A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

Fuel Efficiency in the 21st Century: Identifying Drivers and Barriers for E-Mobility Integration at the Budapest International Airport

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July 2011

Budapest

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ABSTRACT OF THESIS submitted by:
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for the degree of Master of Science and entitled: *Fuel Efficiency in the 21st Century: Identifying Drivers and Barriers for Electric Vehicle Integration at the Budapest International Airport.*

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The 2010 European Strategy on facilitating the introduction of more environmentally friendly and efficient vehicles addresses the necessity to prevent the road transportation pollution. This Strategy discusses the electric vehicle re-introduction that originated several years ago as one of the solutions. This thesis investigated the drivers and barriers of integrating electric vehicles into the Budapest Airport operations in order to reduce GHG emissions produced by the transportation sector and to generate savings. The research question investigated whether the EV technology could satisfy those goals.

The key objective of this study was to facilitate the exchange of experiences between the Frankfurt, Vienna and Budapest International Airports. The two successful case study airports of Frankfurt and Vienna provided crucial information on the drivers and barriers associated with the EV integration into their daily work. The main barriers were the high investment cost of the vehicle and battery, lack of major governmental incentives to purchase the EVs and not standardized expensive infrastructure. The key drivers included the GHG emissions abatement, air quality enhancement, cheap electricity as a fuel, predictability for the airport short-distance Ground Support Equipment sector and avoidance of the energy security issue of fossil fuel.

In the end, the study determined that the electric vehicles were suitable for the Budapest Airport since they can yield financial savings and emissions reduction within the short distance – low speed transportation sector at the Budapest airport. More research will have to be done on the long distance – high speed sector.

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Keywords: Electric vehicles, integration, airport, GHG emissions, drivers, barriers, energy security

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List of Abbreviations

ACA	Airport Carbon Accreditation
ACI	Airport Council International
BEV	Battery Electric Vehicle
CNG	Compressed Petroleum Gas
CO2	Carbon Dioxide
ELMU	Hungarian electricity provider company
EU	European Union
EV	Electric Vehicle
GH	Ground Handling
GHG	Greenhouse Gases
GSE	Ground Support Equipment
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
LPG	Liquefied Petroleum Gas
PEV	Pure Electric Vehicle
PHEV	Plug-in Hybrid electric Vehicle
R&D	Research and Development
RES	Renewable Energy
UNFCCC	United Framework Convention of Climate Change
VAT	Value Added Tax

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1. Introduction

1.1 Background

Within the scope of climate change research and European policy focus on finding measures to reduce the national GHG emissions, e-mobility comes as a promising solution that could revolutionize the road transport, improve air quality and potentially reduce the amount of fuel import (COM (2010) 186; COM (2007) 19; COM (2008) 17; Harrop and Das 2011; Reiner et al. 2010; Kobayashi *et al.* 2009). Electric vehicles (EVs) currently have a small market of vehicles available for purchase, however, for many analysts the pure electric vehicles hold the future of the road transportation sector and will manage to reduce direct CO_2 and GHG emissions by means of substituting the conventional vehicles. Currently most of the existing literature within the field of EVs concerns the technological aspects of the light personal vehicles that can be utilized primarily within the urban setting. However, not much data is available for discussion of the fate of electric engines inside the heavy-duty vehicles that would discuss the electric engines inside heavy-duty equipment or passenger-designated vehicles such as buses or vans both on the international and European level.

At the moment, many small-scale pilot projects are carried out all over the world, which test the EVs potential to reduce GHG emissions and assess the level of customer satisfaction with this technology. However, the urban setting is sometimes too large of a territory to integrate the electric vehicles since it would also mean immediate introduction of the costly charging infrastructure that is needed to support the engines of the vehicles. This is why it would be more interesting and feasible to look at integrating e-mobility primarily at the large organizations or companies that have their own vehicle fleet of various types of equipment (heavy duty and light commercial vehicles). These companies should also be disseminated across the urban setting for the start of e-mobility integration. Thus, the more organizations are involved in installing the charging infrastructure on their premises, the more possibility the urban setting has to cover different areas of the city with the available options for the EV owners to charge their vehicles. One such company that operates a large area and has several vehicle fleets that are constantly employed throughout the day is an international airport (Clean Airport Partnership 2001).

This setting would allow for testing the electric technology inside a relatively small area and make the airports benefit from the overall reduction in the airport ground emissions and significant drop in fuel price

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(ACI Europe 2010, ICCT 2010; McKinsey 2009). Currently the international airports are very preoccupied with the issues of environmental health and safety and look for ways to reduce their overall expenditures on the ground support equipment (GSE) operations (Clean Airport Partnership 2001; ACI Europe 2010). Moreover, today the concept of the alternative fuel becomes a hot topic due to the lack of fuel price stability and energy security within the oil sector since the oil reserves globally are distributed in an uneven manner and might eventually become scarce (FIA 2011; Harrop and Das 2011). Thus, the small-scale integration of electric vehicles at the airports will be the precursor to the major shift in a global mindset in terms of using alternative fuels and renewable energy in order to address the acute issues of air quality and environmental health that challenge the conventional road transportation sector today.

1.2 Research justification

Nowadays the majority of the international airports all over the world are concerned with the improvement of their efficiency by means of addressing their overall performance, energy and electricity demand as well as capacity prospects (Clean Airport Partnership 2001; ACI Europe 2010). While the remodelling of each terminal or hangar might pose a serious threat to the normal operation of the airport and become a financial burden, the substitution of the airport fleet with the EV technology can potentially provide for a major energy efficiency measure (Gillen and Neimeier 2006). Given the ACI projections of the 41% increase in the overall passenger load for major international airports in the EU, one can expect a rapid growth of aviation services and associated ground vehicle services as well as the overall expansion of the airports (ACI Europe 2010). By the year 2030 more than 29 EU airports will most likely suffer from passenger overload and handle twice as many aircrafts as they process today. This increase will have a direct effect on growing energy expenditures and fuel consumption by various working sectors within the airport infrastructure and hence will most likely result in a tremendous increase in internal and external operating expenses such as fossil fuel and energy use, which will result in much more harmful emissions (ACI Europe 2010). Expensive oil dependence of the current heavy duty and light vehicle fleets at different airports contributes to the amount of GHG emissions and results in exposure of designated workers to diesel fumes (Directive 2009/104/EC; ACI Europe 2010). Hence, it is crucial to focus on the long-term planning in order to consider the steady increase in oil prices associated with resource depletion and to provide for the EV integration into the daily airport operation scheme. Additionally, EV integration may be a smart move towards complying with the potentially strict international and national regulations within the field of airport emissions that might emerge given the general concern with the global climate change (COM (2011)144,

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COM (2008) 30; FIA 2011; Directive 2007/46/EC). Currently many international airports are devoted to joining various eco-certification schemes that would allow them to become "green" or "zero carbon" in order to eventually attract more benefits such as customers, investments and valuable workforce (ACI Europe 2010).

So far the integration of EVs concerns mostly the characteristics of the urban setting rather than a limited amount of land designated to a specialized company. Thus, it is crucial to look at companies that employ a large fleet of vehicles on a daily basis in a rather confined space, which they could modify and renovate according to their preferences (Harrop and Das 2011; Gillen and Neimeier 2006; ACI Europe 2010). This way, airports present one of the best grounds for the implementation of EVs since they are capable of changing their infrastructure and planning new transportation routes for the apron. EVs are entitled to have an easy access to the charging infrastructure, which the airport officials could invest in to provide for the combined use of the EV fuelling options for both staff and passengers. Additionally, allowing for a merged use of the charging infrastructure would help the municipality to promote EVs for the city use and eventually expand the network of charging stations (Clean Airport Partnership 2001). Thus, this research is not only designated for the sole use of the airports, but also for consideration and urban planning of the local government. Considering an internal charging infrastructure on its premises the airport will provide for its energy security and ability to run EV fleet on a constant basis (ACI Europe 2010).

At the moment many European airports investigate the e-mobility application to their settings, yet no coherent study has been made on the already existing successful projects within the EU. This research will fill in this information gap and explore various drivers and barriers associated with the EVs operations for the consideration of Budapest Liszt Ferenc International Airport based on the experience of two successful case studies described within the Methodological Approach section below. The necessity to perform this research was clearly identified during the original preliminary interview that I conducted with the Head of the Environmental Development (Ferenc Kis) at the Budapest Liszt Ferenc International Airport. During this interview Mr. Kis was explicit about the goals of the airport to minimize the overall fuel consumption of the ground transportation due to primarily financial and environmental reasons described further in this research. Additionally, this study provides guidance for other interested international airports that might consider integrating EVs into their everyday operations within the foreseeable future. The present research also facilitates

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the interactions between different airports, provide a platform for sharing knowledge and bring back valuable experience of other parties to the Budapest International Airport.

1.3 Research Problem

This thesis fills in the missing information within the field of EV integration into the daily operations of international airports within Europe. Currently there is no real direct partnership or cooperation between the successful airports with EV fleets and airports that are interested in EV integration, which would allow for development of an effective approach towards reaching an overall carbon neutrality within the foreseeable future by European network of large airports (ACI Europe 2010). Although currently there is a developing interest within sustainable electro-mobility with the European legal framework, little research has been done on large companies such as airports, which currently represent the best grounds for introduction and successful implementation of EVs due to their financial and area capacity and increasing interest in the fuel efficiency.

1.4 Research Questions and Objectives

The key objectives of this research is to facilitate exchange of experience within the field of EV integration practices between the selected airports and provide a platform for a successful EV integration at the Budapest Liszt Ferenc International Airport based on the concepts that emerged through analysis presented in this paper. Additionally, the purpose of this work is not to solely support the findings of the literature review with those of field research but rather to identify new emerging concepts that would provide a more in-depth insight into the EV integration experience. In order to fulfil these objectives, the following sets of questions were identified and answered through this research.

The key research question is formulated in the following way:

Does the EV technology respond to the requirements of the Budapest Liszt Ferenc International Airport for adequate reduction of Green House Gas emissions (GHG) from the ground transportation fleet and feasible elimination of financial burden associated with conventional fuel consumption of the fleet?

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In order to answer this question, this research paper investigated two case studies of Frankfurt and Vienna International Airports, which already had major experience in working with EVs within various sectors of airport operations. Interviews conducted with these airports focused on the following set of key s**ub-questions:**

1. What were the original incentives for EVs implementation at each airport?
2. What is the experts' assessment of current application and reliability of the EV technology within the airport sector?
3. What are the prospects of the EVs in a long-term for the airports?
4. What are the key drivers and limitations of this innovative technology that wil affect feasibility of EV integration at the Budapest Liszt Ferenc International Airport with regard to the assessed case studies?
5. How do the airports address the issue of "green" electricity production for EVs? (nuclear, coal, natural gas, renewables, etc.) Are they preoccupied with shifting the fuel emissions load onto the conventional powerplants?

1.5 Scope of Thesis

This research was built around specific geographical and communication boundaries. Geographical boundaries of this thesis include the Frankfurt International Airport in Germany, Vienna International Airport in Austria and Budapest Liszt Ferenc International Airport in Hungary. This boundary was established due to the fact that 75% share of the Budapest Airport belongs to a German airport company HOCHTIEF, which is oriented towards rapid expansion of the infrastructure according to the most efficient western experience (Budapest Airport Zrt. 2011). Consequently, this study also investigates various international and local policies applicable to the EV integration at those specific locations.

The "communication scope", i.e. the professionals chosen for this study are affiliated with the Environmental Departments and Ground Handling Services at the mentioned airports as well as German and Hungarian experts on the charging infrastructure potential within Budapest in order to devise drivers and barriers for EV integration.

The discussion of this thesis is limited to collecting and understanding the drivers and barriers to EV integration that are identified by the preliminary research and further interviews with top-experts at the airports of choice. According to the previously identified objectives, this study does not focus on the opinion of the government (or academia) since EVs are not

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their current primary focus and no strict environmental regulations concerning the ground transport at the airports currently exist (COM (2010) 186). Besides, the airport structure resembles the legislative and executive branches of the government where the feedback system is heavily practiced between different departments.

The scope of the methodology was pre-determined by a thorough primary analysis of the currently available policies within the EU and various secondary materials such as articles, publications and news related to the EV topic. The present research explores the phenomenon from the inside of the professional circle since at the moment no other outside specialist could evaluate the potential of EVs during daily operations within this infrastructure. There is no comparison presented between EVs and other alternative fuels such as biofuel (natural gas, bioethanol, etc.) since this study investigates only the "green electricity potential" within the ground transportation sector at the airports.

1.6 Theoretical Framework

Before we can discuss the theory that underlies this research, it is imperative to understand that the regulation of the airport infrastructure is a complex system based on the feedback mechanism between different functioning units and departments. Despite major EU and national environmental regulations of aviation and airport functions there is also an internal management of the airport, which is carried out by the Environmental Services Unit (Budapest Airport Zrt. 2011; Frankfurt International Airport 2011; Vienna International Airport 2010). Since the current regulation focuses mainly on aviation regulation and yet does not introduce strict regulations on the ground vehicle emissions and functions at the airports, airports develop their own set of internal rules that are influenced by major environmental guidelines for ground transportation sector. Thus, the general airport infrastructure in itself has legislative and executive bodies, where the Environmental Unit is responsible for introducing regulations and rules for the use of ground equipment, which the Ground Handling (GH) services and consequently airlines that use GH services have to comply with. At the same time, the executive bodies have a direct feedback loop response to any new regulation introduced by the airport by altering the prices of the airline tickets, usually not in favor of the customers (Figure 1). Thus, any additional expenses undertaken by the GH services will automatically increase the prices of the airline tickets.

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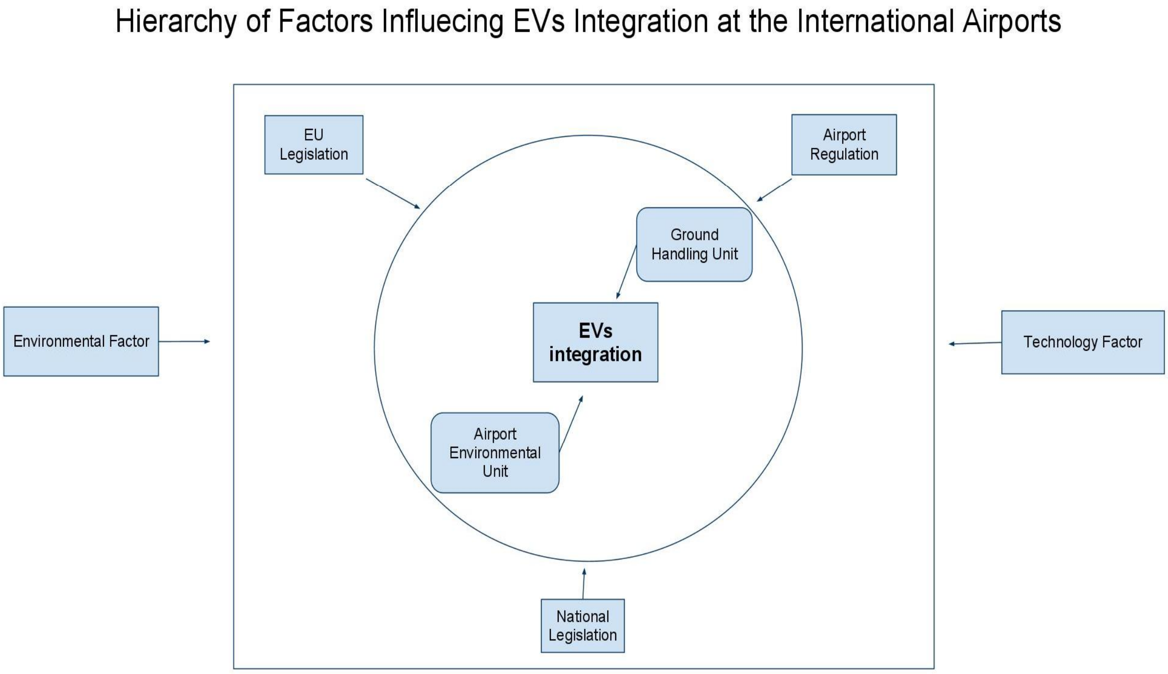

Figure 1. *Relationship between crucial variables affecting the implementation of EVs.*

Figure 1 presents the theoretical framework of this thesis and shows the interconnection of different regulation systems with the Environmental and Technological factors. In this case, the Environmental factors include vehicle fleet emissions and overall environmental load of the oil use, whereas Technological factors contain evolution of EV batteries, availability of charging infrastructure and overall capacity and availability of modern vehicles. The circle system inside the scheme shows the interconnection between the Environmental Services Unit and the GH services that have a direct effect on the potential of EV integration. The rectangular shape outside the circle shows how the feedback system between current legislations affects each parameter and the departments within the circle. The present study will explore the interaction between the above-mentioned spheres and identify the most important barriers and drivers within the EV integration for the airports at present.

As for the theory underlying this framework, this thesis utilizes a theory that is called the “Technological Innovation Systems" or TIS (Speirs *et al.* 2008). This theory underlines and explains a global concept of any new technology development and exploitation especially from the point of view of the actors that participate in overall development of that technology (mostly companies). These companies have a direct influence on the technology through their demand, where the most utilized item, in this case vehicle will become mass-produced and

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popular. TIS theory also investigated the reasons that underlie either a success of a technology or a complete failure. In particular, TIS can be successfully applied to understanding the sustainability of a particular technology, in our case EVs and its fate within the context of social application at present and in the future. This theory gives this research a valuable insight into direct and indirect interactions between different actors such as companies, which have a direct influence on the e-mobility integration. This research identifies a necessity for a direct interaction between different airports in order to provide for experience sharing within the field of EV integration.

This research oriented its conceptual framework towards analyzing potential drivers and barriers of the phenomenon and included a thorough study of international and national policies, interviews with the experts and two case-studies of successful EV integration into airport operations.

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2. Methodology

2.1 Methodological Approach: Preparatory and Research Stages

This thesis utilizes a combination of deductive and inductive approaches to conducting research where the concepts and theories arising from the analysis were supplemented by those derived from the literature review in order to comprise a complete understanding of the phenomenon of EV integration at the airports of choice (Punch 1998; Jones 1996: Creswell 1994). The key goal of the methodology section was to qualitatively assess the current opinion of the Budapest Liszt Ferenc International Airport experts towards the implementation of the EVs and provide a valuable insight of successful EVs application by means of conducting two case studies with the Frankfurt International Airport and the Vienna International Airport. In order to design a valid framework a qualitative methodological approach was used in order to address the originally posed research questions. One of the research questions was to identify the key figures involved in a successful implementation of EVs at the Vienna and Frankfurt International Airports in order to analyze their experience with a further intention to apply that knowledge for the Budapest Liszt Ferenc International Airport. I intended to couple my observations and concepts derived from the preliminary literature review on policies and implementation aspects (*Preparatory stage*) with the interviews targeted at assessing current potential and openness of the Liszt Ferenc Airport towards the concept of EVs operation (*Research stage*). Qualitative interviews became the major backbone method to achieve valuable information from both Liszt Ferenc Airport and the two case studies.

2.2 Preparatory Stage: Literature Review

Prior to structuring the interviews with the experts this study performed an extensive preliminary literature review in order to identify some “overarching” concepts and themes associated with the EVs in general (Punch 1998). Since the major part of all available information was focused either on urban setting integration of EVs, I additionally addressed major airport websites in order to familiarize myself with the intentions of the airports towards EVs implementation expressed in annual online environmental reports. Additionally, scholarly articles and various technical publications were assessed through main online databases such as Springerlink, EBSCO research database, ScienceDirect, CEU electronic library, Google Scholar and Google books. As for the legal policy documents, this research paid particular attention to the Environmental Reports of assessed airports, The European Union's Common

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Transport Policy (CTP), Airports Council International (ACI), SESAR (former SESAME) and European Commission Mobility and Transport related documents (ACI Europe 2010; COM (2010) 186; COM (2011) 144; Fraport 2011; Budapest Airport Art. 2006; Vienna International Airport 2009). Thus, the literature review helped establish the main research focus that concerned heavy duty and light electric vehicle fleet examination and charging infrastructure at the three airports of interest.

2.3 Research Stage: Case Study Approach

The two case studies for this thesis were chosen according to the criteria of the most successful implementation of EVs. The use of case studies in this research is not going to serve the purpose of simple generalization but rather become a strategy to understand the complex nature of the phenomenon within the similar context yet in different geographical locations (Punch 1998). At the same time, the application of two case studies in this case will allow for the Budapest airport to familiarize itself with the successful experiences of its counterparts and draw valuable lessons for EV integration process. Hence, the case studies of the Frankfurt and Vienna International Airports are used as a research strategy rather than just a method (Punch 1998). Despite a traditional sceptical view on the “generalizability” of the case studies expressed in Punch (1998) and Creswell (1994), the case study approach is crucial for this thesis since it allows to explore a poorly investigated phenomenon of e-mobility at two different airports such as Frankfurt and Vienna ones in depth by interviewing the experts within Environmental Health and Safety and Ground Handling Department which have the power to choose the most suitable technology for the airports according to their experience. Most of the information gathered during the interviews will be subjected to some generalization, which will apply only to the airports under study, specifically their Ground Handling services and Environmental Health and Safety Departments.

In order to conduct these two case studies the author used special interview tactics described further.

2.4 Interviews

I found it necessary to focus specifically on the information provided by the experts within the airports and the provider company in Hungary since currently no strict regulations on EVs exist and the advice that could have been provided by other parties would have

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probably deem irrelevant to the objectives of this work. The choice of experts proved to be adequate since they were able to pinpoint the key drivers, limitations and barriers to the EV exploitation at the airport based on their experiences and responsibilities rather then just on standard published materials (Punch 1998). They were also able to pinpoint some negative aspects in using EVs compared to the insight of rather positively structured literature reviews about the field. Finally, they provided a valuable feedback into the environmental and financial feasibility of the project since the work of airports is primarily oriented towards the pleasure of the customer where efficiency of operations and the environmental concern become a secondary focus.

