approach that maps managerial flexibility and guides decision makers based on the set benchmarks and decision rules applied to the CI project. The introduction of policy recommendations allowed to address the second research question and identify how policy regulations can mitigate uncertainty and improve the decision-making process. Despite minor limitations presented further, the research questions are addressed, and research objectives are considered as completed. This research does not intend to completely solve the problem introduced in this research earlier but provide a foundation for further investigations.

7.2 Research limitations

The paper has limitations to data used for the analysis. First, the author's knowledge is limited to technical characteristics of CS and is exclusively based on the theoretical background collected from previous scientific literature (Madina et al., 2016; NPE, 2014; Schroeder and Traber, 2012). Furthermore, data limitations are associated with the lack of available statistics on the EV adoption rate in Finland. Therefore, forecasted CF of future demand and electricity supply may be biased. Scarce scientific literature on the CI for the Finnish market limits the research to the use of data and best practices in the implementation of the CI in other markets such as China, Japan, Israel (Qiantu et al., 2012), Germany (Gnann et al., 2015), Norway (Nørbech, 2013), United States (Schroeder and Traber, 2012), Finland (Markkula et al., 2013) and others. Therefore, these data assumption may not be suitable for Finnish market due to different regulations and price levels.

Moreover, in this research types of EV are generalized and were not distinguished due to data limitations and simplified CF projection. Ministry of Transport and Communications (2011) highlighted that in Finland driving distances are long thus plug-in hybrid EV can be more suitable and cost-efficient. This fact might affect the cost analysis of the research and can be perceived as a recommendation for further investigations.

Another limitation is associated with the sensitivity analysis. The method is limited to a one changing input at a time that does not create realistic circumstances, where several factors change simultaneously.

With regard to the scope of the study, the obtained results allowed to achieve research objectives and elaborate on the research questions. The intention of the study was to contribute to the existing research gap and despite limitations, the study contributed to the scientific progress and narrowed the excising research gap.

7.3 Recommendations for further research

Based in the research findings, implications and limitations, the recommendations are developed for further investigations. This research serves as a basis for further investigation in the field of public infrastructure investments, regulatory policy for the CI project, investment decision-making under uncertainty on the CI project in Finland and application of the ROV approach based on the FPOM. These aspects appear to be of particular interest.

- The public-private partnership financing on large infrastructure projects. How to achieve an optimized co-financing to mitigate risks and uncertainties in infrastructure projects. How real options can contribute to risk sharing in charging infrastructure investments under a private-public partnership?
- A qualitative interview study can be conducted with decision makers with the focus on a research question: What supportive measure for E-mobility would facilitate implementation of the CI in Finland: effectiveness, efficiency and feasibility of policy measures?
- A framework for investment decision-making under uncertainty. Formalization of non-monetary and qualitative factors into decision analysis of the CI project.
- Investment decision-making under uncertainty with application of multiple options on the CI project and analysis of their interaction: an interaction of a growth option and time-to-build option of the CI project in Finland. How multiple real options affect an investment decision-making process of large infrastructure projects?
- A real option to stage for the investment analysis of the CI project. The use of the FPOM as a method for value of real options on different stages of the project. How does a real option to stage affect a decision-making process of the CI investments in Finland?

Further research in the field of investment decision-making under uncertainty of the large public infrastructure projects can be investigated based on this master thesis. The findings of the study have shown that the fuzzy pay-off method (FPOM) has significant theoretical implications, therefore subsequent researchers are recommended to apply this method on the investment analysis further in investigations of large CI projects. In additions, an extension of this study with suggested topic above may enhance practical implications for policy and decision makers.

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