This qualitative research employs in-depth topical semi-structured interviews with ten professionals within the field according to the snowball sampling method (Punch 1998; Jones 1996; Creswell 1994). In the snowball sampling a researcher accesses most of the valuable contact experts from other sampled professionals in a reference manner. The snowball sampling of interviewees for the case studies was determined based on the reference to their professional expertise in EV integration. As for the interviewees at the Budapest International Airport, they were also identified according to the snowball technique according to their direct involvement in deciding upon the current vehicle fleet faith. Before each interview all of the interviewed experts approved of the public use of their names and opinions in this thesis (Jones 1996).

Ideally, the snowball method or the “chain referral sampling” should lead to the so-called “saturation point” when most of the data has already been mentioned and begins to repeat itself during new interviews (Jones 1996; Punch 1998). This “saturation point” was reached during this research. Prior to originating my interviews, I prepared a list of approximate questions for both the case studies and the Budapest Airport interviews, which can be found in Appendix I. Yet it is imperative to remember that the semi-structured interviews imply open-ended questions and therefore not all of the questions could be answered in one interview. I organized follow-up sessions when I needed to collect lacking information that was necessary for the analysis. In-depth interviews based on this principle allowed me to research the EV phenomenon more thoroughly based on the lifetime experience of people who know the principles of EV work or are actually involved in their implementation.

Names and affiliations of the interviewees used in this study are shown below.

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ELMU (Key electricity provider, Hungary)

Ms. Katja Reimann, Corporate development directorate, Business expert

Mr. Szabolcs Tokei, Corporate Development Directorate, Senior corporate development associate

Effective communication with these experts allowed for an overview of charging infrastructure and EVs potential at the city of Budapest and gave some insights into opportunities of the Budapest Airport.

Budapest Liszt Ferenc International Airport

Mr. Ferenc Kis, Environment, Health and Safety Department, Head of Environmental Development

Ms. Zsuzsa Munkácsi, Environment, Health and Safety Department

Mr. Kis was the key contact throughout the entire study and provided an extremely valuable insight into the work and perspectives of the Budapest Airport. I conducted several follow-up interviews with Mr. Kis about the EV integration topic, which allowed for an in-depth understanding of the topic.

Malev Ground Handling (GH) services, Budapest Airport

Mr. Csaba Szanislo, Head of the Vehicle Department

Mr. Szanislo provided a valuable insight into the general characteristics of vehicle fleets owned by the Malev GH company and also conducted a tour around the facility in order to demonstrate the vehicle capacity and areas susceptible for a change.

Celebi Ground Handling (GH) services, Budapest Airport

Mr. Ibrahim Ediz Ozkahya, Project Manajer

Mr. Istvan Gerenyi, Logistics Manager

Mr. Ozkahya and Mr. Gerenyi showed another important perspective of a licensed GH company at the Budapest International Airport towards the idea of EV integration into their daily operations. Mr. Gerenyi was also able to provide an overview of the currently available technology.

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Case studies

Frankfurt International Airport

Mr. Andreas Eibensteiner, Fraport AG Environmental Management

Mr. Boris Weber, Fraport Ground Services Ground Support Equipment, Project Manager GSE

Mr. Eibensteiner delivered a very interesting overview of the Frankfurt International Airport functions and EVs operations. Mr. Weber also was so kind as to provide a tour around the airport's apron and identify diesel vehicles vs EVs.

Vienna International Airport

Mr. Johann Nichtenberger, Ground Handling Contracts and Purchasing

Mr. Nichtenberger provided valuable information from the point of view of both Ground Handling services and Environmental Department due to the busy schedule of the Vienna Airport contact experts.

2.5 Data Analysis

Originally the literature review pre-determined the overarching concepts associated with the EV integration in general (Punch 1998). List of those themes was used in order to provide a backbone for the interview analysis, yet the analysis also looked for the newly emerging concepts and themes that were not mentioned in the list. Thus, the transcribed interviews were thoroughly analyzed using both the selective pre-determined list of concepts and the "open coding" that searched for new concepts. The author looked for any data that could potentially refer to either drivers or barriers to the EV integration within the field of interest. The results obtained from the two case studies were compared to each other in order to find similarities and differences within the responses of the experts. The results were grouped into the most suitable categories that were identified through the literature research and through grouping of the responses I found the most interesting. I compared the responses of the two case study airports (the Frankfurt and Vienna Airports) in a table and further analyzed the drivers and barriers within each overarching category in Chapters 7, 8 and 9 of the research analysis section.

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After the analysis of the case studies I performed the same procedure with the interviews from the Budapest International Airport in order to produce a comparative analysis of the drivers and barriers identified at the Budapest airport and at the case study airports in order to assess the effectiveness of e-mobility at the Budapest airport. Finally, I also analyzed the interviews received from the ELMU electricity providing company, which allowed me to draw the recommendations and conclusions for the city of Budapest in terms of potentials for EV integration.

2.6 Justification of Validity, Reliability and Representativeness

In order to account for the validity of collected data this research chooses to triangulate the data (Punch 1998). Triangulation involves the selection of several (at least three) different methods of inquiry that would allow for data cross checking. This method resulted in using the data from literature review research, case studies and in-depth interviews as well as field observations (Punch 1998). Additionally, triangulation allows for a better picture of the phenomenon given many data sources were used and the data analysis was performed according to the standard protocol described in Creswell (1994) and in Punch (1998). This thesis aims at being a benchmark for both the Budapest International Airport as well as other interested airports in assessing benefits and issues of integration of EVs and therefore it needs to present a credible set of data based on expert experiences. Finally, this work will be submitted to the Environmental Health and Safety Department at the Budapest Airport in order to provide recommendations and overview of successful practices within EV integration at Frankfurt and Vienna International Airports.

2.7 Limitations of the Research

This thesis presents an exploratory study approach and therefore I encountered many difficulties on the way to establishing a completely new analytical framework due to the lack of available literature within the field of electric vehicles at the international airports.

Due to the time constraint it was rather difficult to establish contact with the interviewees yet I managed to get the best representative sample for this study. Prior to the actual interview, I had to conduct a preliminary phone research that helped me identify the availability of the suggested contact person. Whenever the experts that could not manage the meetings, I requested for a knowledgeable substitute experts that could provide the same information to me.

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The interview conducted in Vienna had to be postponed due to the harsh weather conditions and posed some issues for me in obtaining the necessary information. Thus I had to postpone the meeting and the consequent analysis until the end of June since it was the most suitable timing for the interviewee.

Additionally, not every interviewee managed to respond in the same exhaustive manner to all of my questions, which is a typical phenomenon in qualitative research methods that was described by Punch (1998). In order to avoid the lack of information from some experts I followed the publication's recommendations to follow-up on the interviews with the email conversations yet sometimes it was too difficult to receive a response for the posed questions due to the lack of time of the experts.

2.8 Research Structure

Chapter 1 describes the background of e-mobility and presents the objectives and research questions as well as the scope and theoretical framework that were developed in this thesis.

Chapter 2 presents the methodology approach that was used in order to obtain information that would answer the stated research questions and satisfy the objectives of this work.

Chapter 3 explains the background of the EVs in Europe in general and then proceeds in discussing the current situation within the EV sector at three selected airports. This chapter reviews the concept of energy efficiency at the airports from the perspective of European fuel security and the role of Evs in emissions abatement.

Chapter 4 discusses the technological properties and characteristics of various electric batteries used in EVs today. This section is crucial for further understanding of technical discussions during interviews that touch upon the life of vehicles and their performance compared to regular diesel or gasoline vehicles.

Chapter 5 analyses the current market for electric and hybrid vehicles in order to explain the reader the issues associated with the production and purchase of this technology.

Chapter 6 presents the combination of secondary sources research followed by analysis of the existing policies on the international European level and also national levels of Germany,

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Austria and Hungary that evaluates the interest and focus of the existing legislation towards the potential integration of e-mobility into different settings (urban, airport, etc).

Chapter 7 demonstrates the main body of the analysis section where the collected data is thoroughly analyzed and major barrier and limitations are established for the e-mobility introduction into the airport operations based on the interviews with previously mentioned experts from the two case studies – Frankfurt and Vienna International airports.

Chapter 8 applies policy analysis together with the drivers and limitations identified within the previous chapter to the case of Budapest International Airport in order to assess the potential for the e-mobility integration into this airport's daily work.

Chapter 9 focuses on the e-mobility potential of the city of Budapest and discusses the value of e-mobility integration of the Budapest International Airport for the urban areas of Budapest based on the interviews conducted with the experts from ELMU electricity provider company.

Chapter 10 identifies the most realistic recommendations for the Budapest Airport in terms of EVs application on its premises and overviews potential development pathways for e-mobility at the airport as a part of the larger urban setting such as Budapest.

Chapter 11 reviews and summarizes all of the conducted research and presents concluding remarks on the research itself and discusses further investigation of e-mobility prospects that will need to happen within the Environmental Health and Safety Department and the GH Companies at the Budapest airport.

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3. Concept of E-mobility in EU and Case Study Airports.

3.1 History of E-Mobility

First electric vehicles appeared before the internal combustion engine at the end of the 19th century (Harrop and Das 2011; EUCAR 2009; Offer *et al.* 2011). The electric vehicles used to be rather popular prior to the development of the oil industry, when the idea of using electricity for the vehicle movement was left behind. EVs could cover the distance of approximately 30 to 40 kilometers maximum and were very slow and expensive. The principle of EV operation differs completely from the ICE vehicle since there is no burning process associated with energy release and this way no GHG emissions are generated while the vehicle drives (Taylor 2008). The typical EV relies on some sort of a rechargeable battery that is capable of holding the electric charge for some time and to thus generate power that would propel the vehicle (Harrop and Das 2011; Kobayashi et al. 2009; Van den Bossche et al. 2005; EUCAR 2009). It is completely different from the common ICEs where the energy responsible for moving the vehicle is obtained through burning the fossil fuel and is accompanied by release of various pollutants into the atmosphere through the tailpipe. The EVs, however, are almost entirely emission-free during their operation mode. However, if the electricity comes from the coal power plant it would still yield indirect GHG emissions that would be attributed to the electric vehicle (Harrop and Das 2011; FIA 2011; Thiel *et al.* 2010). Thus, 100% reduction of emissions will only be possible for the EV given it uses the electricity produced from the renewable energy source (Directive 2009/28/EC; Meyer *et al.* 2007; Thiel *et al.* 2010; ICCT 2010; Lipman and Delucchi 2002).

Apart from the lack of direct emissions from the vehicle, electric engine preserves the energy better than the ICE and avoids any potential losses during the vehicle operation. As for the internal combustion engine, the actual movement of the car requires approximately 15% of the energy obtained from burning the fossil fuel, whereas almost 60% is lost as heat, or wasted due to the aerodynamic issues and other processes that take place within the vehicle engine (Kobayashi et al. 2009; Taylor 2008). However, today the overall energy efficiency of the ICE steadily increases due to the competition between the recently produced vehicles on the market. This way, the competition between the energy efficiency of the electric engine will always be compared to the energy efficiency of the advanced gasoline or diesel vehicle that relies on the tested predictable ICE technology. The main difficulty of the electric vehicle

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market is to prove the reliability of its products, establish an attractive price and to provide suitable charging (Sovacool and Hirsh 2009; Harrop and Das 2011; Reiner *et al*. 2010).

In this case, the only option for the quick promotion of the EVs would be the top-bottom approach of decision-makers who are concerned about the present emissions from the road transport (COM (2007) 19). Figure 2 shows the share of the GHG emissions from the overall transportation sector (aviation, maritime and road transport), which accounts for almost 25% of all emissions that are accounted for by the EU 27 Member States (Europe's Energy Portal 2011; Thiel et al. 2010; Meyer *et al.* 2007). Figure 3 shows a precise distribution of emissions between different transportation sectors, where the road transport has the biggest contribution.

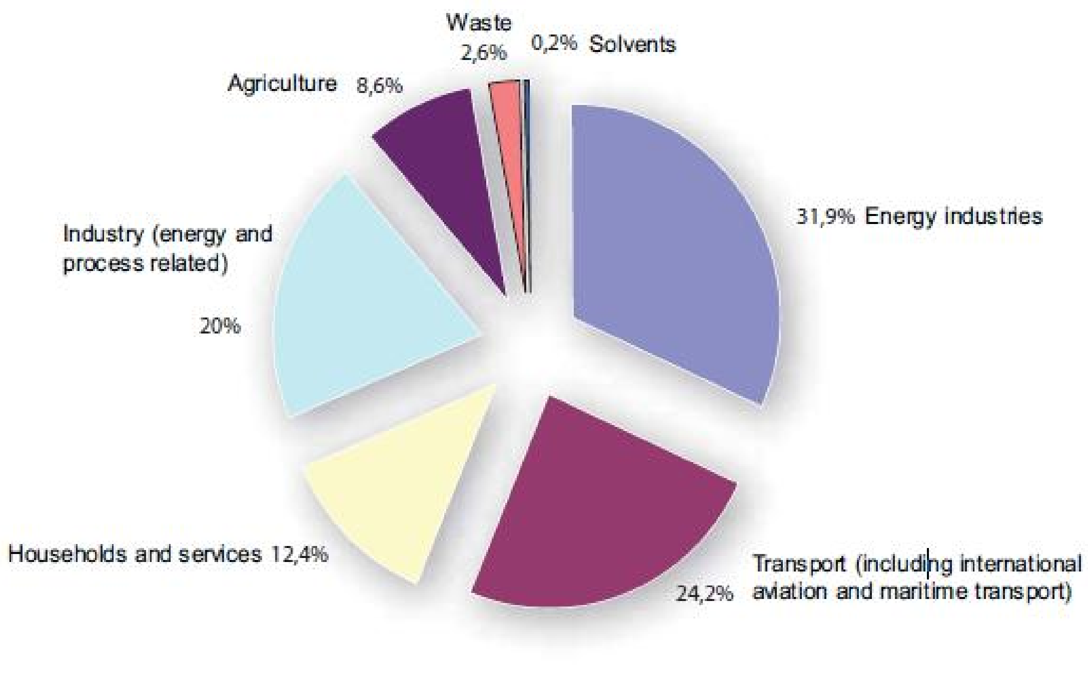

Figure 2. *2007 statistics for the EU-27 GHG emissions according to each available sector (Source: European Environment Agency 2007)*

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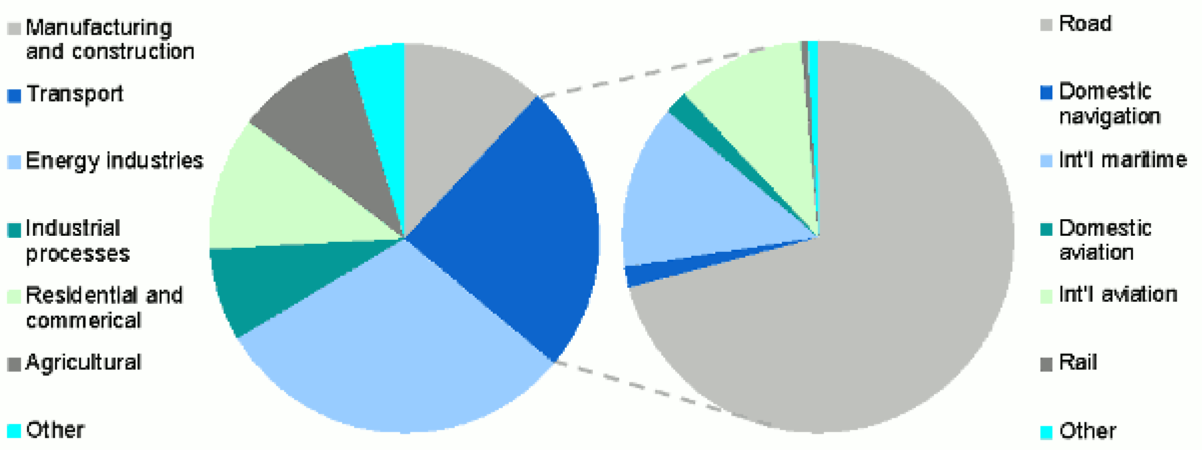

Figure 3. *More precise representation of the EU 27 transportation sector emissions, where the road emissions have the largest share (Source: European Commission Climate Action URL:* ***http://ec.europa.eu/clima/policies/ transport/index_en.htm***

The current situation is such that the global concern for the climate change and human health brought the idea of EVs back into the spotlight and the majority of manufacturers are investing into different types of electric vehicles. The European government sees alternative fuel such as electricity as a potential solution to the significant concentration of pollutants generated by the internal combustion and thus supports various attempts of the member states to adopt this technology (COM (2007) 19; COM (2011) 144; COM (2010) 186). Additionally, another reason for promoting electric vehicles is the rechargeable battery component that needs further development and can be simultaneously used for the energy storage from the renewable energy sector (Harrop and Das 2011l Kobayashi *et al.* 2009; EUCAR 2009). Thus, by supporting the development of battery and vehicle manufacturers, the European Union sees a potential contribution to the renewable energy development as well (Directive 2009/28/EC).

3.2 E-Mobility Concept in EU

Currently the European Union is preoccupied with both the fuel security and its obligations towards the Kyoto protocol, an agreement that enforces the EU states' contribution to the overall reduction of the global GHG emissions, which is currently set at 20% by the year 2020 (COM (2008) 16; COM (2008) 17; COM (2008) 30; COM (2008) 16). At the moment, the transport sector all over the world consumes more than 50% of the globally processed oil (EIA 2008). Most of the transport is dependent on oil and only a small part of it (5%) runs on alternative fuels such as electricity, liquefied natural gas, etc.

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This fuel dependence of the EU is alarming given that the oil reserves are a depletable resource and eventually will seize to exist (FIA 2011; Harrop and Das 2011; Directive 2009/28/EC). This way, there is a need to search for the viable and efficient alternatives that are environmentally benign. Table 3 shows the distribution of the top seventeen countries – the key reserves of oil and the years associated with the consumption patterns they practice today. According to the years demonstrated in Table 3, the oil stocks are not ever-lasting and rather soon will be exhausted given the global population and demand growth.

	Reserves	Production	Reserve life		
Country	10^9 bbl	10^9 m^3	10^6 bbl/d	10^3 m^3/d	years
Saudi Arabia	267	42.4	10.2	1,620	72
Canada	179	28.5	3.3	520	149
Iran	138	21.9	4.0	640	95
Iraq	115	18.3	2.1	330	150
Kuwait	104	16.5	2.6	410	110
United Arab Emirates	98	15.6	2.9	460	93
Venezuela	87	13.8	2.7	430	88
Russia	60	9.5	9.9	1,570	17
Libya	41	6.5	1.7	270	66
Nigeria	36	5.7	2.4	380	41
Kazakhstan	30	4.8	1.4	220	59
United States	21	3.3	7.5	1,190	8
China	16	2.5	3.9	620	11
Qatar	15	2.4	0.9	140	46
Algeria	12	1.9	2.2	350	15
Brazil	12	1.9	2.3	370	14
Mexico	12	1.9	3.5	560	9
Total of top seventeen reserves	**1,243**	**197.6**	**63.5**	**10,100**	**54**

Figure 4. *Global stocks of oil (Source: Harrop and Das 2011).*

Search for the new technology such as the electric vehicles is also defined by the benefits it will bring to Europe such as reduction of fuel import, improvement in air quality and elimination of numerous accidents associated with the conventional vehicle accidents (Cowan and Hulten 1996; Skerlos and Winebrake 2010). Given all of the above-mentioned benefits the e-mobility could provide, the European government is just starting to look into the sustainable transport and e-mobility concept, yet there are not many strict rules that apply to this sector (COM (2010) 186; COM (2007) 19). However, there is a possibility for the road transport to be included into some kind of the "cap and trade" policy that will oblige companies with large vehicle fleets to comply with air pollution restrictions and even upgrade to the alternative fuels such as electricity (COM (2008) 16; European Commission 2009).

Already the commitment of Europe to reducing its GHG emissions already resulted in such policy tool as the EU Emissions Trading Scheme, which targets large point sources of pollution such as industry for example and establishes a special threshold for the emissions it can produce throughout the year. In case the issued quota of emissions was not reached, the industry could trade its leftover credits to another member of

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the system. This system follows the principle of “cap and trade” where the overall limit of emissions within the EU member state will be under control. This system could also potentially apply to all major point sources of pollution, especially international airports, which have their own large fleets of both heavy-duty and light commercial vehicles (FIA 2011; Eppstein *et al.* 2011; COM (2007) 19).

3.3 Importance of the EVs in the “Fuel Efficiency Fever” of the Airports

Nowadays the international airports all over the world are in the spotlight of the “energy efficiency fever”, where they identify reduction of overall emissions from both the aviation sector and airport terminal operations as a necessary measure for coping with the projected passenger increase in the future (ACI Europe 2010; Budapest Airport Zrt. 2011; Frankfurt International Airport 2011; Vienna International Airport 2010). European airports are committed to the idea of sustainable development since it is important for financial savings, and promotion of the airport as a responsible company that cares for the environment. Originally, the concerns about sustainability and reduction of emissions appeared due to the concern for the aviation impact on the atmosphere and settlements around the airport zone. These concerns triggered extensive research within the noise pollution reduction, aviation fuel efficiency and reduction of aircraft emissions both in the air and on the ground. Consequently, sustainability concern transferred to the everyday operations at the airport itself and the ground emissions from servicing the aircrafts and passengers. This way, there was a trigger for these organizations to cooperate in order to influence the governmental decisions, create international standards and to achieve the best results on their sustainability pathway (Budapest Airport Zrt. 2006; Fraport 2011; Vienna International Airport 2009).

Such international cooperation resulted in creation of the Airport Council International (ACI), the global non-profit organization which brought together the airport and airline representatives together with the aircraft producers from all over the world in order to positively contribute to the climate change abatement. The ACI was also responsible for introduction of the Airport Carbon Accreditation program, where the airport has to account

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for all of its emissions and eventually reach the target of carbon neutrality, i.e. no direct emissions (ACI Europe 2010). Accreditation process is based on the ISO 14064 standard that is devoted to the carbon footprint.

Once the airport is accredited, it needs to initiate the program for reducing its emissions. One of the best and easiest sectors where the emissions can be diminished is the Ground Support Equipment (GSE) fleet that belongs to the Ground Handling services (GH) at the airport. This sector is responsible for considerable emissions even and also fuel consumption since it operates mostly diesel engines and large heavy-duty machinery. Additionally, it is much easier to start off with replacing the GSE vehicles than to immediately introduce significant changes to the Terminals within the airports structures that will require careful planning and time for the approval from the board. Thus, this thesis focuses on the drivers and barriers associated with introducing electric vehicles into the GSE sector within the Budapest International airport that has recently joined the ACA scheme and introduces successful experiences of the Frankfurt and Vienna International airport that already introduced some electric vehicles to their GSE fleets (Fraport 2011; Vienna International Airport 2009).

Prior to discussing the airports, it is necessary to analyze and understand the organizational structure within the airport, which is responsible for making decisions in terms of GSE and implementing those decisions.

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3.4 Section: Managerial Structure at the Airports

International airports are special organizations that are typically shared by state owners and private companies that are responsible for airport effective management and operations (ACI Europe 2010; Budapest Airport Zrt. 2006; Fraport 2011; Vienna International Airport 2009). International airports usually have a management board and a supervisory board, which are crucial for the airport's decision-making concerning long-term development strategy and compliance with international and national environmental regulations. The airport itself is a legislative body, which holds all the rights to develop internal regulations for the tenants such as the airlines and ground handling companies.

Despite the fact that the airport has the power to enforce various strict environmental regulations it faces the key obstacle of airline and ground handling negotiations. Logically, airlines are the key supplier of the airport's revenue and in case they are not satisfied with the airport legislation or negotiation they might relocate their base into a competing neighbouring international airport in the closest EU state (Gillen and Neimeier 2006). If the airport enforces harsh regulations for expensive ground handling equipment for example, the GH services will have to charge the airlines more given they would need to receive a payback for their initial investment. The airlines in the modern world are extremely keen on protecting their budget from any sources of "unnecessary expenditures" and thus they might see such regulation as an act of airport reluctance and lack of care for the airline. This way, the airport has to always carefully negotiate any kind of proposals for either introducing a new ground emissions abatement scheme or addressing the overall fuel consumption of the GH companies.

The Ground Handling companies at the airports are a separate entity that can be represented by several organizations working simultaneously within one airport. These companies sometimes compete between each other in order to provide a cheaper and more efficient service for the airlines. This effort of providing a cheaper service may result in the GH Company's unwillingness to switch to the alternative fuel or technology due to the higher investment costs associated with the upgrade (Gillen and Neimeier 2006; Budapest Airport Zrt. 2006; Fraport 2011; Vienna International Airport 2009). GH units operate various types of machinery, which can be divided into heavy-duty transport, light commercial vehicles and passenger service vehicles. Heavy-duty vehicles are typically represented by various luggage tractors, container loaders, Auxillary and Ground Power Units (APU and GPU), lavatory and catering trucks, passenger stairs, etc. Passenger service vehicles involve buses and mini-vans that are responsible for taking airport customers to and from the aircraft across the apron. Finally, light commercial vehicles can be employed for the ramp agent service and "Marshaller follow me" vehicles that are responsible for providing various services to the aircraft such as regular checks and transport to and from the gate (Budapest Airport Zrt. 2006; Fraport 2011; Vienna International Airport 2009). It is imperative to understand other airport and GH experiences in order to assess the best area for EV integration out of all these three options,

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since the technology is rather expensive and it is simply impossible to invest simultaneously into purchasing a whole new variety of vehicles. So, this work based its primary research on identifying those best areas for EV implementation based on interviewing representatives from the GH companies and Environment, Health and Safety division at the airport about their opinions and experiences within the field of ground transport operations and equipment.

Thus, one of the key purposes of this study is to demonstrate that an international cooperation between different airports will allow for learning various sustainability and conservation methods that could be further utilized in order to achieve the European standard of carbon neutrality faster and easier (ACI Europe 2011). Three different sizes of the airports were assessed where the Budapest airport was the smallest one, followed by the Vienna International Airport and then Frankfurt International airport in terms of the amount of passengers being handled (Budapest Airport Zrt. 2011; Fraport 2011; Vienna International Airport 2010).

3.5 Target: Budapest Liszt Ferenc Airport, Hungary

One of the most important transportation hubs in Central-Eastern Europe, Budapest annually serves the connection purposes of over 8 million passengers and approximately 34 airlines to a variety of destinations (Budapest Airport Zrt. 2011). The airport is owned by the international company “HOCHTIEF Concessions”, which holds a 75% share and 25% share is possessed by the Hungarian State. The airport is strongly committed to its environmental ISO accreditation scheme 14001:2004 obtained in 2006 and Airport Council International (ACI) carbon accreditation (ACA) certificate, which was given to the airport in 2011 (Budapest Airport Zrt. 2006). Both of these certificates support the statement that the airport is willing to proceed towards internationally recognized concept of “carbon neutrality” and to invest into the company's overall sustainability. The Budapest Airport commitment to the ACI scheme supports its intentions to reach out for significant decrease in overall emissions, both from the aircrafts and from the ground operations. According to the ACI definition of various targets that have to be achieved by a member of the carbon reduction program, the Budapest airport will have to prioritize its overall emissions in order to satisfy the first requirement of the certificate. Further the airport will have to address the issue of airport's energy use and finally reach a “carbon neutrality” target (ACI Europe 2010).

Since the Budapest airport got involved into the mentioned environmental schemes, it managed to achieve significant reduction in overall emissions registered at the premises of

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Terminal II by means of two air-monitoring stations. According to the Environmental Report issued in 2006 and consequent publications of the airport on its corporate sustainability, measured carbon dioxide emissions demonstrated a significant difference between 2007 (16217 tons) and 2005-2007 (55031 tons) that the airport was able to reach by means of eliminating some of the older vehicles, addressing aircraft movement and engine work on the ground and introducing buses for staff purposes instead of private cars within the airport premises. The Airport is monitored according to the "National Allocation plan" and the "Allowances List" (EU ETS) that pre-set the values for the potential carbon dioxide emissions, where these constituted for the years between 2005 and 2007 58 560 tons and approximately 19520 tons since the year 2007 (The European Topic Center on Sustainable Consumption and Production 2009a). Due to such a drastic change in the carbon dioxide permissible amount, the airport seriously started to consider its point sources of pollution. Thus, this result supported the concept that if the airport gets involved in internationally recognized emissions regulating program it will have a positive push towards reducing its environmental impact (Skerlos and Winebrake 2010; COM (2010) 186). One of the primary targets that can be addressed at the airports in terms of CO2 emissions are the aircrafts and the ground service vehicles that are involved in the aircraft maintenance operations, cargo handling, passenger service and overall monitoring of the airport zone.

Currently European Union focuses on reducing harmful emissions from aircrafts and their coming integration into the International Emissions Trading Scheme (REF). Yet the topic of ground vehicles remains somewhat unnoticed given their small share compared to the overall airport emissions (about 5% from the total emissions load at the airport) (Budapest Airport Zrt. 2006; ACI Europe 2010), however, it is a constantly present polluting source that maintains relatively high levels of pollution if it is not compared to the aircraft emissions. The entire fleet of airport vehicles is recognized as the «moving pollution source» and yet this source can be rather easily addressed and changed if the airport decides to consider abatement of CO2 in this sector. This concept is crucial for this thesis since it became the backbone of the research on Evs as a solution for a moving source of pollution at the airports.

The management organization that currently operates the Budapest airport (Budapest Airport Zrt. 2011) is currently looking into the energy consumption patterns of the airport , where the key targets are the heating and air conditioning of the two Terminals and fuel consumption of both aircrafts and ground vehicles. The latter is especially important due to the constantly fluctuating growth of the fuel prices and overall energy security issues associated

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with oil excavations and refining. The future consumption of fuel will be expected to increase gradually as the airport will expand and aim to attract more airlines with consequent increase in Ground Handling Services that will serve the airline purposes.

Currently the airport is undergoing major renovation and construction works due to its goals of expanding the premises and services, for example investment into development of the project named “Cargo City”, which will be located close to the second terminal area (Budapest Airport Zrt. 2011). This project will eventually cause a raise in the number of both heavy-duty and light vehicles employed at the GH companies with a consequent increase in operational and fuel costs. Currently one of the airport's major triggers for addressing the CO2 emissions from the ground transportation sector is the fuel economy and long-term planning for the carbon neutrality goal it has committed to when it entered the ACI scheme.

Most importantly, the staff members of the Budapest airport actively tackle the concept of EV integration into normal operations by means of communicating the idea to the airlines and GH services where I managed to participate in the original contact establishment process. Once the airport assesses the feasibility of the electric vehicles and makes estimations for both the ground handling and light vehicles consumption on its premises, further actions such as an establishment of the charging infrastructure and purchase of the electric vehicles will take place. In order to assess limitation and barriers of EV technology for the Budapest Airport it was crucial to sample the opinions and experiences within the airport’s Environment, Health and Safety Department and between two major GH companies namely Celebi and Malev GH that are responsible for daily airport operations both at the apron and around the airport.

This thesis focuses on providing the supporting legal and case study base for the Budapest airport in order to assess the perspective of EVs at the airport together with barriers and drivers for EV integration identified from the exploratory case studies of Frankfurt and Vienna international airports that have already started to successfully utilize electric vehicles in different transportation sectors.

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3.6 Case study: Vienna International Airport (Flughafen Wien AG), Austria

Second airport under study in this work, Vienna International Airport handles more than 90 airlines and over 19 million passengers annually and is one of the main competitors of the Budapest International Airport for the airline placement (Vienna International Airport 2010). This airport underwent privatization in the beginning of the 1990s and at the moment

40% of the airport are equally shared by the Lower Austria province and Vienna state, where the rest 60% belong to the employee foundation (10%) and other private stockholders (50%). Vienna Airport is an active member of environmental discourses with the rest of the Austrian community, which showed major positive achievements within its air quality and noise abatement.

At the moment one of the major airport's goals is to achieve the status of the "Green Airport" according to the Austrian and International standards. I chose this airport due to several parameters such as success in implementing electric vehicles in its daily operations, similarity to the Budapest Airport in terms of introducing some natural gas vehicles to its fleet and also quite recent involvement of the airport into CO_2 emissions calculations (Vienna International Airport 2009). Thus, one of the questions that had to be integrated into the interview with Vienna was the overall performance of the natural gas vehicles and potential competition with electric vehicles. According to Austrian Environmental Report (Austrian Airports Association 2010), natural gas engine generates much less CO_2 exhaust (by 30%) and reduces the amount of nitrogen oxides emitted (NO_x) together with other substances (i.e. PM_{10}) during ground operations. This way, it is obvious that the LPG or CNG fleet does not reach 100% emissions abatement that could have been provided by the electric vehicles yet the reduced amount of CO_2 is still significant compared to the diesel and petrol engines that were heavily utilized for the apron vehicles at Vienna Airport in the past (Vienna International Airport 2010).

Currently, Vienna Ground Handling as a large monopolist at Vienna airport (except for private small companies) expresses a growing interest in both electric and natural gas vehicles, where the GH has purchased over 40 apron vehicles operated by natural gas vehicles already starting in 2008 (VW Caddy) and is looking into further upgrading of the rest of the ramp agent cars within the next several years (Vienna International Airport 2009). At the same time, GH also invested in several heavy-duty electric vehicles, yet those were not as highly advertised in the environmental report compared to the natural gas fleet. Sampling Vienna Airport would serve a good comparison for the Budapest airport given their commitment to the natural gas fleet for the apron vehicles and overall perception on the future of electric vehicles at the airport that will be presented further in the analysis.

The purpose of this case study was to determine the overall perception of the electric vehicles by the experts at Vienna airport and GH and to understand the future of EVs in the airport's long-term development strategy

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3.7 Case study: Frankfurt International Airport (Flughafen Frankfurt), Germany

The forth-largest passenger airport in Europe with a turnover of more than 50 million passengers and more than 120 airlines, Frankfurt International Airport is operated by the Fraport Company (Frankfurt International Airport 2011; Fraport 2011). This airport is a renowned member of the ACA scheme under the ACI organization since it was the first airport to be assessed according to the ACA scheme due to its commitment to the goal of reaching carbon neutrality (ACI Europe 2010). Apart from major campaigns on reducing the overall environmental impact of the airline industries and airport terminals, Frankfurt airport simultaneously considered the ground transportation sector for potential emissions abatement purposes. The airport was originally devoted to using some of its equipment in an electric mode back in the 1980s, yet the competition for fuel stagnated the development of the electric units for some time in the past. Extensive calculations on the long-term benefits of the electric vehicles that are currently performed by the Environmental Department and Ground Handling Services at the Fraport operating company support the gradual switch within the identified areas of transportation into the electric mode from the diesel versions. At the moment the airport identifies more than 15% of the emissions (approx. 34.82 tons) for the transportation share from the just airport emissions excluding the aircraft-related emissions. This figure serves as a trigger for the EV initiative of Fraport since the company is preoccupied with its air quality and worker health and safety. Currently the airport has approximately 10% of its 3000 and more unit vehicle fleet converted into the electric engines and a small part allocated to the hybrid tow trucks that use an electric engine during their operations within the luggage sector of the terminals. According to the Airport's Sustainability Report (2010) the electric engines are mostly incorporated into the Ground Handling equipment, whereas the light passenger vehicles that the airport has tested and was satisfied with are two Mitsubishi iMiev models (Fraport 2011; Mitsubishi Motors 2011). The Frankfurt airport is determined to double the amount of electric engines within such sectors of its GH fleet as container high-loaders and attempt to reach 100% electrical engine conversion within the airport's conveyor belts by the end of 2015 in order to meet the ACA goals of emission reductions and energy consumption within the transportation sector. The airport is in close collaboration with the geothermal power plant that supplies a part of its heat and electricity demand and therefore produces green energy for the vehicle needs. Thus, the airport is on the right way to achieving carbon neutrality within the foreseeable future (Fraport 2011).

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Frankfurt airport is highly motivated to stay on the electric vehicle track due to its own sustainability initiative, support of the government and customer care. The airport's commitment to achieving successful integration of e-mobility was even rewarded in 2009 by the "ECarTech" award in Munich (Fraport 2011). Frankfurt International Airport demonstrates a successful campaign for EV integration that was achieved due to careful financial and environmental planning in addition to the concern with the worker health and safety requirements. This work explored the Frankfurt efforts in bringing e-mobility into its daily operations and collected valuable experience from the experts directly involved in EV implementation projects, which were further utilized to assess the barriers and drivers for the EV initiative at the Budapest Liszt Ferenc Airport. The next two chapters will give an overview of the electric batteries and available electric vehicles that currently exist on global market and to introduce the available EV options for the airport purposes.

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4. Trigger to Success – Technological Overview of the EV Traction Battery

Prior to discussing the present situation of the electric vehicles at the international airports it is crucial to understand the technology behind the electric engines and to identify different types of batteries that operate EVs today. This chapter will focus on discussing the most important characteristics of the most popular batteries that define the performance of different types of electric vehicles. The details of the rechargeable battery types discussed further below will be described in depth in Table 3 of the Appendix I.

4.1 Lead acid battery: the oldest battery produced

Lead acid battery is the oldest type of battery that was manufactured for the first electric vehicles that appeared in the end of the 19th century (Harrop and Das 2011). This type of battery is best known for its heavy weight needed to sustain a longer mileage for the average vehicle (Harrop and Das 1010; Van den Bossche *et al.* 2005). Although today the weight of the battery is viewed as a disadvantage for the light commercial vehicles due to the issue with aerodynamics, it is extremely appropriate in the heavy-duty vehicles such as forklifts used at the airport warehouses that must maintain the balance due to their weight. The lead acid type is also relatively cheap compared to other kinds of batteries where one kWh costs approximately 150$. As for the other batteries, one kWh can cost more than 200 dollars (or exceed the price of 140 euros) (Harrop and Das 2011). Additionally, this type of battery also withstands overcharging when it is plugged in for too much time and can also cope with high currents. This way, the lead acid battery does not have the so-called "memory effect" where constant overcharging would cause it to hold less energy with every consequent recharging (Harrop and Das 2011; Kobayashi et al. 2009; Van den Bossche *et al.* 2005). In terms of the environmental impact, the lead acid batteries have one of the best recycling systems where almost all of original material incorporated into the battery is converted into the new one. This is another reason for the reduction in cost since no metal extraction works have to be carried out.

Nevertheless, despite all of the discussed advantages, the lead acid type of battery has one major issue that concerns the mileage this battery can yield per charge. Usually, given that the specific power of the lead-acid battery ranges from 25 to 30 Wh/kg, the maximum range it can yield would be less than 50 miles before it will have to be recharged again. At the same time, some heavy duty equipment can potentially solve the range problem by upgrading the energy density of the battery through adding more lead acid batteries to the vehicle. This

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action will significantly increase the weight of the equipment, yet it will provide for larger overall mileage or working hours of the equipment. Last but not least, the lead-acid battery is quite sturdy and cannot be damaged easily which adds to the overall advantages of the technology. Thus, the lead acid battery works best for the vehicles that do low speeds and short distances, which is perfect for the previously identified GSE sector that is responsible for the work around the aircraft (Harrop and Das 2011; Van den Bossche *et al.* 2005).

4.2 Nickel Metal Hydride (NIMH) battery

The leader among the plug-in hybrid electric vehicles (PHEVs) that will be discussed in the next chapter that focuses on the EV market, the NiMH battery has a larger specific power compared to the lead acid technology (up to 70 Wh/kg compared to the maximum 30 Wh/kg in the lead acid battery) and thus theoretically allows for a larger mileage (Harrop and Das 2011; Kobayashi *et al.* 2009; Van den Bossche *et al.* 2005; Nemry *et al.* 2009). This is the new generation battery, which takes less time to recharge compared to the lead acid (6 hrs vs. 8 hrs in the latter) and holds the charge for a longer time. This battery is also relatively resistant to overcharging and has no memory effect. Additionally, NiMH has an increased tolerance to the temperature fluctuations and can be stored both in a charged and discharged mode. NiMH is famous for supporting the Toyota Prius hybrid that recently appeared on the market and got positive reviews.

As for the disadvantages of the technology, the most acute issue is connected to the lanthanum metal supply – the rare earth metal that is by definition is not readily available in the nature (Harrop and Das 2011). Compared to the lead acid battery where the components are not hard to find, the NiMH if produced in large quantities would potentially pose a security issue for the energy supply of customer countries. Additionally, countries that mine for rare earth metals in general might potentially exercise their privileges upon the customer countries and terminate the supply of those materials, which could lead to the failure of the technology. With this in mind, it is important to consider the availability of the components that are a part of any battery used in the electric vehicles in order to escape the energy security issue. All in all, this battery represents a rather reliable technology so far which is still subject to development.

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4.3 Nickel Cadmium (NiCd)

This battery is rather popular for serving the electric vehicle propulsion (Harrop and Das 2011; Kobayashi *et al.* 2009; Van den Bossche *et al.* 2005; Nemry *et al.* 2009). This battery has a specific power of 45 to 60 Wh/kg and offers the mileage somewhere in the middle of the lead acid and the NiMH batteries. Additionally, the NiCd battery can be stored for a long time. The biggest obstacles on the way of mass production of this battery are its toxicity levels, which are defined by the presence of the Cadmium component, the overall high cost of the unit and the memory effect. Compared to the NiMH which costs approximately 250$ per kWh (approx. 170 euro), NiCd in turn can have a cost within a range of 400 to 800 dollars per kWh. As for the memory effect, this battery is rather sensitive to overcharging, which usually results in loosing its storage capacity when it is overcharged many times. Thus, due to the high costs of the battery and its toxicity levels it would be rather inefficient to promote this kind of energy storage device for the mass production in the future.

4.4 Lithium Ion batteries

At the moment, lithium ion batteries are the “hope” for the future electric vehicle production. This battery achieves significant reduction in its weight and has promising results in terms of the overall mileage per charge (Harrop and Das 2011). In term of specific power lithium ion technology can reach up to 160 Wh/kg and thus become a worthy competitor to the modern ICE engines. Given the technology constantly evolves and adapts to the societal needs, one would expect the lithium ion batteries to soon displacing both NiMH and potentially even lead acid once it become rather cheap due to the development of the economies of scale. One key issue that is associated with this type of battery is similar to the NiMH and concerns the access of the rare earth metal such as lithium. More than 90% of the global reserves of lithium are located in China and thus mass production of this type of battery could impose security issues on the consumers of lithium ion batteries (Harrop and Das 2011; Kobayashi *et al.* 2009; Van den Bossche *et al.* 2005; Nemry *et al.* 2009). However, apart from this issue, the promising range the vehicles could do already can be witnessed through the Tesla Roadster vehicle (approximate cost of 100,000$ or 70,000 euro), which allocates 250 miles per single charge. Thus, as long as the security of the production and economies of scale are developed, the lithium ion technology could potentially allow for electric vehicles to compete with the ICE engines given the latter do not enhance their efficiency.

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Another battery that relates to the Ni family is NiZn (Nickel Zink) yet this technology is still under development and does not have much information about it published yet.

4.5 Zinc Air (Zn Air) batteries

This battery belongs to the metal-air type, which also includes an aluminum counterpart (Harrop and Das 2011; Van den Bossche *et al.* 2005; Kobayashi *et al.* 2009). This battery has the specific power of approximately 200 Wh/kg and thus it holds a high potential for competing with the lithium ion technologies. At the moment there are not many specialized companies around the world that invest into manufacturing this type of the battery and therefore it is not yet clear whether this technology is feasible. This technology is based on the replacement of electrodes, which almost mimics the fuel cell technology not discussed in this thesis. Issues associated with switching the electrodes can become a major issue associated with this technology, which has to be fixed before it can go on a market. Finally, these types of batteries are still quite expensive and relatively new on the market, where an extensive assessment of their characteristics has to be performed before the decision is made about whether they should be mass produced.

Another type of fuel cell like technology is the redox battery, which have an extremely complicated system of operation and thus cannot be considered to be the mainstream production at the moment for the safety reasons.

4.6 Sodium Nickel Chloride (NaNiCl) or Zebra battery

The Zebra battery is a promising technology that relies on the available components compared to the rare earth metals used in Lithium Ion or NiMH batteries (Harrop and Das 2011; Van den Bossche *et al.* 2005). So far this technology is rare as well as the Zn Air and thus is rather expensive. At the same time the raw materials that are used for the production of this battery are relatively cheap and thus could potentially develop on the market in case the rare earth metal mining is compromised.

Despite the availability of components for the possible mass production, this technology has a significant disadvantage due to overheating given that its mode of operation requires high temperatures (approximately 300C) and for severely damaging the vehicle itself. Yet, NaNiCl has some potential for the use in electric vehicles given its high specific power (125 kWh/kg).

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4.7 Summary of batteries

As one can see from the description above, there are a variety of batteries that were incorporated into the electric vehicles or hybrids at some point in time. There is no ideal technology, it is rather a matter of personal preference and experience for the customers to use the battery available right now, disregard its disadvantages and learn to adapt to their work as it happens in case of the lead acid battery. Another option is to develop and intensively test a new technology such as Lithium Ion batteries in order to compensate for the larger mileage and faster speed of the vehicle that could compete with the contemporary ICE engine (Taylor 2008). The important aspect of developing batteries for EVs is the concern for the vehicle properties such as its weight and amount of the free space to accommodate the battery and not to reduce the amount of passengers (Harrop and Das 2011). The weight of the car matters for the light commercial vehicles since heavier vehicles accelerate slowly and have issues with the aerodynamic properties. However, these properties are different in the heavy duty GSE equipment where the equipment has to be heavy to lift or transport large cargo or luggage loads. Figure 2 shows the comparative analysis between the volumetric and gravimetric energy density and energy that define the weight and size of the batteries described above.

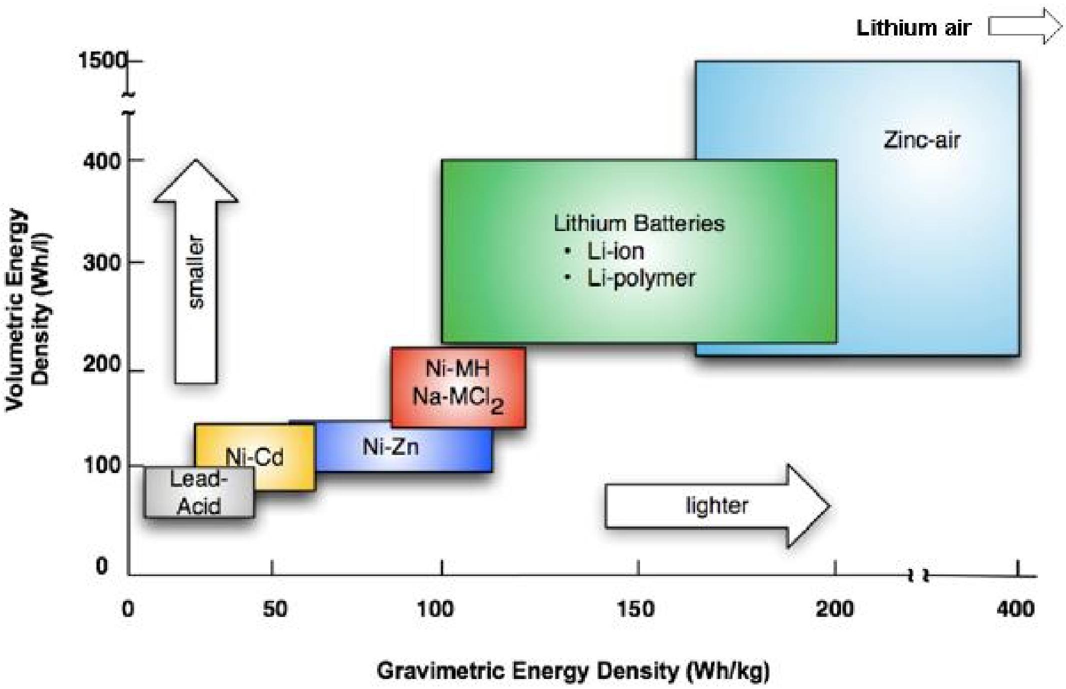

Figure 5. *Comparative analysis of the volumetric energy density and gravimetric energy density between the mentioned battery types that defines their size and weight (Source: Harrop and Das 2011).*

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Suffice it to say, more research and tests are needed in order to understand which of these batteries holds the potential for the future market. Currently the average life of the batteries ranges from 3 to 5 years, which is not enough since these batteries are very expensive on the global market (Harrop and Das 2011). The governments will have to invest into R&D associated with the battery life and overall performance. Additionally, some promising technologies such as the Lithium Ion battery can potentially prove inefficient since they have a great environmental impact due to the mining of the depletable lithium resource. At the same time, the Zebra batteries could be further improved to the point where the high temperature of the operation process harms neither the battery nor the vehicle. However, the development of the ICE is not stalled either and thus the competition between the batteries and the diesel and petrol engines will always remain high (Taylor 2008). The ICE is currently also working on its fuel efficiency and potentially could avoid major fuel losses from the engine operations by means of advancing its technology. Thus, the advancement of the electric batteries has to develop significantly in order to become a viable competitor for the ICEs.

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5. EV Market and Vehicle Types

5.1 Pure or battery electric vehicles (PEVs or BEVs): focus of this study

This paper will focus on the pure or battery electric vehicles (from here on mentioned as PEVs) and their application at the international airports across Europe due to their potential for significant elimination of GHG emissions (Harrop and Das 2011; Diamond 2009; Nemry 2009). The vehicles themselves do not pollute the atmosphere since they run on electricity, yet there is a possibility that the pollution will be shifted towards the sources of electricity such as coal power plants for example if the access to renewable energy is limited or not available at all. Renewable energy development is an essential factor that will allow for almost 100% GHG and specifically CO2 emission reduction from the electric vehicles (Directive 2009/28/EC; COM (2010) 186; EUCAR 2009; Ahman 2006).

PEVs are the vehicles that rely only on the charge of the battery that runs the electric engine to propel the vehicle. The best representative of this technology is the golf car that is the only type of vehicle today that is mass-produced in the pure electric way (Harrop and Das 2011). Currently this technology runs on lead acid batteries, NiMH or even lithium ion batteries (China's Zhong Tai PEV), where the latter provides for the longer charge and mileage for the vehicle (Harrop and Das 2011). Although historically the PEVs could not drive for more than 50 kilometers in ideal conditions, today the R&D is focused on developing that range. In fact, the most current achievement in terms of mileage is approximately 50 miles or 80 kilometers for both the pure electric vehicles and hybrid vehicles. Significant expansion of range depends on the Lithium Ion battery that replaced the NiMH in several SUVs and light commercial vehicles (BYD E6, Mitsubishi iMiev, Nissan leaf, Subaru Stella and Zhong Tai) in China (Harrop and Das 2011; Mitsubishi Motors 2011). These vehicles have a perspective on the European market once the charging infrastructure allows for easy recharging within the urban conditions and once the prices of the vehicles become comparable to those of conventional engine vehicles. Currently the Subaru Stella can perform 90 km drive on a single charge, whereas the Nissan Leaf already offers 160 km with its Lithium Ion battery (Harrop and Das 2011; Kobayashi *et al.* 2009). Apart from purchasing pure electric vehicles, some European battery and EV providers have an option to replace the ICE with the electric engine for regular vehicles. However, this option costs approximately the same amount of money or even more compared to the price of a new PEV. This way, the pure electric vehicles are on their way to rapid development and potentially even conquering of the global market where they might sooner or later compete with the ICE vehicles by means of price, predictability of range, regenerative braking (when the energy released from brakes recharges the battery), safety, fuel efficiency and reliability of the technology.

5.2 Hybrid Electric vehicles (HEVs)

These vehicles are the "bridge technology" between the electric and conventional engine vehicles. HEVs combine the ICE and the battery for their operations that allows them

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to extend the overall range of kilometers travelled and to drive some distance in an emissions-free mode (Harrop and Das 2011; Diamond 2009; Galus *et al.* 2010; Eppstein et al. 2011; Delucchi and Lipman 2006). There are several different types of hybrids nowadays where the most popular vehicles are conventional hybrids (Toyota Prius, Lithium Ion battery, 89 g CO2 per 1 km) that recharge the battery by means of regenerative braking and sharing waste energy from the ICE (Toyota 2011). The size of the battery is small in this case and thus the mileage that can be achieved on electric driving is small. This thesis will not consider conventional hybrids in its discussion due to the fact that most of these vehicles still emit up to 100 grams of CO2 per km.

The most promising bridge technology between electric and internal combustion engine vehicles is the plug-in hybrid (PHEV), which allows for a longer range and fuel security due to the ICE on board and will be discussed together with the PEVs in this thesis. Given the recent improvements in the overall range of the batteries that hybrid just like the PEV can count on approximately 80 km for just the electric drive mode (Harrop and Das 2011). The best feature of this technology is the reliability of the fuel where the vehicle can always switch into the petrol mode if the vehicle runs out of the charge. Technically, this technology is extremely efficient for the citizens of some town or city where the daily maximum driven mileage per person is usually 50 to 80 km and no other charging infrastructure is available apart from the regular plug at home. Given the owner can recharge the vehicle overnight from the conventional plug, the vehicle will be able to cover the average driving distance required to go to work or a shopping mall on the electric charge. Thus, such travel would emit much less grams of CO2 compared to the standard conventional vehicle and the city will suffer less from the pollution.

Despite the mentioned advantages of the hybrid technology, the maintenance of such vehicles is rather expensive and exceeds the one for the PEV since the hybrid has two sources of energy such as the ICE and the battery. The necessity to constantly check both operational systems will come at a double cost for the owner, which is not extremely attractive for the potential customers. Additionally, the PHEV is the heaviest vehicles, where the PEV comes next and the ICE is the lightest vehicle (Thiel et al 2009; Harrop and Das 2011). Given all these issues associated with the PHEVs, it is important for both the vehicle cost and the maintenance costs to be reduced either by means of incentives from the government or the manufacturers or by purchasing the PEV.

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5.3 Infrastructure

Finally, there is a need for the standardized charging infrastructure that will be able to quickly serve the charging purposes of all types of PHEVs and PEVs (Harrop and Das 2011; Galus *et al.* 2010). Currently many vehicle manufacturers unite in order to create a joint agreement on designing the form and structure of the charging system, which would be available throughout Europe. For example the Hanover fair that took place in 2009 proposed a solution for the standardized charging plug that consisted of three pins and allowed for different recharging options (max 400V) (Harrop and Das 2011). The recharging infrastructure has to be efficient and fast in charging (less than half an hour), prevent potential battery overcharge and to create "smart systems" where the vehicle communicates with the charging station via an electronic system and a each refill at the charging station could be billed to the owner's household electricity consumption (Harrop and Das 2011; Diamond 2009; Galus *et al.* 2010; Eppstein et al. 2011; Delucchi and Lipman 2006). The search for the best charging infrastructure includes E.ON, EDF, nPower, RWE and other electricity suppliers that will be connected to the charging infrastructure through the grid. One of the key concerns with the electricity supply is the possible relocation of the emissions from the vehicle onto the conventional power plants, which will eventually emit more pollutants when the demand for the electric vehicles rises. Thus, the European discussion right now also considers the opportunities for provision of purely renewable energy for the demand of electric vehicles and hopes to combine rapid renewable energy development with the battery and vehicle enhancement.

The renewable energy discussion directly relates both to the airports discussed in this research and the countries where they are located. Germany develops various sources of renewable energy that can yield "green electricity" such as hydro, solar, wind and biomass (Europe's Energy Portal 2011), whereas Austria does not have a reliable source for the hydropower development and Hungary has started investigating the "green electricity" opportunities connected with the solar and hydropower. Conclusively, the charging infrastructure is crucial for making the EV technology work at its full capacity and allow for the road transport to become carbon neutral. A combined development of batteries both for the storage of energy from the RES and use of energy by the EVs is a successful strategy to find the best technology that would satisfy both the consumers and the European goals of reducing the GHG emissions by the year 2050 (COM (2007) 19; Reiner *et al.* 2010; Directive 2009/28/EC).

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5.4 Other types of alternative fuel: hydrogen fuel cells, natural gas and biofuel

These types of fuel will not be discussed in depth in this paper, yet it is necessary to mention that many countries such as Germany and Austria research these technologies apart from the EVs in order to find the perfect solution for achieving the maximum energy efficiency and reduction of emissions from their vehicle fleets. All of these alternative fuels also work as substitutes for the conventional fossil fuel yet in different ways: (1) hydrogen fuel cell converts the chemical reaction into electricity, (2) natural gas is either compressed (CPG) or liquefied (LPG) and is burnt to produce energy and finally, (3) biofuel also has to be burnt in order to release energy for the vehicle propulsion (Harrop and Das 2011; Xuan *et al.* 2011). It is possible that in the future some of these alternative fuels would become more serious competitors with the conventional fuel and the electricity, yet many of these fuels have various difficulties associated with the production, safety or use at the moment.

5.5 Market development until the year 2025

According to general predictions, the next decade will be characterized by the growth of the hybrid market and less growth from the PEVs (Eppstein et al. 2011; Delucchi and Lipman 2006; Reiner *et al.* 2010; Galus *et al.* 2010; Harrop and Das 2011). Global sales of all types of hybrids and the pure electric vehicles are expected to grow by 25% and maximum 10% respectively. In order to significantly increase the numbers of sales for PEV market it will be necessary (1) for the government to introduce various financial and policy incentives and (2) for the battery technology to reach the maximum capacity that could compete with the conventional ICE vehicles. The biggest issues for the electric vehicles are the following factors:

(i) technological development of the battery,

(ii) extremely expensive original cost of the vehicles,

(iii) reliability of the charge on the road

(iv) the lack of the charging infrastructure.

Once there four factors are addressed by the vehicle and battery manufacturers together with the government and policy makers, the EVs will be able to increase in numbers on the European roads. After all, it is the cooperation between different stakeholders that will yield an effective integration of the EVs into the cities and towns. Thus, once the State prioritizes the environmental issues such as air pollution within the urban areas and demands to reduce the concentrations of road emissions, this will potentially give a push towards the new electric

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mode of driving. Prior to formulating concrete recommendations to the European and national government in terms of promoting the e-mobility, it is necessary to assess the current situation of the European and national policies of the countries where the airports of interest are located.

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6. Precursor Policies to E-Mobility Integration

6.1 European Union Policies and Strategies – Application to the Airports

The European Union currently views the concept of e-mobility integration into the road transport as an important precursor to the global warming abatement success (COM (2010) 186; COM (2011) 144; Directive 2009/28/EC; COM (2007) 19; European Commission 2009). Since the electric vehicles is a developing technology that can account for an almost complete reduction of the GHG emissions (excluding production cycles for both battery and vehicle), the international policy puts much hope into the ability of this technology to gradually displace diesel and petrol vehicles on the European roads (COM (2010) 186). Thus, currently the transport and climate change policies attempt to provide a platform for a successful integration of EVs into the daily European life and primarily the urban setting. This chapter will discuss only the most important international and national policies and strategies that were recently developed and target several aspects of e-mobility.

At the moment there are few policies and strategies that directly discuss the EVs and their integration into the urban transportation system. The most important vision for the Europe at the moment is the "*European Strategy on Clean and Energy Efficient Vehicles*" which was presented to the public in 2010 (Com (2010) 186). This policy discusses the benefits of the already existing technology and compares it to the prospects of the diesel and petrol vehicles within the next several decades. It identifies the potentials and obstacles on the way to achieving effective introduction of e-mobility to the modern society and touches upon various areas that will have to be closely investigated and covered by governmental incentives such as (1) the charging infrastructure standardization and availability according to the range of the modern EVs, (2) necessity to develop a reliable source of renewable energy for the mass consumption of EV owners, and (3) promotion of both the efficient and sustainable ICE technology together with the alternative fuel vehicles (hydrogen, LPG, biofuels, EVs, etc.) (COM (2010) 186; Directive 2009/28/EC). This strategy identifies the current absence of a coherent framework that would allow for effective integration of clean vehicles into the European setting. Amongst the proposed measures for creating a viable framework the European Union proposes to reduce even more the already imposed limit for the emissions generated by new personal vehicles of CO2 (130 g/km) before 2015 and also to impose a strict limit on the heavy duty equipment (COM (2007) 19). This latter aspect is crucial for the

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airports since many GSE equipments are heavily polluting sources since they use plenty of fuel. Thus, in case the EU will impose any type of taxation on the emissions from that sector of vehicles, the airport will have to pay.

The European strategy on efficient vehicles was derived from the Communication document on the "*Results of the review of the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles*" issued in Brussels in 2007 (COM (2007) 19). This document established the above mentioned threshold of the CO2 emissions for the passenger vehicles based on the EU commitment to the Kyoto protocol and the goal of "*reducing the overall emissions by 20% until the year 2020, where the comparison was based on the levels of the year 1990*" (COM (2008) 16; COM (2008) 17; COM (2008) 30). According to the original and the emergent documents, the road transport should be one of the key sectors that should intensively participate in the climate change abatement since its share of emissions is quite large (Directive 2009/28/EC; COM (2007) 19). Thus, the successful introduction of e-mobility, which can have zero emissions given renewable energy supply, coupled with the measures that will help the EV market grow and achieve competitive price range are essential steps on the way to reducing the anthropogenic impact on the environment.

The Fédération Internationale de l'Automobile, otherwise known as FIA is a European Bureau that pays special attention to the development of the transport sector in the whole world (FIA 2011). Recently the FIA issued a document called *"Towards E-Mobility: The Challenges Ahead"*, which focused on the aspects of successful EV integration into the urban setting such as market development, infrastructure standardization, change in the behavioral patterns of the citizens, technological development and other factors (FIA 2011). It also promoted the idea of e-mobility as the most sustainable option that could achieve serious reductions in overall GHG emissions worldwide, yet it identified the lack of legal framework within the EU at the moment, which could help promote the EVs among large companies and regular vehicle users. FIA issued this policy in accordance with the "*EU Commission White Paper on Transport*" that overviewed the introduction of the clean vehicles as a necessary strategy to satisfy the responsibility of the European Union and separate member states towards the Kyoto Protocol (COM (2011) 144).

Another regulation that might eventually include the emissions of the road transportation is the "*EU Emissions Trading Scheme*" (European Commission 2009; COM (2008) 16). At the moment ETS will start accounting for the emissions generated by the aviation industry, although previously this sector was not included into this scheme. Previous

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discussion on potential inclusion of the road transport into the ETS faced a challenge to define the bodies responsible for pollution. Since charging every car owner would be too complicated, there could be a possibility to charge the vehicle manufacturer. However, this possibility was abandoned and the road transport was excluded from the scheme. At the same time, current opinion is such that the road transport is one of the most polluting sources globally and therefore there is a possibility to integrate at least companies with large ground fleets into the EU ETS. Since the airports are large consumers of fuel such as diesel, it is possible that the next sector for the ETS application could be the airport emissions that are generated by the ground support equipment operations.

Last but not least, there is a policy directive that refers to the safety of the workers in enclosed working area and promotes the use of the electric vehicles where the concentration of emissions produced by the ICE exceeds the standards: "*Directive 2009/104/EC of the European Parliament and of the Council of 16 September 2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work (second individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)*" (Directive 2009/104/EC). This policy applied to all of the airports within the EU and specifically to the warehouse and the luggage assortment areas where the staff can get intoxicated with the by-products of combustion process such as soot and carbon monoxide. This way, electric vehicles prove their advantage of the ICE vehicles by means of having emissions-free and less noisy operations.

Among the proposed measures that were identified in all of the above mentioned policy documents, the key change will have to introduce the concept of e-mobility into the "*Directive 2007/46/EC"*, which at the moment is the leading document that describes the rules that apply to the road transportation within the EU (Directive 2007/46/EC; COM (2011) 144; COM (2010) 186). It is crucial for the European policy framework to devote special attention to helping the electro-mobility research and development and providing incentives for the present EV market in order to stimulate the reduction of harmful emissions and also stimulate the renewable energy development that goes along with the e-mobility concept. Also, the key tool for successful EV implementation is cooperation and partnership between different initiatives that are concerned with e-mobility such as, for example, the International Council of Clean Transportation and "*European Automotive Manufacturers, EUCAR*" (ICCT 2010; EUCAR 2009). Fruitful cooperation will yield a better understanding of the forces that could stimulate a more efficient integration of e-mobility into the European lifestyle.

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6.2 Applicable policies in Germany

The “National Conference on the E-Mobility Strategy” (“*Nationale Strategiekonferenz Elektromobilität*”) was held in Germany in 2008 (Berlin) and discussed the Governmental plans on introducing more than one million EVs to the country up until the year 2020 and five times as much by the year 2030 (Reiner *et al.* 2010; FIA 2011; DIW Berlin 2003). This conference resulted in establishment of the “National E-Mobility Development Plan” that was issued by the Federal Government a year later in 2009. Since the plan was established, the government started to provide financial incentives for the purchases of the electric vehicles such as the five-year “exemption from the annual vehicle registration tax” (Reiner *et al.* 2010). The government also supported the initiative of the major electricity provider RWE, which started investing into installing charging infrastructure stations throughout Germany. At the moment, the government is also considering investing into the R&D within the e-mobility field and organizing pilot projects for the EV integration in order to reach the maximum reduction of the country’s emissions within the next several years.

6.3 Applicable policies in Austria

Austria is also keen on implementing various pilot projects that involve the integration of EVs into various settings. One of the major incentives that the Austrian Government issued to the followers of the EV technology follows the German example and concerns the minimization of the vehicle registration tax (Reiner *et al.* 2010). Since the year 2000 several Austrian provinces invested into assessing their GHG emission rates in order to see which kind of alternative fuel (LPG, CNG or electric vehicles) would fit their plans in terms of providing incentives for the respective market and R&D.

6.4 Hungarian policy that relates to the e-mobility

Finally, the Hungarian national policy does not have specific policies that address the e-mobility at the moment, yet the Government provided several specific rules and regulations on the “*End of Life Vehicles and Tires*”(“*Government Decree on the end-of life vehicles*” issued in 2004) and waste that originates from the electronic equipment (“*Government Decree 264/2004 on taking back the wastes of electronic equipments*”) where the battery as waste is

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given special attention *("Government Decree on taking back of batteries and accumulators 91/157 (93/86, 98/101) EEC")* (The European Topic Center on Sustainable Consumption and Production 2009b; The European Topic Center on Sustainable Consumption and Production 2009c; The European Topic Center on Sustainable Consumption and Production 2009d; Reiner *et al.* 2010). Thus, despite the fact that Hungary does not yet provide any incentives to the companies or vehicle owners that invest into the EVs, it has a good policy base for the recycling of end-of-life vehicles and batteries which is the essential platform for the future use and disposal of the electric vehicles once they become popular on the national market.

All of the above mentioned policies have a major role in shaping current perception of the case-study airports on the integration of electric vehicles into their daily operations. The following chapter will provide an overview and analyze the drivers and barriers that were identified by the interviewed experts in the Frankfurt, Vienna and Budapest international airports.

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7. Frankfurt and Vienna International Airports: E-Mobility Perception

7.1 Current situation

Table 1 summarizes the entire scope of barriers and drivers identified by the experts from both Frankfurt and Vienna case-study airports.

Table 1. Key drivers and barriers to EV integration identified by three different airports and ELMU.

	Frankfurt International Airport		**Vienna International Airport**	
THEME	DRIVER	BARRIER	DRIVER	BARRIER
Financial aspect	*1. Increasing costs of conventional fuel 2. Long term savings 3. Incentives from manufacturers 4. Lifecycle and capital value cost of EVs 5. Low maintenance costs*	*1. High investment costs (EVs) 2. High inter-departmental leasing costs 3. No payback for commercial e-vehicles at the moment 4. Hard to obtain Governmental incentives*	*1. Increasing costs of conventional fuel 2. Long-term savings*	*1. High investment costs (EVs) 2. Competition with other alternative fuel (natural gas)*
Market aspect	*1. Ability to negotiate and convert vehicles through tenders 2. Plenty of specialized companies for GSE production*	*1. Availability of vehicles 2. Need to customize EVs for each airport*	*1. Ability to negotiate and convert vehicles through tenders*	*1. Availability of e-vehicles*
Organizational & Behavioral aspect	*1. Benefits of collaboration (Governmental authorities and other airports) 2. Voluntary accreditation schemes (ACA: (Carbon neutrality) 3. Competition and Brand image 5. Availability of Green electricity*	*1. Airlines are against high prices for EVs 2. Behavioral unwillingness to adapt to a new technology (Airlines, GH)*	*1. Benefits of collaboration (Government and Austrian Ministry of Environment) 2. Concern for the Environment 3. Competition and Brand image ("Green Airport")*	*1. Airlines are against high prices for EVs*

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R&D aspect	*1. Reliability for short-distance GSE sector* *3. Infrastructure* *4. Constant improvement of technology* *5. Safety* *6. Long vehicle life*	*1. No Reliability for long-distance sector* *3. Infrastructure in cargo center* *4. Maintenance location* *5. Batteries life and memory effect* *6. Competition with other alternative fuel (fuel cells)*	*1. Reliability of old technology* *2. Constant improvement of technology coupled with RES* *3. Safety*	*1. Maintenance facilities and space allocation* *2. Batteries life and memory effect* *3. Infrastructure* *4. Competition with other alternative fuels (natural gas)*
Policy aspect	*1. Policy on Worker Health and Safety (indoor and outdoor GSE)* *2. Potential ETS inclusion* *3. National and EU air quality regulations and GHG abatement* *4. Energy security*	*1. Internal policy is affected by Airlines and GH* *2. No exact policy for airports on EVs/only voluntary schemes (ACA)*	*1. Policy on Worker Health and Safety (indoor and outdoor GSE)* *2. National and EU air quality regulations and GHG abatement* *3. Energy Security*	*1. Internal policies are affected by Airlines and GH*

According to Table 1 we can conclude that both airports had a very similar perception of the factors that have either a negative or positive influence on the EV integration into the daily life of the airport. Since most of the identified drivers and barriers described above are identical, they will be analyzed further based on the five overarching themes or categories that were used as a backbone for grouping the results such as (i) financial, (ii) market, (iii) organizational and behavioral, (iv) R&D and (v) policy aspects. The mentioned themes will be discussed one by one in the order shown above with the financial aspect being the first topic

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and the policy aspect the last one. Moreover, each theme will go into further analysis of first drivers and then barriers that came across the interviews.

7.2 Financial aspect

This theme was created based on the constant referral of both case study airports to money and savings as the key components of EV integration. Within this section both Frankfurt and Vienna airports discussed primarily the expenses associated with the EVs, which were either justified for the airport purposes or on the contrary were considered a complication on the way to introducing e-mobility.

7.2.1 Drivers

1. Increasing costs of conventional fuel

Global crisis and overall awareness about depletion of oil resources made major transportation sectors realize that gasoline and diesel might not be the most reliable fuel for the future. The escalating trend for the prices for both diesel and petroleum (gasoline) became one of the key concerns of large companies like airports where the necessity to reduce the overall costs of fuel is constantly discussed by both Vienna and Frankfurt airports. According to rough estimates, the cost of diesel approximately constitutes 8-10 euros per 100 km, whereas the electricity recharge needed to cover the same 100km is approximately 3-5 euros (Eibensteiner pers. comm. 2011, Nichtenberger pers. comm. 2011, Weber pers. comm. 2011). Figure 6 demonstrates the trend for the increasing fuel prices in Europe for the period of 2007-2011.

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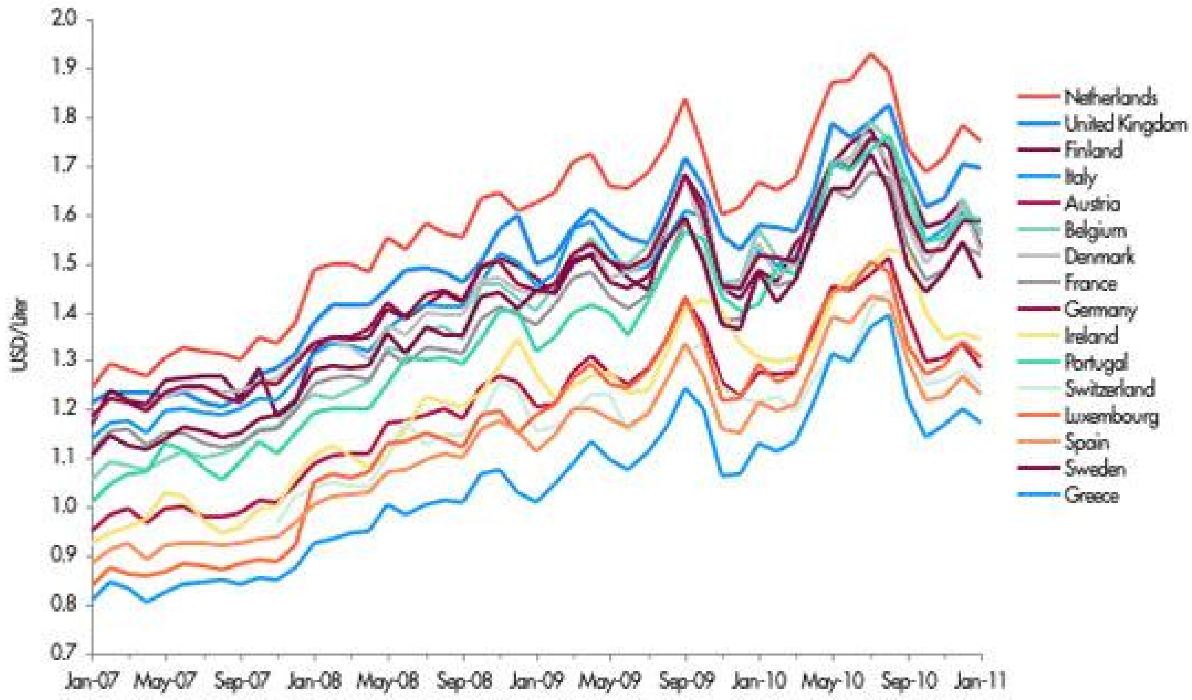

Figure 6. *This figure demonstrates the trend for the fuel prices in USD over the period of 4 years, which encompassed the time of the crisis (Source:* ***http://www.shell.com****).*

Frankfurt as the third largest airport in Europe handles more than 120 airlines and has to provide for a non-stop ground handling operations in order to service all of the incoming and departing flights (Frankfurt International Airport 2011). According to the discussion on GSE most of the heavy-duty trucks that operate at the airport have large fuel tanks and usually exhaust plenty of fuel. Frankfurt alone has a capacity of approximately 9,000,000 liters of diesel fuel that the entire fleet uses per year due to the large scale of ground operations (Weber pers. comm. 2011). The amount of fuel used for daily services comes at large costs that tend to increase each year and can be roughly calculated according to the current price of diesel in Germany, which is supposed to be cheaper than gasoline (July 19, 2011: gasoline is 1.558euros per liter) (Europe's Energy Portal 2011). One liter of diesel fuel (as of July 19, 2011) costs approximately 1,406 euros yet a regular market price cannot be used for calculating the expenditures of the Frankfurt airport since at least the 20% VAT value is extracted from that cost for the airport purchase (Weber pers. comm. 2011). Thus, the crude airport price for liter of diesel now is equal to 1,1248 euros. For rough estimation purposes this calculation shall imply the price for diesel was constant throughout the year and the amount of fuel used by 3,500-unit fleet was equal to exactly 9,000,000 liters (Weber pers. comm. 2011). Thus, the airport is subjected to rough annual payment equal to 10,123,200

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euros (where additional VAT would account for the additional 2,530,800 euros on top of this sum) for the entire airport fleet for the whole year given steady diesel prices and use of the same vehicle fleet without any additional purchases. The fleet consists of approximately 3,500 vehicles, where 1000 are light commercial vehicles and about 300 vehicles already have electric engines. Every vehicle consumes different amounts of diesel and will yield different prices per year (Eibensteiner pers. comm. 2011).

An electric substitute for GSE such as for example conveyor belt loader that is designated to load and unload luggage from the aircraft, can be much more efficient in terms of operational costs given the price of electricity needed for its steady operation. In order to measure a crude cost for operating an e-conveyor, it is imperative to realize that the amount of diesel and amount of electricity used at the airport is calculated per working hours, not driven kilometers since many vehicles use most of the fuel while parked during operations (for example, loading and unloading cargo). A standard loader consumes between 0.58 and 1 euros per 1-hour work, which for the full working day of 8 hrs (one shift) constitutes approximately 8 euros. For airport as the industrial consumer in Germany the average price for 1 kWh is 0.72 euros (Europe's Energy portal 2011; Weber pers. comm. 2011). This way, 365 days will yield approximately 2920 euros for working only 8 hr shift whereas in reality these belt loaders work from 6 am to 12 pm (18 hrs shift would amount to 6570 euros per years). Yet this is just the price for the number of working hours and electricity cost for each of them.

If we consider investment costs and hours that are operated by the battery, the numbers will significantly change. For example, a typical e-conveyor belt loader purchased by the Frankfurt airport in the year 2000 cost 71, 989.71 euros (Weber pers. comm. 2011). Just for a comparison, a normal diesel belt loader bought approximately the same time cost 45,898.67 euros. Thus, the difference between the prices of two different engines accounts for 37,908.96 euros! This is almost the price of a new diesel conveyor belt loader. According to the data collected by the Frankfurt airport, the average maintenance costs associated with the piece of this electric equipment was equal to 16,106.00 euros and the maintenance of electric battery per year amounted to 440 euros. Finally, running hours of engine yielded annually the cost of 6523.50 euros for this units of GSE. The average lifecycle cost of electric conveyor belt loader for three consequent years was approximately 137,000 euros and the capital cost was calculated to be 116,950 euros (Weber pers. comm. 2011).

The major difference between the electric and diesel loaders lies within the fuel consumption, where each consequent working hour the diesel counterpart uses approximately

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4.90 euros worth of fuel. All in all, final cost for three years of not as much operation as the e-conveyor performed and average fuel costs per year amounting to 10970 euros the average lifecycle costs was 155,000 euros and the capital cost was 123,700 euros (Weber pers. comm. 2011). Given this difference it is obvious that within 3 years the cost of electric conveyor belt loader is paid back. Yet the price of the electric GSE unit compared to that of a diesel alternative is drastically more expensive – almost the entire price of a new diesel vehicle! However, given such a fast payback in only 3 years it is obvious that the electric conveyor belt loaders are an efficient way to save money. Therefore it is crucial to test the equipment prior to purchasing more units in order to calculate the payback time of the unit and to understand whether the e-vehicle is more cost-efficient considering the prices for both the unit and the battery and whether it yields more savings in a long term.

2. Long term savings

The previous chapter described in depth the financial differences between operational costs of electric vs. diesel equipment such as the conveyor belt loader. Generally, if the airport would look only at the operational costs of the equipment, it would most probably choose electric vehicles. Since the electricity price at the moment, which is much cheaper than the diesel price per liter (0.72 euros per kWh vs. 1.1248 euros given 20% VAT reduction per one liter of diesel) looks more attractive in a long term, it is expected to benefit the airport by allowing for financial savings, which could be further spent on investments into energy efficiency of the airport terminals or charging infrastructure (Europe's Energy Portal 2011). The Vienna airport emphasized the importance of savings yielded by the EVs since it is extremely keen on reaching the "Green Airport Standard" within the foreseeable future (Nichtenberger pers. comm. 2011). The Frankfurt airport is also preoccupied with this matter since it was the first ACA-accredited airport, which is on its way to the "Carbon neutrality" status (ACI Europe 2010).

3. Incentives from manufacturers

At the moment the production of EVs is restricted to a small size and hence is extremely expensive for both manufacturers and potential customers. One of the most attractive tactics to interest a potential consumer such as an international airport would be to reduce purchasing or leasing cost if the consumer purchases several vehicles at the same time. According to the Frankfurt airport there are many different small or medium enterprises that

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specialize on manufacturing electric vehicles and practice such offers. The Frankfurt airport is particularly interested in sharing its concerns and interests in new technology with partner airports, which might also express their interest in this new technology. Thus, when several airports such as Dresden, Hamburg, Leipzig and Stuttgart support the Frankfurt airport in ordering a new EV model, they will be able to claim significant reductions in costs for the overall order from such companies as GBT (American) and Mulag (local German) (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011).

4. Lifecycle and capital value cost of EVs

The Frankfurt airport specifically mentioned these drivers for the EV integration since it is rather important to consider the long life of EV unit and estimate its value for the future (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011). At the moment this value remains rather high compared to that of a regular diesel alternative unit, where the ICEs tend to develop and become better with time in terms of fuel consumption and lifecycle costs, yet the electric vehicles outweigh that development at the moment due to the cheapness of electricity and their low consumption of this it (Weber pers. comm. 2011).

5. Low maintenance costs

Finally, this driver is also extremely important within the financial aspect since all of the GSE units need to undergo regular maintenance due to safety prerequisites (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011). Frankfurt airport mentioned relatively low maintenance costs as an important driver for expanding its EV fleet, which is important to discuss in order to account for any potential drawbacks of this technology. Indeed, since EVs have a very expensive investment cost, which is discussed in the next chapter, it is essential to recognize the opinion of the case study airports on potential maintenance issues. However, according to the Frankfurt airport, the maintenance costs are rather low and EVs do not demand more attention than the regular ICE vehicles. Infrequent repairs coupled with long life of an e-unit support viability of this technology that saves the customer its money.

7.2.2 Barriers

1. High investment costs (EVs)/ High inter-departmental leasing costs

Investment costs came as the first barrier to EV integration in both Vienna and Frankfurt conversations, where modern EV technology is still undergoing some changes and is

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not mass-produced at the moment. Economies of scale or mass-production of EVs would help reduce the cost of the battery and engine within the GSE area (Eibensteiner pers. comm. 2011). In fact, this barrier is crucial for the airport as an organization since despite its willingness to reduce its GHG emissions within the ground transportation sector, both the GH Company and the airport itself might encounter problems with budget allocations that might not allow for a large EV fleet purchase. This is one of the major reasons for slow integration of EVs into airport fleets throughout the countries of the European Union since the airports will need to carefully plan ahead for the types and the number of vehicles they would like to purchase.

At the moment electric light commercial vehicles are extremely expensive compared to the normal ICE cars, where the difference in prices is determined by the cost of battery and maintenance. Frankfurt airport is currently in possession of several light vehicles, which include two Mitsubishi iMiev units provided by a Mitsubishi representative in Germany (Mitsubishi Motors) and a Chevy Matiss that was specifically converted into the EV according to the Frankfurt airport's request by a vehicle company located in Dresden (Eibensteiner pers. comm. 2011). Currently the new updated version of iMiev is expected to cost 30,000 euro for just the basic model. At the same time, the Japanese Mitsubishi website recently announced the price of approximately 16,000 euro for the same model (Mitsubishi Motors). Thus, the original price of the commercial EV would serve a barrier to the leasing of these vehicles to other departments within the airports where the investment cost will increase the cost for leasing significantly and make it unattractive. According to both Frankfurt and Vienna airports the differences between the costs for the light commercial vehicles and heavy-duty vehicles for the GH purposes depend on the payback time, which will be described further on (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011).

3. No payback for light commercial e-vehicles at the moment

Mr. Weber, one of the key technical GH experts at the Frankfurt airport mentioned that according to the airport practice one sector of purchased vehicles that cannot reach a payback for its original costs are the light commercial e-vehicles. Currently the price for light EVs is so unreasonably high that it makes it unattractive to use the EV technology instead of the regular gasoline vehicles. According to both Mr. Eibensteiner and Mr. Weber from the Frankfurt airport, despite a potentially better technology of electric engine in regular light vehicles, at the moment it is not as accessible as the e-GSE with a faster payback time (3-7

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years out of approximately 11-15 years on average of operation). Thus, since EV technology for the light vehicles is too expensive at the moment, there might be a possibility to look into other alternative fuels such as natural gas or hydrogen fuel cells (Weber pers. comm. 2011).

4. Competition of EVs with other alternative fuels (natural gas, hydrogen fuel cell)

The Vienna airport made its choice in terms of light commercial vehicles used on the apron such as "follow me" cars and ramp agent cars where it purchases a natural gas fleet of caddies. Thus, currently a better option might be other alternative fuels such as natural gas within the sector of light commercial vehicles used at the apron (Nichtenberger pers. comm. 2011)

5. Hard to obtain Governmental incentives

The Frankfurt airport identified this barrier due to its experience with the time needed for providing all the necessary requirements and paperwork in order to qualify for the proposed subsidies. Currently the Governmental incentives idea is under development in the European countries compared to the United States where the incentives from such organizations as the Federal Aviation Administration (FAA) or the Department of Energy (DOE) are a regular phenomenon (Clean Airport Partnership 2001; Harrop and Das 2011). One governmental subsidy that works extremely well at the moment is the car registration tax and saves approximately 63 euros off of each newly purchased vehicles (Eibensteiner pers. comm. 2011). When it is several vehicles that require this registration tax, then the benefit of this policy becomes obvious.

7.3 Market aspect

The market aspect plays a significant role in shaping the perception of the EVs where the attraction for the customer depends on the availability of vehicles, their price and variety of customized options. This analysis has already touched upon the extremely high prices of the commercial e-vehicles that are never compensated throughout the lifetime of the vehicle. Currently interviewed experts from both airports mention two key drivers that address the fate of the GSE on the market that are discussed below (Eibensteiner pers. comm. 2011; Nichtnberger pers. comm. 2011; Weber pers. comm. 2011).

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7.3.1 Drivers

1. Ability to negotiate and convert vehicles through tenders

Market for the EVs has been mentioned several times by all of the respondents from both case study airports, where at present there is a possibility for the end-user to negotiate with the manufacturer and to obtain the most suitable option of a vehicle that would perfectly suit the pre-set purposes. According to the Frankfurt Airport, there is a chance to request an upgrade of the lead-acid battery capacity for the Ground Handling Equipment since the weight of the units does not matter within this sector (Weber pers. comm. 2011). It might be a good idea to have an enlarged capacity of battery specifically for the pushback tractors, which are currently available in the EV prototype edition and deal with large and heavy loads of the aircrafts. This way, more capacity would provide for longer hours of work time and ability to push bigger aircrafts. Another aspect of the market that was mentioned by the Frankfurt airport were the benefits of the tenders, which allow for a fair competition between different electric equipment manufacturers for a better price and more suitable electric units for the airport. This way the airport will be able to get a full scope of the market offers and make the best choice (Eibensteiner pers. comm. 2011).

2. Plenty of specialized companies for GSE production

Another driver within the market sector is the competition and availability of various specialized manufacturing companies that focus on the GSE production within both Austria and Germany. According to the experience of both airports, it is worth investing time into market screening in order to have several different suppliers for all kinds of equipment. This way, the airport and the Ground Handling services will be able to get the best equipment with desired characteristics such as long life, enhanced range and battery capacity. For example, Frankfurt utilizes such companies as Mulag and GBT (American production) (Einebsteiner pers. comm. 2011; Weber pers. comm. 2011). Vienna airport is also keen on choosing the best players within the ground-handling arena in order to expand its fleet (Nichtenberger pers. comm. 2011). This way, given the current unsteady market for electric vehicles and maintenance, large consumers such as airports have a privilege in requesting specific types of GSE and choosing from a range of various suppliers.

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7.3.2 Barriers

1. Availability of vehicles

Despite the previously mentioned ways to overcome such issues as market gaps within the area of electric ground support equipment, right now the availability of vehicles is still scarce. According to the experience of the Vienna airport only a limited number of electric vehicle types can be purchased at the moment such as tow tractors, fork-lifts, conveyor belt loaders, passenger stairs and right now there is a development within the field of high-loaders (Nichtenberger pers. comm. 2011). Other types of GSE that are designed to travel over longer distances are still under development due to technical difficulties, which will be further described in the R&D section. Thus, the airport would not be able to automatically switch into a completely electrical fleet even if it had both funds and the willingness to do so at the moment. Once more types of vehicles are tested and supported by the demand from the airports the conversion of GSE into the electric engines will become more accessible (Eibensteiner pers. comm. 2011).

2. Need to customize EVs for each airport

Once again, the need for the customization of electric types of GSE can be both a trigger and a barrier for the airports on their way to the electrification of the fleet. Once an airport decides to switch a specific type of a vehicle such as a high-loader into an electric mode, it might experience issues with choosing from the already existing types of high-loaders that are present on the market and do not necessarily fit the airport's requirements. The offered option from the manufacturer might be too big or too small and thus the airport will either have to explore options for importing GSE from another reliable company or request a special type of the vehicle to be made separately, yet this option might cost even more than purchasing an available e-vehicle and then adapting ground handling operations to it (Eibensteiner pers. comm. 2011).

7.4 Organizational & Behavioral aspect

The organizational structure within the airport encompasses collaboration between and within different departments where the goals that the company puts forward for its employees shape their priorities. In terms of energy efficiency for example the Environmental Health and Safety Department might see the priority in modifying the fleet of the Ground Handling Department whereas the Ground Handling Department has a different priority of reducing the

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costs of the expenditures associated with purchase of new equipment (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011; Weber pers. comm. 2011). It is the ability to negotiate priorities that helps the integration of EV technology into the vehicle fleet at both the Frankfurt and the Vienna airports, where all of the projects need to be thoroughly tested first before any conclusion is reached on a new technology (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011).

7.4.1 Drivers

1. Benefits of collaboration (Governmental authorities and other partner airports)

Since we have already discussed the necessity to pursue collaboration within the airport environment already, it is crucial to look into an overarching cooperation that might have a positive effect on the EV integration into GSE fleet at the airports. In case of Frankfurt, there is a strong positive political pressure that comes from the State of Hess and the city of Frankfurt, which helps the airport justify its expenditures for the expensive electric fleet. Currently the area of Frankfurt is considered to be the "environmental zone" (Eibensteiner pers. comm. 2011) that pays close attention to the maximum permissible concentrations of various air pollutants within and outside of the city center with the help of specialized monitoring stations. At the moment the Frankfurt airport is not a legal part of this environmental zone but it expects an initiative from the local authorities and EU legislation, which will bind it to join the "environmental pilot project". With this in mind, the airport has to strictly monitor its air quality due to the emissions threshold level established by the city of Frankfurt. Right now the regulation is such that the maximum permissible concentrations for the air pollutants cannot be breached more than 40 times per year and according to the Frankfurt airport estimations the air pollutant concentrations surpass the threshold more often than that (Eibensteiner pers. comm. 2011). Thus, cooperation between the government and the airport promotes the e-mobility initiative of the airport due to its ability to abate the concentration of current emissions from the fleet. Additionally, another cooperation is present at this airport, where the Frankfurt airport also involves other neighboring airports (Dresden, Stuttgart and others) when in need to order new e-equipment. Since more technical equipment can be ordered from the manufacturer given a larger demand from several airports, all of the parties can expect a discount on the ordered equipment units.

As for the Vienna airport, there is a close collaboration between the Austrian Ministry of Environment, the authorities of Austrian provinces and the airport itself, which targets the

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most efficient integration of e-mobility project into the daily operations of the airport (Nichtenberger pers. comm. 2011). The airport gets state support for expanding its vehicles fleet and also invests into devising a strategy for reducing its emissions levels in a long term. This way, a joint effort of municipalities, state authorities and different airports manage to yield a productive platform for successfully introducing electric vehicles into the airport functions.

2. Voluntary accreditation schemes (ACA: carbon neutrality)

The Frankfurt airport was the first one to be accredited by the ACA system and thus embarked on a journey of reaching the goal of "carbon neutrality" (ACI Europe 2010). An internationally recognized accreditation scheme like ACA is an inspiring opportunity that shows that the airport cares both about its environment and safety given its plans to reduce the overall anthropogenic impact on the surroundings. The ACA scheme implies going through several different stages where the first stage demands the airport to declare its carbon emissions and leads to the final stage when the airport is officially declared to be "Carbon neutral" (ACI Europe 2010). Due to this initiative the Frankfurt airport has an impetus to expand its e-fleet and address other sectors that yield high concentrations of pollutants within the airport. Thus there is a reason to first identify the vehicles that would produce the best CO2 abatement results if changed into the electric engine. This strategy allowed for the airport to identify the conveyor belt loaders, high loaders, luggage tractors and other equipment as the best sector to introduce the EVs to since the operational costs of diesel counterparts and their CO2 emissions were very high (Figures 7-11).

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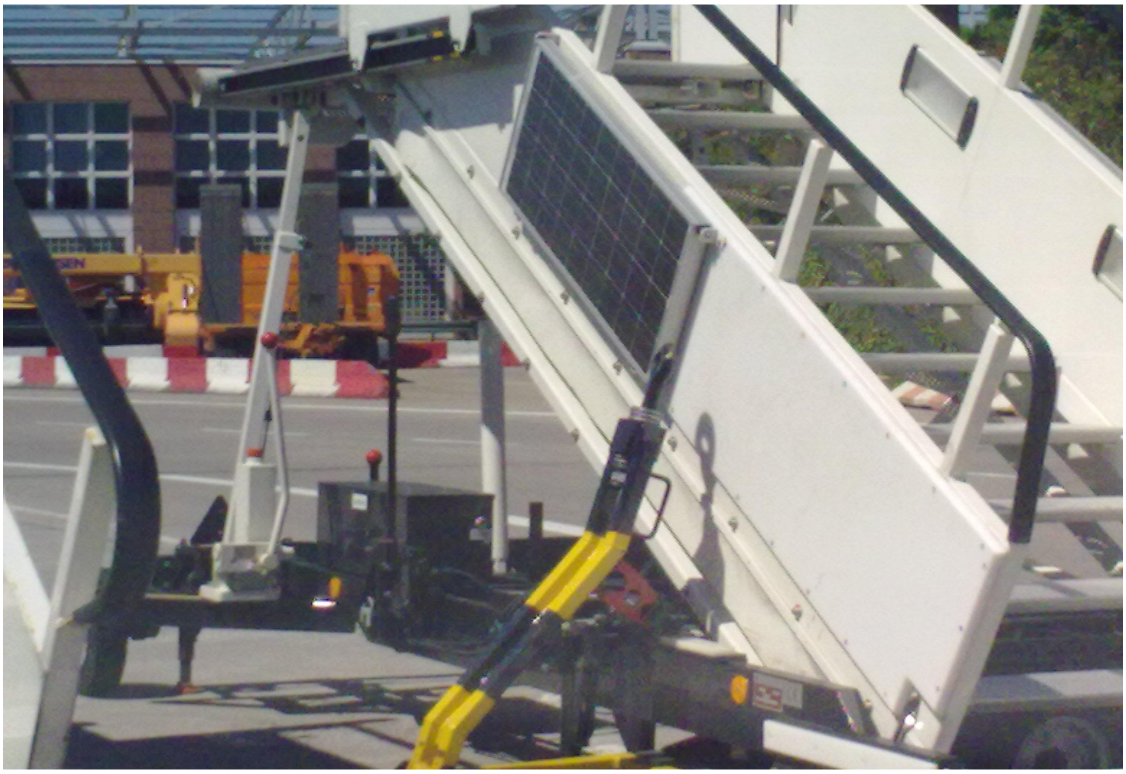

Figure 7. *Solar powered Passenger stairs at the Frankfurt Airport. The picture was taken during the visit to Frankfurt Airport.*

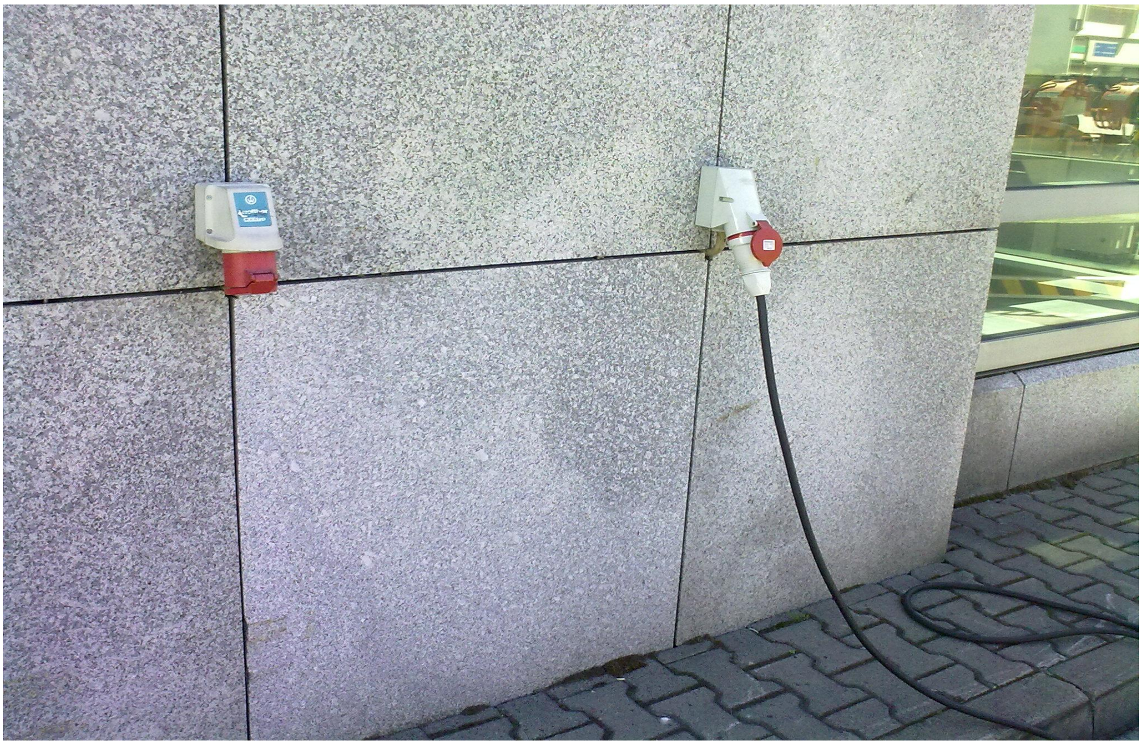

Figure 8. *The electric high-loader plugged into the wall socket (photo taken at the Frankfurt Airport)*

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Figure 9. *Electric high-loader (on the left there is a chord that is switched into the plug on the picture above)*

Figure 10. *Hybrid tow truck at the Frankfurt International Airport*

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Figure 11. *The pack of the lead-acid batteries used for the hybrid tow truck above.*

Additionally, such a voluntary scheme allows for the airport to follow current regulations of the EU on allocated emissions for Germany. This way, the Frankfurt airport is a responsible body that aims to reduce the emission burden of the state (Eibensteiner pers. comm. 2011).

As for the Vienna airport, it does not have an international voluntary accreditation scheme at the moment but it it is aiming to achieve the status of "Green Airport" within Austria sometime in the foreseeable future (Nichtenberger pers. comm. 2011). The environmental strategy of the Vienna airport is carefully planned by its Environment, Health and Safety Department in close collaboration with the Austrian State and the Ministry of Environment as it was previously mentioned. The Vienna airport participated in the "mediation project" that assessed total emissions not only for the airport but also for the local provinces and other shareholders from 2000 until 2005 (Vienna International Airport 2011). Participation in this pilot project created a good environment for the EV fleet expansion at the airport, which is currently looking into more options to satisfy its environmental goals.

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Additionally, the airport closely monitors its noise pollution and attempts to enhance its performance annually. This way, voluntary schemes and projects provide a valuable trigger for the EV initiative where the airports devise a strategy and a plan to achieve its final goal of emissions reduction (Nichtenberger pers. comm. 2011).

3. Competition between airports for the better brand image

Within the European Union a concept of competition between closely located airports becomes a trigger for reducing their prices and enhancing air quality. This competition allows the airport with a more "environmentally friendly" profile to attract more airlines and thus more passengers in order to boost the airport's revenue (Gillen and Neimeier 2006). For example, although Vienna is a key connection hub within the Central Europe it still has competing neighboring airports in Bratislava and Budapest, which might offer the better financial and organizational environment for the airlines. On the one hand, bringing EVs into the daily operations will lead to lower fuel costs after the payback time, which could reduce the overall payments of the airlines for the GH services and become a trigger for the airport to invest into more EVs. At the same time, it is very difficult for the Vienna airport to impose a quick conversion of a regular vehicle fleet into the EVs since it has to consider the additional costs that the airlines will have to pay for the investment costs into EVs, which are very high at the moment. Thus, the competition and brand image can be both a trigger and a limitation at the same time for the company that considers purchasing large fleets of EVs (Nichtenberger pers. comm. 2011). The same applies to the Frankfurt airport and other national airports located nearby (Eibensteiner pers. comm. 2011).

4. Availability of Green electricity

Finally, another driver within the organizational section is the green electricity provision for the airport. Technically, once this technology exists and allows for a relatively cheap (in comparison with diesel prices) fuel provision for the e-fleet at the airport, the company will have more willingness to switch from its conventional fuel dependence to a new source. This driver arises from the awareness that just switching from diesel to coal-produced electricity might only shift the burden of emissions onto the already existing power plants given mass production of EVs in the future (Nichtenberger pers. comm. 2011). This way, the Frankfurt airport established a connection to the major producer of the geothermal energy (RWE) where this source provides for both heat and electricity supply at the airport. Thus, the

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airport can claim that the introduction of EVs achieved an almost 100% reduction in GHG emissions due to the renewable energy supply (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011).

Another point of view towards "Green electricity" belongs to the Vienna airport and its use of the natural gas vehicle fleet (Nichtenberger pers. comm. 2011). Natural gas is considered to produce much less emissions (approximately 30% reduction) that diesel and thus is a more environmentally friendly fuel. Yet natural gas is not considered a renewable source and does not allow for an absolute abatement of emissions in a long term compared to the renewable energy and electric vehicles. Austria, however, is investing into its wind power and thus can choose a renewable energy mix for its electricity provision.. This way, "green electricity" does serve as one of the drivers for EV integration at the airports.

7.4.2 Barriers

1. Airlines are against high prices for EVs

A previously mentioned barrier, the attitude of the airlines towards increasing costs charged for their operations at the airports is usually negative (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011). If the GH services are forced by the airport management board to invest heavily into the e-fleet, they will project their expenditures onto the costs of their services provided for each airline. This way, the airlines might be faced with a choice of either paying plenty of money in order to compensate for the GH investments and therefore increase prices for the passenger tickets or to refuse to use this particular GH service or even an airport itself. Thus, given that the money issue is extremely sensitive at the structure like an airport where each large investment will be compensated by the airport tenants (airlines & GH), the airport board has to be very careful with its EV integration strategy timeline and plan for potential subsidies instead of putting the entire financial load onto the GH services and airlines

2. Behavioral unwillingness to adapt to a new technology (Airlines, GH)

Finally, this barrier is also imperative to consider since some companies might be scared of the change if they do not have enough knowledge about the technology and benefits it might bring. This behavior can be observed within the airport departments, GH services or airlines where the "old yet tested" technology seems to be more reliable than the new one (Eibensteiner pers. comm. 2011). This barrier can be overcome by means of educating different departments about benefits and issues associated with EV integration and careful planning for a slow introduction of the technology into the airport's life.

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7.5 R&D aspect

7.5.1 Drivers

1. Reliability for short-distance GSE sector

In their interview, both Mr. Weber and Mr. Eibensteiner distinguished the GSE types according to their operations and purposes at the Frankfurt airport in order to demonstrate the most suitable transportation sectors for EV substitution (Nichtenberger pers. comm. 2011; Weber pers. comm. 2011). The Frankfurt airport devises three categories for their GH equipment that is operated usually by the ICE engine (excluding the vehicles without engines):

- Short distance, low speed, working engine while the vehicles are parked (high-loaders/pellet loaders/lifting platforms, conveyor belt loaders, passenger stairs, forklifts, some tractors)
- Long distance, high speed, engine works mostly during driving ("follow me" cars, ramp agent cars, pushback tractors, luggage tow and freight tractors, passenger stairs, water waste, lavatory and catering trucks, fuel truck, tractors, container transporters, de-icing vehicles and other vehicles (cabin cleaning, vans, etc.))
- Passenger vehicles (buses, mini-vans)

According to the experts' opinion, the best sector for successful EV integration at the moment is the category with short distances, low speed and high fuel consumption in a parking mode. Given the previously described limitations of the e-technology in vehicles, this choice is justified since most batteries used in the GSE are lead-acid, which can only do long ranges only if they are present in large numbers. More lead acid batteries significantly increase the vehicle weight and size. Although almost none of the GSE vehicles are restricted in terms of their size and weight, there are standards that the manufacturers rely on when producing e-prototypes of diesel alternatives. In order to get a longer range for the battery capacity, the airport would need to customize the vehicle with the manufacturer, as this thesis has already discussed in the previous section (Weber pers. comm. 2011). Currently out of all vehicles that fit the short range-low speed category, the one that is easily modified in terms of its weight and size is the pushback tractor. As it was previously mentioned, there is an electric prototype for the pushback tractor at the moment that circulates around different airports if Germany, which unfortunately does not perform to the standards of the Frankfurt airport in terms of carrying the aircrafts back and forth between the cargo and the apron compared to the

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performance of the diesel tractor. Thus, the airports can count on reliability of the electric vehicles within the short distance-low speed category at the moment.

The same principle is adopted in the Vienna airport, where the categories of vehicles that are converted into EVs are tractors (plus one with the load area), forklifts, conveyor belt loaders and three towed passenger stairs. Mr. Nichtenberger supported the emphasis of Mr. Eibensteiner and Mr. Weber about the responsibility of the airport towards providing efficient and fast support for the aircraft maintenance and passengers and thus it can only adopt the technology, which is predictable in its performance. Thus, until new technologies are well tested and become available such as the lithium ion battery, for example, which would allow for a longer range and faster overall speed of the GSE, the airport can only use the short-distance equipment that it can rely on (Nichtenberger pers. comm. 2011).

2. Infrastructure

Currently most of the GSE units have the opportunity to charge their electric batteries within the proximity of the terminal in between the airport peak-hours, which are different throughout the week due to the different schedules of incoming aircrafts and usually occur in the morning, late afternoon and evening (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011). The charging infrastructure is as simple as a regular electric plug that is able to provide full recharge on average within 6 to 8 hours. The working hours during which the equipment is able to operate per one charge differs according to the use pattern of the vehicle, where for the same types of machinery (for example, forklifts) some units will be used more heavily than others according their location on the apron and the number of the incoming flights within that zone (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011). For example, extensively used forklifts will be capable of operating for 3 to 4 hours and less used ones will recharge once in 8 hours. The airport in Frankfurt also has a public charging station that is used for both electric and diesel light vehicles at the moment. Given careful planning of EV operations and precaution in terms of recharging the units when they are not operated, a simple solution such as a plug will be able to make the EV technology more available throughout other airports as well.

3. Constant improvement of technology

One of the benefits of technology is the fact that it never stumbles upon development. Today's technology, especially within the sector of battery research, is extremely promising

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due to the inter-sector interest in battery capacity. Battery and vehicle manufacturers are not the only sectors, which are keen on a competitive performance of their battery – it is also the Renewable Energy sector (Nichtenberger pers. comm. 2011), which needs more efficient batteries for storage. Given this shared interest, the battery producers have a double incentive to improve the already existing battery technology and to discover alternative options for the battery components in order to make it more accessible for the general public and specialized companies such as airports. At the moment both Frankfurt and Vienna representatives are very satisfied with the performance of electric batteries within one of the transportation sectors, yet improving technology might be able to allow for EV introduction in long distance-high speed fleet of the airports as well (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011; Weber pers. comm. 2011). Thus, the daily evolution of the e-technology might eventually solve all of the urging needs of the airports all over the world in terms of battery capacity and competitive daily vehicle performance that could perform to the standards of or even better that the diesel technology.

4. Safety

The Frankfurt and Vienna airports both are very satisfied with the performance of their GSE and light commercial vehicles in terms of safety (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011). All of the functioning units within the airports are accredited according to the national requirements and are allowed on the premises of both the airport and German and Austrian roads. Additionally, Mitsubishi iMiev vehicle went through the standard crash-test and according to German standards it received a good rating for its safety performance, which is a competitive level of safety with the regular diesel alternatives (Eibensteiner pers. comm. 2011). It is important to understand that there is a need for maintenance for every type of the vehicle, whether it is heavy-duty or light one, diesel or electric. In terms of the EVs it might be even cheaper to get a discount on the overall maintenance since public incentives from the manufacturers are rather developed in terms of large orders from the airports. Given an increase in production and sales of electric GSE, the overall prices will most probably drop and the safety precautions will enhance due to the increase in public investment and interest.

5. Long vehicle life

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Finally, the last identified driver concerns the lifetime that is characteristic for the electric vehicle nowadays. Given proper maintenance and overall care these vehicles within the GSE sector are capable to serve anywhere from 12 until 15 years on average (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011). If the battery inside the system cannot hold the charge any longer, there is an opportunity to replace it with another one or even upgrade to a larger capacity (2 instead of 1 battery). At the moment this driver also mentions the fact that a diesel engine is more prone to the damage caused by the ICE work compared to a cleaner engine of the EV where no exhaust is produced and hence the battery functions at a steady pace (Harrop and Das 2011; Taylor 2008).

7.5.2 Barriers

Despite a variety of drivers that were explained in the beginning of the R&D section, there are also numerous limitations within the technology aspect that currently need to be solved in order to make the e-technology more acceptable for different sectors of the airport transportation.

1. No Reliability for long-distance sector

Although the short-distance sector of the airport transportation works perfectly well with the EV technology given careful planning and the training of personnel, the long-distance sector cannot rely on the existing GSE battery technology (Weber pers. comm. 2011). Although there is a constant development within the battery capacity and performance, not all of the recently introduced improvements such as lithium ion or nickel metal hydride batteries were tested on the heavy-duty equipment. The behavioral need to first see the benefit of technology before purchasing it prevents the airports as well as other companies from testing the least explored options. This behavioral pattern is justified by the airport operations, which prioritize efficiency and have to satisfy its customers no matter what equipment is used. This way, since no reliability for the e-vehicles for the long-distance performance exists, the airport will not experiment until the technology will be better explored (Eibensteiner pers. comm. 2011).

2. Infrastructure in cargo center

It is very easy to establish a basic infrastructure such as regular electric plugs within the electricity supplied terminal area (Eibensteiner pers. comm. 2011). Another heavily used

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sector of the airport is the cargo hub, which is usually separated from the main passenger terminals and located on the outskirts of the airport. This zone does not necessarily have efficient electricity wiring that would satisfy the charging needs of different types of GSE simultaneously (Weber pers. comm. 2011). This way both interviewed airports allocated the majority of the EVs used at their premises towards the apron service whereas the diesel units usually supply the cargo area (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011; Weber pers. comm. 2011). Even if an electric unit will be needed within a closed warehouse it will have an option to solely use a regular plug inside the premises since there will not be a large number of such vehicles claiming regular recharge and not having an infrastructure for it. Thus, if the airports wanted to expand the EVs into the cargo area, they would have to modify the infrastructure, which is hard to do at the airport.

3. Maintenance location

Mr. Nichtenberger identified maintenance needs as another significant barrier to the use of EV technology within the Vienna airport. In fact, it requires more space for the actual works on the equipment, more trained professional personnel within this field and the knowledge in arranging contracts with the manufacturing companies in order to distribute responsibilities in case the battery is damaged or needs major maintenance works due to malfunctioning (Nichtenberger pers. comm. 2011). The same barriers came up during the interviews with the experts from the Frankfurt airport that expressed an explicit desire to allocate a responsibility for the battery malfunctioning to the manufacturer due to the originally high investment costs of the vehicle itself which did not justify more expenses for the battery malfunction (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011).

4. Batteries life and memory effect

This section was discussed within the literature review and came up numerous times during the interviews since this is the major limiting factor of the technology nowadays. Despite the long life of the vehicle itself which is identified as a driver for utilizing the e-technology, the life of a standard lead-acid battery can be minimized due to improper use and the so-called “memory effect” where the battery looses its ability to hold the charge for a long time. This factors is the key barrier to EV integration since the airport will have to face difficulties in arranging for the so-called “swap battery system” (the battery is fully charged yet taken out once empty) or establishing a contact with the manufacturer where it would be their

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responsibility to switch the battery once it is dead (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011)

5. Competition with the other alternative fuel (fuel cells, natural gas)

This barrier has been already identified within the theme of financial aspect, where the alternative fuel such as natural gas and vehicles adapted to this technology might potentially cost less than the EVs. Here the barrier is once again brought up due to the fact that the refueling truck can bring this type of fuel to any location around the airport. There is no need to recharge the unit several times per day and to have multiple charging plugs for example when these alternative fuels are utilized, yet they might not offer the level of CO2 abatement that the electric technology does (Harrop and Das 2011). Thus, alternative fuels might offer more mobile solutions to refuelling, yet more research is needed to calculate precisely the amount of reduction of the GHG emissions that they offer compared to the EVs.

7.6 Policy aspect

The final overarching theme that was identified within the interviews was the policy drivers and barriers, which will be discussed in further detail below.

7.6.1 Drivers

1. Policy on Worker Health and Safety (indoor and outdoor GSE)

Electric vehicles are gaining popularity within the European Union policy, especially when it comes to the workers' health and safety recommendations and directives. The key reason for utilization of the EVs is the concern with carbon monoxide and soot produced by the ICE, which is extremely dangerous for the health of personnel especially in enclosed areas such as cargo area warehouses for example. Given EVs are emissions-free, they are highly recommended for working in enclosed spaces according to the European legal document "*Directive 2009/104/EC of the European Parliament and of the Council of 16 September 2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work (second individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)*" (Directive 2009/104/EC). Specifically, the document states the following:

"2.17. All work equipment must be appropriate for protecting workers against the risk of the work equipment catching fire or overheating, or of discharges of gas, dust, liquid, vapor or other substances produced, used or stored in the work equipment" (Directive 2009/104/EC).

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When relating this quote to the airports, these organizations are responsible for providing the suitable and harmless environment for the health of their workers where emissions from the diesel engine will not get trapped in a closed area such as warehouse for example (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011). Another quotation extracted from the Directive explicitly prohibits the use of diesel engines within an enclosed territory:

"2.5. Mobile work equipment with a combustion engine may not be used in working areas unless sufficient quantities of air presenting no health or safety risk to workers can be guaranteed" (Directive 2009/104/EC).

Thus, the EVs within the GSE such as forklifts and trucks get an additional incentive from EU policy where the airports are obliged to use them instead of diesel alternatives in order to protect workers' safety. It is also a responsibility of the airport to establish a proper ventilation system or install filters at the end of the pipe of its diesel vehicles in case it is working within the open warehouse structure. At the same time the kinds of filters currently present on the market have to be properly cleaned on a regular basis, which makes the operation of diesel vehicle more expensive and hard in terms of maintenance (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011; Weber pers. comm. 2011).

2. Potential Emissions Trading Scheme (EU ETS) inclusion of the airports

This driver justifies the long-term thinking of both the Frankfurt and Vienna Airports about the prospects of airport emissions in the future. Currently, the debate about the airlines entering the ETS will finally bring the airlines to the responsibility for their overall emissions generated by both local and international flights (to and from 27 European states plus Norway, Iceland and Liechtenstein) within the next year of 2012 (European Commission 2009; COM (2008) 16), yet the emissions generated directly by the airports have not been discussed yet. This does not mean that the airports will never have to comply with a legal policy that targets their direct emissions from terminals and ground transportation. Thus, currently the two case-study airports are investing into the future according to their prediction concerning emergence of more regulations proposed by the European Commission for controlling airports as large pollution sources (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011). Thus, both Frankfurt and Vienna airports receive benefits from step by step conversion of the diesel GSE into the e-engines since the airport ground transport generates a substantial amount of emissions per year.

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3. National and EU air quality regulations and GHG abatement

Green vehicles are very popularized in the previously mentioned "European Strategy on Clean and Energy Efficient Vehicles" (COM (2010) 144) in the light of the climate change issue and the initiative "to reduce 20% of the GHG emissions by the year 2020" (COM (2008) 16; COM (2008) 17; COM (2008) 30). The Strategy originated from an international concern for the state of the environment at the moment and in the future. There was also another initiative that addressed various sources of emissions where the vehicle manufacturing companies have to reduce their impact on CO2 concentration in the environment (COM (2007) 19). These European programs along with the UNFCCC and continuous monitoring of CO2 emissions levels gives a push to the national policy framework in order to reach a desired goal of significant enhancement of the environmental conditions. Germany and Austria are pro-active countries in terms of promoting emissions reduction within large industry sectors and also addressing transportation modes (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011). Since airports serve the purpose of the showcases for the achievements of the national governments, they have to be in close communication with the state and follow up on the latest energy efficiency trends proposed by the international community. Strong orientation of the state towards reducing anthropogenic impact from the road transport has a benign effect on integration of alternative fuels where electricity is one of the major promises. For example, there is a State program that takes place in Austria at the moment which is called the "Klima Activ Mobil Counseling Program: Mobility Management for Enterprises" (Nichtenberger pers. comm. 2011). This program funds the attempts of the enterprises such as the Vienna International Airport to contribute to the climate change abatement of the entire Austria. This project has a special section on the "Workplace Transport operations" that can significantly amortize the prices of the purchased alternative fuel machinery that reduces the emissions of CO_2, NOx and particulate matter such as the electric equipment.

This way, both Frankfurt and Vienna airports experience positive "pressure" (key word identified from the interviews) from the state and benefit from various incentives from their governments, which are expected to increase within the foreseeable future.

4. Energy security

Finally, the last driver for EV integration is energy security. Given the fact that conventional fuel prices increase annually due to the depletion of the oil natural resource some other alternative fuels such as

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natural gas may be also an issue due to the nature of non-renewable resources. Electricity however can be produced in a sustainable way from wind, hydro and solar energy or even biomass, which are renewable resources that are expected to become more reliable through time as the technology becomes more advanced and therefore might not reach extreme prices. Besides, non-renewable source such as oil is not distributed equally where some countries that utilize modern ICE vehicles might face the challenge of obtaining fuel once natural stocks are depleted to a crucial limit. At the same time, there is a crucial need for the e-technologies to find trustworthy abundant substitute (Nickel, Na, etc.) for the rare earth metals given the need to produce the electric batteries in large amounts if both EVs and RES develop rapidly within the nearest future. Currently, most of the metals that fall under the category of "rare earth" are located in China, which might exercise some bans on expanded excavation practices in the future (Harrop and Das 2011). This way, despite the fact that oil is depleting, the rare earth metals could also pose some serious issues in a long term for the mass production purposes (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011).

7.6.2 Barriers

1. Internal policy is affected by Airlines and GH

The airports despite their ability to enforce any possible legislation upon their tenants such as GH and various airlines cannot easily do so due to the mentioned reasons such as competition with other airports where the airlines might switch to other airports and financial benefits from those companies. Thus, no airport will choose a strategy to drastically switch into an electric mode if it is given a choice to slowly introduce several vehicles annually due to the fear of not covering all of the investment costs by the airlines and GH department (Eibensteiner pers. comm. 2011). Since the airport structure financially depends on the rent from both airline services and ground handling operations, it will not choose to violate its income. Thus, another barrier to fast integration of e-engine into the vehicle fleet of the airport would be the contribution of those two tenants.

2. No exact policy for airports on EVs/mostly voluntary schemes

Apart from the above-mentioned policy regarding workers' health and safety on the premises of the airport and the need to abandon diesel engines when working at enclosed areas there is no specific international or national policy that would force the airports into gradually adopting the electric vehicles. This barrier was mentioned several times throughout the analysis since the governmental support and incentives are also dependant on the policy. According to the experts from both airports, currently many of the European e-mobility project or even governmental subsidies address largely the individual vehicle ownership since these subsidies are still in the beginning of their development (Eibensteiner pers. comm. 2011;

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Nichtenberger pers. comm. 2011). As long as the country or an airport will face a challenge of complying with some restriction on diesel engines and will have to introduce more EVs the incentives will potentially be more developed and available.

7.7 Significance of the findings

The analysis section presented above is supposed to serve as guidance for the Budapest airport regarding the integration of electric vehicles into their daily operations. It is imperative to see the drivers and barriers identified by the successful actors on the airport energy efficiency arena in order to draw the conclusions and learn lessons from them. Despite different size of the airports (Budapest – above 8 million people, Vienna – slightly more than 19 million and Frankfurt – above 53 million passengers) the drivers and barriers identified for the two case studies will appear in the Budapest interviews as well since this thesis focuses on the most important issues of technology implementation, such as money, market availability of technology, projected technological development, behavioral patterns and policy framework. The next chapter will discuss the findings from the Budapest airport and ELMU as well as incorporate the drivers and barriers that were identified by the case study airports.

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8. Analysis of the Budapest Liszt Ferenc International Airport

Table 2. Drivers and barriers identified by the Budapest Liszt Ferenc Airport and ELMU electricity provider.

	Overarching aspects	DRIVERS	BARRIERS
Liszt Ferenc International Airport Key words: +Money +Infrastructure +Question + Feasibility	Financial aspect	*1. Economic reason is the #1 driving force behind EVs* *2. Electricity is purchased at a much lower price than market one* *3. Tenders offer the best price possible*	*1. Diesel GSE is much cheaper but electricity prices can start rising* *2. Green electricity might be too expensive* *3. No subsidies from the airport*
	Behavioral aspect	*1. Smaller capacity and distances of the airport* *2. ACA certification*	*1.Behavior/ unwillingness to change* *2.Little cooperation between departments*
	Market Aspect		*1. Not much offered at the moment (Ford Fiesta)*
	R&D aspect	*1. Dissatisfaction with LPG at the moment* *2.Different charging options are possible already now* *3. Solution – to reinstall the e-engine into the existing equipment*	*1.Charging Infrastructure* *2.Reliability of the technology* *3.Smoke collector sometimes is an alternative*
	Policy aspect	*1.Policy on workers' safety – incentive for EVs* *2.Hungarian law pays back for the sold e-batteries to the manufacture*	*1.Not mainstream to reduce emissions but to save the money/ no push for EVs* *2.Permission for construction and remodelling takes 1.5 years*

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ELMU (with relation to the future of EVs in both city and airports) Key words: +Positive/promising +Development +Infrastructure +Trigger +Future	Financial aspect	** ELMU incentives: no charging fees for the first year * Economizing: Fuel security and variable costs (800 HUF vs. 2400 HUF)*	** Expensive technology /issues with payback*
	Organizational & Behavioral aspect	** PR & company outreach – in future to focus on end-users * Airports the best company to address their emissions*	**Behavioral challenge in adapting to a new technology & long term planning * Lack of successful experience sharing*
	Market aspect		** Lack of market for infrastructure * HU market is not attractive to manufacturers*
	R&D aspect	** Future to technology: already now people can drive efficiently given battery capacity * Diesel development – could work side by side with EVs * Bridge technology is developing (HEVs) * Batteries also used for other purposes like RES*	** Green electricity is an issue in HU, yet not in GE *No quick substitute to diesel *Lack of feasible partnership for infrastructure * Lack of standardized charging infrastructure*
	Policy aspect	** Future: tax reductions and exemptions, establishing national platform to e-mobility*	** No action from the state/mostly PR & verbal support (BKK)*

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During the interviews with the Budapest airport the key overarching theme that appeared throughout the conversations was the finance and money involved in EV integration (Gerenyi pers. comm. 2011; Kis pers. comm. 2011; Bogats pers. comm. 2011; Ozkahya pers. comm. 2011; Szanislo pers. comm. 2011). Money was the key limitation and the key driver for introducing electric vehicles that were identified by the airport among other overarching themes. There were many similarities between the findings from the case study airports and the Budapest airport analysis, which were grouped identically with the case study analysis into five overarching themes and subtopics that will be presented and discussed below.

8.1 Financial aspect

8.1.1 Drivers

1. Financial savings is the #1 driving force behind integration of EVs

Experts from the Budapest airport as well as the GH companies completely agree with the already mentioned opinion of the Frankfurt and Vienna specialists that the electric fuel is much cheaper in the long run for GSE purposes (Bogats pers. comm. 2011; Eibensteiner pers. comm. 2011; Kis pers. comm. 2011; Nichtenberger pers. comm. 2011; Szanislo pers. comm. 2011). The Budapest airport is almost two times smaller than the Vienna International Airport and thus the amount of equipment it uses for transportation purposes does not have to be as big. At the moment the Budapest airport has a contract with three ground handling companies where Malev (Hungarian company) and Celebi (Turkish company) have the biggest share of operations and a fleet of approximately 130 vehicles each (Bogats pers. comm. 2011; Gerenyi pers. comm. 2011; Szanislo pers. comm. 2011). The third company, Gr. Europe only serves two airlines and thus adds up to the total number of GSE vehicles at the airport to 300 units (Budapest International Airport 2011). The overall consumption of all vehicles is yet to be calculated by the GH and the airport but since Malev has very old equipment (some Toyta buses are more than 25 years old) and is interested in switching into electric fleet, it probably implies that the consumption of diesel currently does not comply with the highest European standards (Szanislo pers. comm. 2011). Both GH companies purchase fuel from the Budapest airport and have relatively low regulated prices established by the airport. At the same time, Malev would be willing to switch into electric vehicles to obtain financial savings in a long term and thus have a chance to expand its fleet (Szanislo pers. comm. 2011).

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Despite high investment costs, the overall maintenance and charges for the electric GH equipment use will eventually pay themselves back within several years according to the Frankfurt and Vienna experience. Additionally, Celebi GH is already utilizing electric machinery such as electric forklifts at the premises of its warehouse. This innovation was introduced yet again due to the EU Directive on workers' health and safety that was already discussed in the case study analysis (Directive 2009/104/EC). According to Celebi's review, e-forklifts are rather efficient in terms of money savings and serve well the purposes of protecting health of the staff and surrounding environment (Ozkhaya pers. comm. 2011; Gerenyi pers. comm. 2011). Thus, since there is an increasing interest from the ground handling companies such as Malev and the airport itself in the use of electric vehicles, the integration of e-mobility will have a promising future at the Budapest airport, especially given the airport's plans on further expansion and further development of the "cargo city" (Budapest international Airport 2011; Kis pers. comm. 2011). In order to calculate the savings that would originate from the conversion of the diesel fleet into the electric one, both Malev and the Budapest airport will have to create a price list for <u>investment costs, battery costs, working hours per unit per year and fuel prices per unit per year</u> for both diesel and electric vehicles in order to calculate the payback time and long-term savings. In the previous section on the financial drivers at the Frankfurt airport a similar calculation was shown for the electric conveyor belts, which prove themselves to be cheaper than the diesel engines.

2. Electricity supply is much cheaper than the market price

The airport as a large consumer usually negotiates with its provider E.ON for much lower electricity prices compared to the regular market price (Kis pers. comm. 2011). Since money was identified as the major driver for EV integration at the Budapest airport, it is obvious that much cheaper prices for electricity as a fuel will be one of the pre-requisites for a successful implementation of EV technology. Yet this driver only takes into account the operational and variable costs associated with the EV technology and does not count the battery and original investment costs. At the moment the commonly used projections for comparison between electric and diesel consumption are such that for 100 km the average e-light vehicle (road transport) will demand 3 to 5 euros, whereas diesel already costs about 8-10 euros (Eibensteiner pers. comm. 2011; Reimann pers. comm. 2011) on average for the same range. For the GSE sector this difference will be even more pronounced given than a regular 100 or 200 liter engine in a diesel forklift for example will costs much more that an

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electric version (Weber pers. comm. 2011). For example, one electric conveyor belt loader will use approximately 1 euro or less worth of fuel for one working hour (Weber pers. comm. 2011), whereas a regular diesel vehicle can use several liters of diesel per working hour and thus cost at least four times as much even considering that the prices for diesel do not include VAT.

3. Tenders offer the best price possible

Being a large electricity consumer, the Budapest airport takes an advantage of various tenders for electricity supply, vehicle supply, etc (Kis pers. comm. 2011). These tenders allow for a better understanding of the available market offers and attract companies with great discounts given the order is large. Thus, the airport could acquire the strategy of Frankfurt airport, where each vehicle type within the GSE fleet would be requested in an electric version through a tender and further purchased from different international renowned specialized companies (for instance, GBT and Mulag that are used by the Frankfurt airport). This strategy is the best opportunity to attract international manufacturers who have already established themselves on the e-vehicle market and can offer both a good price and maintenance. Another option for introducing the EVs would be to request a refurbishing company to modify the engines of the already existing fleet into the e-types (Gerenyi pers. comm. 2011; Kis pers. comm. 2011; Szanislo pers. comm. 2011). This option will have to be negotiated by the airport and the manufacturing company and carefully planned in order to provide for a reliable electric conversion.

8.1.2 Barriers

1. High investment costs of EVs due to the absence of economies of scale

Germany and Austria have been so far trying to promote the idea of producing and utilizing electric vehicles, which is starting to be one of the goals for domestic and international airports. Thus, more manufactures have an incentive to specialize in introducing electric engines into various types of light vehicles and GSE given a growing demand for EVs (Eibensteiner pers. comm. 2011). In Hungary the demand for electric vehicles has been low so far and thus vehicle manufacturers paid little attention to the electric engine production (Kis pers. comm. 2011). Given little demand within the e-transport sector there are no economies of scale – a term which refers to a benign influence of growing production on cost reduction (Reiner *et al.* 2010; Harrop and Das 2011). Just like in Germany and Austria, the prices for

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light commercial vehicles are extremely high and prices for electric equipment are even higher. Considering a potential rise in demand from the Budapest airport, it is important to look into the already existing electric vehicle manufacturers across Europe and US before a market for those vehicles develops in Hungary.

2. Diesel GSE is still relatively cheap and electricity can start rising in prices

Another point of view that was rather common amongst the Ground Handling experts was the perception of the risks of going into all-electric vehicles (Gerenyi pers. comm. 2011; Szanislo pers. comm. 2011). Although diesel prices are rising, most people still see them as affordable yet for the electricity they are afraid the prices will follow the same growth scenario. This short-term planning is not beneficial for a large structure like the airport since the fuel security is a hot topic of the 21st century and electric vehicles might become a good solution given that the electricity they use comes from the renewable sources. Additionally the prices for electricity range between peak and off peak hours where the nighttime charging would cost much less compared to the charging during the day.

3. "Green electricity" might be too expensive

This concept emerges from the previous section of diesel vs. electricity prices, where some experts view electric vehicles as an efficient technology that saves money, yet they are afraid of the possibility that green electricity might become too expensive and take away many environmental benefits of the EVs which utilize electricity from traditional polluting natural sources (Kis pers. comm. 2011; Gerenyi pers. comm. 2011). Yet, this approach raises the issue of shifting the burden of emissions from oil combustion to conventional power plants (for example coal). One solution to this would be either negotiating with E.ON supplier, which might offer renewable tariffs at an acceptable price for the airport and hence approach the ACA target of zero emissions of CO2. Another option would be for the Budapest airport to explore the options for geothermal energy within its premises (Kis pers. comm. 2011). This second option is based on the experience of the Frankfurt airport, yet it is rather difficult to realize since currently it is not clear whether the geothermal capacity could satisfy the airport's need for both heat and electricity, or it would be just barely enough to cover for the heat production. The option where the electricity supplier will potentially offer a green tariff to the airport is more realistic at this point in time, whereas geothermal sources would take plenty of time to locate and then to manage in a proper way (Kis pers. comm. 2011).

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4. No subsidies from the airport

This barrier arose from the discussion with all three airports, where certain subsidies from the airport structure would be beneficial for the ground handling departments if no other subsidies are present at this time. For example, some US airports are practicing a partial return policy on the purchased equipment for GH purposes in order to stimulate the substitution of their diesel GSE into the electric alternative (Clean Airport Partnership 2001). The issue with such an initiative at the Budapest airport would be the question as to where the reduction of GH emissions belongs – to the airport, airlines or the GH services. The airport usually licenses the GH services for regular operations on the premises, yet GH companies are completely separate entities that are responsible for aircraft maintenance and purchase diesel or electricity from the airport but they do not belong to the airport (Bogats pers. comm. 2011; Kis pers. comm. 2011). This way, the provision of subsidies for electric equipment for the Budapest airport might be viewed by the board as an unnecessary and luxurious expenditure due to the major expensive airport expansion works at the moment. This way, the provision of airport subsidies at the moment might not be a plausible method for aiding e-mobility integration.

8.2 Organizational & Behavioral aspect

8.2.1 Drivers

1. Smaller capacity and distances at the airport compared to the case studies

This aspect of the Budapest airport is in fact beneficial for introducing e-mobility since the airport does not have as big of a fleet as the Frankfurt airport for example (300 vehicles vs. 3500 vehicles) and thus a potential for replacing the entire fleet by electric engines within the next decade seems to be more plausible. The airport has two terminals, where Terminal I has a rather small apron for servicing incoming and departing aircrafts and thus electric vehicles would be more than applicable (Bogats pers. comm. 2011; Kis pers. comm. 2011; Szanislo pers. comm. 2011). This assumption is made according to the fact that these vehicles will have to move within the maximum 500-meter radius, which is suitable for the EVs given that they work best with short distances according to the Frankfurt and Vienna airports. The situation with Terminal II is slightly different since it is a new terminal, which operates a larger apron and services more aircrafts. Yet again, here the distances around the apron will be absolutely

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manageable by the EV GSE and there will be a possibility to install numerous plugs right next to the Terminal II aircraft parking hubs as a simple recharging infrastructure.

2. Peak hours to be served by EVs

According to the Malev and Celebi GH companies, the key goal for the EVs within the GSE sector would be to work continuously throughout the peak hours at the airport (Bogats pers comm. 2011; Gerenyi pers. comm. 2011; Szanislo pers. comm. 2011). Peak hours usually constitute around two to three hours of constant engine work and maintenance of approximately 20-25 aircrafts in a row. Given that most of the electric GSE available today uses the lead-acid battery which lasts anywhere from 3 to 8 hours on a single charge, this goal can be easily achieved due to the large capacity of the vehicle. Thus, the EVs will save emissions, diesel and money of the airport while performing all the same operations on the apron, as the old diesel equipment would do.

3. ACA certification

Finally, a voluntary accreditation scheme ACA has a very positive incentive on the Budapest airport in terms of achieving the goal of carbon neutrality (ACI Europe 2010). As previously described, ACA focuses on several stages of airport emissions, where the final goal would be the status of an absolutely “green airport” with no harmful emissions recorded. Since the Budapest airport recently joined the ACA initiative in 2011, it will have an organizational stimulus to enhance its overall environmental status throughout the next coming decade (Kis pers. comm. 2011).

8.2.2 Barriers

1. Behavior/unwillingness to change

The experts from the GH companies are extremely preoccupied with the behavioral aspect of introducing a new technology into the operations of the airport since they might have to hire more personnel and training in order to provide an effective use of the EV technology (Bogats pers. comm. 2011; Gerenyi pers. comm. 2011; Szanislo pers. comm. 2011). The greatest concern for the companies is the potential human error, where staff might forget to plug a unit of equipment after performing some work and then the next day the unit would not be operational due to the lack of charge. This is also an issue of airport operations security, where during the peak hours most of the units of the GH companies are at work

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simultaneously and there are no backup vehicles. Despite this fear, the experience from the Frankfurt and Vienna airports demonstrates the compliance of the staff with internal EV regulations, where all e-equipment is constantly plugged in when not in use. Naturally it is the matter of personnel training and care for the equipment that will make EV successful at the Budapest airport in the future, yet no additional personnel is needed to plug in the vehicles after working hours – the drivers can be responsible for that. As the experience shows, it all works well, as long as the training is provided.

Additionally, there was another factor identified by Mr. Gerenyi (Celebi), which concerned the willingness of the drivers to use diesel instead of electric drives when given a choice. According to the experts, this assumption was made on the basis of the operations of open warehouse, where the staff is given a choice between EV forklifts and diesel forklifts. Most of the time, the staff goes for the diesel forklifts due to their acceleration properties and speed characteristics. This way, it will take some time to educate the staff and make them appreciate the technology by pointing out the health benefits that they will receive when working with EVs (Generyi pers. comm. 2011).

2. Little cooperation between departments

This barrier proved itself to be crucial since the GH companies rarely communicate to each other about their accomplishments in terms of the equipment. The airport has only recently expressed interest in the GH equipment specifications due to the ownership change and willingness to reduce its emissions (Kis pers. comm. 2011). Celebi GH Company has already had an experience working with the e-forklifts, which can be shared with the Malev GH and the airport to assess the effectiveness of this technology for the Budapest airport and eliminate potential issues that might be associated with this type of machinery (Gerenyi pers. comm. 2011).

8.3 Market aspect

The discussion of the Hungarian e-market identified no drivers within this overarching theme. As for the barriers, all of the experts at the Budapest airport and GH companies mentioned that the Hungarian EV market at the moment is rather undeveloped and does not present many types of electric vehicles (Gerenyi pers. comm. 2011; Kis pers. comm. 2011; Szanislo pers. comm. 2011). Currently, the focus of the Environment, Health and Safety department is on purchasing four Ford Fiesta light electric vehicles in order to originate the e-

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mobility initiative at the airport, yet the present market is not cheap for either refurbishing a diesel vehicle or for purchasing an absolutely new unit. Thus, light commercial electric vehicles are not the best option to go for given their initial costs and the lack of subsidies from the government or manufacturer. It might be a more feasible project to first investigate the GSE potential given high CO_2 abatement potential of those vehicles.

8.4 R&D

R&D is the second most important overarching theme in the conversations with the Frankfurt, Vienna and Budapest airports. Since this is a rapidly developing sector, it attracts much hope for the future development and provision of cheap available technology that would potentially compete with modern diesel engines.

8.4.1 Drivers

1. Dissatisfaction with the LPG technology at the moment

The Budapest airport used the same technology as Vienna in terms of running the ramp agent cars (VW caddies) with LPG alternative fuel (Szanislo pers. comm. 2011). In fact, this technology turned out to be a failure since the alternative fuel only initiates when the temperature of the cooling liquid and the engine reaches 60C. The ramp agent cars usually travel only for approximately 300 to 500 meters on the apron before they reach an aircraft and park for the time of servicing the plane. Since the car is driven for such a short period of time, it does not reach the essential temperature of 60C and thus does not utilize LPG fuel. This means that the alternative fuel is not used and 80% of the time the vehicles run on simple diesel. Besides, the LPG fuel which is used at full capacity would generate only 30% less emissions compared to the EVs that are supplied by either regular or green electricity (Eibensteiner pers. comm. 2011; Weber pers. comm. 2011). The fuel tank of such a caddy is used within approximately 5 days and allocates 35 liters of diesel per 100 km which is extremely inefficient given that modern engines already manage to use less than 10 liters of fuel per 100 km. Thus, one technology that works well for the Vienna airport does not seem to have a success at the Budapest airport. This is why it is crucial to first perform tests on the new technology and see how many savings it yields and whether it is efficient enough before the airport will be able to make a choice to purchase more units.

One of the best solutions for the Budapest airport in terms of ramp agent vehicles which was proposed by the Head of the Vehicle Department at Malev GH, is the golf car,

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technology with a modified nickel metal hydride battery to provide for a quick recharging on the spot (Szanislo pers. comm. 2011). Golf cars are one of the oldest e-vehicles that have been tested and successfully performed for many years and have an available amount of space to carry two ramp agents and all the necessary luggage. Finally, these vehicles cost around 3,000,000 HUF or approximately 10,000 – 12,000 euros, which is much less compared to electric light commercial vehicles (around 30000 euros). Thus, given careful planning of the airport and the GH services for the best available options, various possibilities can be found as substitutes to the extremely expensive technology or diesel expenses.

2. Different charging options are possible already now

Another driver for EV utilization at the Budapest airport is the simple plug in technology and lead-acid battery or nickel metal hydride option (Gerenyi pers. comm. 2011; Kis pers. comm. 2011; Szanislo pers. comm. 2011). Both batteries usually last for a longer time than the current lithium ion technology and can withhold regular charges. In this case lead-acid technology is worse than the nickel metal hydride since it has the previously mentioned “memory effect” and can die faster. Nevertheless this type of battery is rather cheap and has one of the best recycling options that has been tested for several years and is heavily practiced in the world. Other smart charging systems that are very expensive and at the moment are potentially not feasible could come in later on when the airport decides to expand its GSE fleet above 300 vehicles (Gerenyi pers. comm. 2011; Kis pers. comm. 2011; Szanislo pers. comm. 2011). Additionally, given the orientation and structure of the terminals, each aircraft hub could be modified to have several plugs for the EVs in order to provide for the on-the-spot charging solution.

3. Solution – to reinstall the e-engine into the existing equipment

Finally, another option for utilizing the e-vehicles would be to simply refurbish the already existing vehicles and to insert the electric engines into the core of the units (Generyi pers. comm. 2011). Thus, by removing the diesel engine and oil, the unit will gain an electric engine, which will spare the necessity of purchasing diesel and changing oil. Thus, the equipment unit will be cheaper in maintenance and potentially cheaper in reconstruction price compared to purchasing new equipment. This option will have to be customized with the vehicle manufacturers, yet it is not impossible to consider it when the equipment itself can serve for a long time or was purchased recently.

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8.4.2 Barriers

1. Charging infrastructure

Barriers identified by the Budapest airport mostly consider the infrastructure and reliability of the existing technology of EVs (Gerenyi pers. comm. 2011; Kis pers. comm. 2011; Szanislo pers. comm. 2011). The utmost concern relates to the charging infrastructure and especially: long hours of overnight charging and potentially re-charging the vehicle during the working hours, location of the infrastructure at the airport and inability to easily reconstruct the apron, central and decentralized charging options and finally choosing between the Direct Current (DC) vs. the Alternating Current (AC) charging infrastructure. According to the experiences of the Frankfurt and Vienna airports, a wise planning will allow the airport to easily satisfy the charging needs with the common direct plug-in option for charging their EVs.

The highly advertised smart charging systems are still in process of being developed and cost too much when they have to accommodate more than one vehicle at a time. This advanced system might not be the best charging option at the moment, since it is not justified by the number of cars the airport will be willing to convert into the EVs. According to Mr. Szanislo from Malev GH Company, the Company would be willing to exchange the fleet of the ramp agent vehicles (60 out of approximately 130 vehicles total) for the electric vehicles within the next five years (Figure 13).

Figure 12. *One of the oldest buses on the Malev GH Company (Malev GH visit).*

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Figure 13*. Most of these ramp vehicles run on LPG fuel (Malev GH Company visit)*

Given the speed of technological development, five years could bring serious reductions in prices of the EVs due to the national and European campaigns as well as a better capacity for charging more than one or two vehicles simultaneously. Thus, given the goals of Malev GH Company, one of the potential solutions would be to have at least the plug-in chords all around the apron to connect the ramp agent cars when not in use and then have a couple of parking lots within the airport premises that could provide for decentralized plugs for each vehicle to be recharged overnight. Another advanced technology could be the inductive charging, where the current would be spread all about the parking area within the metal plates embedded into the concrete and vehicles would have to establish a tire contact with the metal plate (Weber pers. comm. 2011). This technology will probably not be available within the next couple of years, yet it gives hope for an easier recharging procedure. As for the present situation and viable recharging options, in addition to the regular plugs it would be very efficient to have one central station with a quick charge (less than 15 minutes) for the cases of emergency of special equipment that requires constant recharging and is essential for the ground operations at all times. Thus, as long as at least slow overnight charging and plugs at the Terminal hubs for the aircrafts will be provided, the charging of EVs will not be a big issue.

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2. Reliability of the technology

This issue was raised several times by both the Frankfurt and Vienna International Airports, where the reliability of the electric engines is certain for the short range-low speed sector of the GSE (Eibensteiner pers. comm. 2011; Nichtenberger pers. comm. 2011; Weber pers. comm. 2011). In the case of the Budapest airport, this is exactly the sector that needs the primary switch from diesel into electric technology. Given a positive experience from other airports that managed to successfully utilize EVs, the Budapest airport has a very promising future with the EV technology given the size of the apron at both terminals. Additionally, as a "bridge technology" another option for the ramp agent vehicles would be the previously mentioned hybrid vehicles, yet those ones are also expensive and demand serious market screening in order to identify the best options the Budapest airport would be willing to invest into. However, hybrid vehicles have a very expensive maintenance and the airport will have to calculate how feasible hybrids would be in the long term.

3. Smoke collector sometimes is an alternative

Finally, the last barrier to EV integration within the R&D theme is the option of installing special filters at the end of the pipe of the GSE. The Celebi GH Company uses this method, where there is a specific burning filter that has to be cleaned and replaced every two weeks. This option is used inside the semi-open warehouse and so far proved to be rather successful (Gerenyi pers. comm. 2011). Despite its benefits, this technology implies constant expenditures for purchasing the new filter and is subject to occasional damages of those filters, which could potentially result in exposure of staff to harmful substances such as soot and carbon monoxide. This way instead of paying additional money for the filters on top of diesel fuel, it is worth to invest into EV technology, which is environmentally friendly and has low operational costs.

8.5 Policy aspect

The last overarching theme that arose in every consultation with the experts from the Budapest airport was the policy aspect and emerging incentives or the lack of those within the field of EV integration.

8.5.1 Drivers

1. Policy on workers' safety – incentive for EVs

Once again, the previously mentioned directive (Directive 2009/104/EC) on staff safety and procedures associated with the use of specialized equipment inside the enclosed industrial

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areas is active throughout the EU and applies in particular to the airport's warehouses and the luggage servicing area. Within the Budapest airport the luggage area is semi-open and thus diesel vehicles are still allowed to operate inside of it (Gerenyi pers. comm. 2011; Kis pers. comm. 2011). However, despite the fact that the luggage area is semi-open and has access to the fresh air, on a hot summer day when the wind is still, this area might accumulate some hazardous substances that would have an effect on the staff exposed to it. At the moment the best option for the luggage trucks would be a hybrid tow truck that has a operational mode for both the diesel engine and an electric engine, where the latter can be used once the truck enters the premises of the terminal. An example of that technology was mentioned during the discussion of the Frankfurt GSE, where those trucks are utilized. Since this area is a part of the terminal itself, it will have to be eventually carbon-neutral due to the ACA accreditation and this is a driver for the switch into at least a hybrid option of a tow truck if not a pure EV.

2. Hungarian law on "taking back batteries and accumulators to the manufacturers" has a positive implication

In fact, one of the already existing Hungarian policies concerns the sale of the used lead-acid batteries from e-equipment back to the manufacturer for recycling purposes (The European Topic Center on Sustainable Consumption and Production 2009d; Gerenyi pers. comm. 2011). This law is very profitable for the airport if it chooses to utilize a mostly electric vehicle fleet at least for the ramp agent cars. Thus the airport will not have to take care of the batteries at the end of their life and will contribute to the turn-around of the lead-acid batteries that could be used for other vehicles as well as later in their lifecycle. Thus, if the Hungarian government already started to consider recycling the batteries for both EVs and from other sources, it would mean that one of the questions about e-mobility such as the end of battery life has been already addressed. Potentially more EV-concerning legislation will come out within the foreseeable future.

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8.5.2 Barrier

1. It is not common to prioritize reduction of emissions over money/No push for EVs

As for the barriers, once again there is no national policy that would address the conversion of diesel engines into EVs. Hungary will eventually have to comply with the "European Strategy on Clean and Energy Efficient Vehicles", yet this document was published only this year (2011) and still needs more time to affect the national legislation. The only policy that can be currently affected by the airport and GH is the internal policy of the airport, which was also discussed within the case study section for the Frankfurt and Vienna airports. As previously mentioned, the airport has a potential to force the GH services to convert at least a part of its diesel GSE into electric drives, yet due to the competition between neighboring EU airports and the resistance of the airlines to the sudden change and consequent increase in prices for GH services, the airport can only attempt to negotiate the need to see more EVs on the apron. Also, at the moment intense reconstruction measures and the expansion of the airport will put the question of EV implementation aside and regard it as a next possible step in reducing carbon emissions (Kis pers. comm. 2011).

2. Permission for construction and remodelling takes 1.5 years

Last but not least, the official paperwork associated with the potential reconstruction of the apron and the terminals would take a long time in case the airport decides to follow the electric engine track (Bogats pers. comm. 2011; Kis pers. comm. 2011). This presents another barrier to EV integration into the regular airport operations, which at the moment could exert too much pressure onto the staff of the Environment, Health and Safety department, already taking care of improvements within the energy efficiency of airport terminals. Since the efficiency of the charging infrastructure is one of the key barriers to EV integration, once the airport and the GH companies come to a mutual conclusion that EVs will be integrated into the Budapest airport, they could potentially go for the simplest charging infrastructure that would not imply intense modifications of the apron and install as many plugs as possible for an easy access of the technology to them. Additionally, it would be very efficient to allocate a place for mass parking, where the vehicles would also have separate plugs installed either into the ground of the nearby warehouse or parking facility in order to recharge overnight. These options would be easier to implement at the moment compared to installing a smart metering system, which has to develop still.

This way, given all of the above-mentioned barriers and drivers we can say that integration of EVs is not an impossible task for the Budapest airport at the moment, yet it would require much thoughtful planning, market screenings and staff training in order to make the EVs successful at the airport premises. According to the experience of two case study airports, the Frankfurt and Vienna airports, this task is not overwhelming and will require an extensive cooperation between the airport management and GH companies as well as the surrounding municipalities and the city of Budapest. Yet the airport is not an isolated structure

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from the rest of the city and thus it is also crucial to look into possibilities that might arise from the cooperation between the Budapest airport and the city of Budapest. The influence of EV integration at the Budapest airport on the municipalities and other interesting emerging concepts are described further below and based on the ELMU interviews.

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9. ELMU: the Budapest Airport and the City of Budapest – Mutually Beneficial Partnership

This section will analyze the same five overarching themes that were presented in the two previous chapters of the drivers and barriers for the city of Budapest and the Budapest airport. Most of the topics were already discussed in depth and, therefore, this chapter will focus on the general analysis of the financial, market, behavioral and organizational, R&D and policy aspects of EV integration within both the urban and the airport setting in Budapest. This section will overview the opinions of the two experts from the key electricity supplier company (ELMU) on the EV future within the city of Budapest and the role of the airport in introducing electric drives into the community.

ELMU is a Hungarian electricity company that is currently looking into providing the electric charging infrastructure options specifically adapted to ease the EV use in the urban setting. At the moment ELMU focuses on the infrastructure development for light commercial e-vehicles, where the major goal of the company is to adopt the German experience of RWE electricity supplier that managed to install over 500 electric charging stations throughout Germany and keeps promoting e-mobility (Reimann pers. comm. 2011). At the moment the company has invested into its own charging station that is located just outside its office in Budapest and is available to the vehicles within the city. According to both Ms. Reimann and Mr. Tokei, the precursor for a successful integration of the EVs within Budapest would be the cooperation between large corporations that can purchase the available smart charging infrastructure and the state of Budapest, which can supply various incentives for these companies (Reimann pers. comm. 2011; Tokei pers. comm. 2011). One of such companies that have the best opportunity to provide a positive EV education and incentives to the community is the Budapest Liszt Ferenc International Airport. As it was previously mentioned, the airport structure and organization are well suited for both short-distance and long-distance EVs.

In our conversation, the representatives of ELMU company also identified a similar number of the overarching themes that affected the introduction and further success of the electric vehicles both at the Budapest airport and in the city of Budapest. These overarching themes will be discussed in the same order as previous chapters and as shown in Table 3.

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9.1 Finance aspect

According to the experts' opinion, electricity companies have one of the major roles in promoting the electro-mobility in Budapest since they can negotiate the installation of the charging infrastructure with the local authorities and large companies such as malls, gyms and business corporate centers. Since electric vehicles cannot operate without the full charge, it is rather logical to first of all provide the infrastructure within the city in order to attract future customers. The main idea is to make the charging infrastructure available everywhere in the city in order to compensate for the relatively short range of electric vehicles at the moment (Reinmann pers. comm. 2011). An average projected consumer of the electric fuel for the EV should at least (1) have an opportunity to have a simple charging plug at home where he or she could charge the vehicle overnight, (2) have a charging station at his or her workplace for the 8-hour working day in order to have the battery fully charged when needed, (3) be able to recharge the vehicle at any large mall or a shopping center and (4) manage to find a free charging infrastructure at large gyms. Thus, if the electricity provider manages to negotiate the infrastructure costs and installation procedures with all of the above mentioned authorities, the use of EVs will become much more efficient since the driver will always have an opportunity to recharge his or her vehicle at any given location. Despite the high cost of the charging infrastructure that is available at this moment, the cooperation with the state could yield some major financial incentives such as partial return on investments to the companies that will be willing to install the infrastructure on their premises.

Another financial aspect is the reduction of the state's dependence on imported fuel. If Budapest intensively invests into the development of the e-mobility and associates charging stations, it could reduce the international imports of oil and thus save the money for further e-mobility and green renewable energy improvement. The renewable sources of electricity are not well developed within the Hungarian market at the moment, yet according to the European strategies on improvement of vehicles and overall share of RES for each European state will stimulate further research and development within the field.

Finally, the savings for the customers that would come from using electricity as fuel compared to the diesel will be large already now since per 100 km an EV would cost approximately 800 HUF (Hungarian forints), whereas diesel fuel will cost three times as much (2400 HUF) for the same range (Reimann pers. comm. 2011). Since the operational costs are lower for the electric vehicle, there is a high chance that once the economies of scale will be

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available in Hungary or the nearby European states, the investment costs of EVs will significantly drop and the vehicles will be just as available to an average citizen as their diesel counterparts.

This way, once the Hungarian EV market will feature more electric vehicles and more affordable prices, both the future owners of the EVs and the authorities of the city of Budapest would benefit from e-mobility development in a long term.

9.2 Behavioral and Organizational Aspect

The ELMU experts also consider the behavioral patterns and perception of the electric vehicles as a crucial component, which has to drive the switch between from the diesel and petroleum fuel into the electric one. The common misconception is such that people are used to knowing that they can get anywhere by means of diesel or petroleum (100, 200, 300km) and the refueling time would take them only about 10 minutes total. As for EVs, there is a perception at the moment that the range of the car is too small (from 30 to 100 km) and the recharging takes too much time (6 to 8 hours). Average vehicle owners do not count their daily mileage and do not realize that in fact in an urban setting the maximum distance they could ride per day would be around 80 km given the traffic jam and that range would be perfectly covered by the modern EVs. Also, given the availability of the infrastructure throughout the city (malls, gyms, business centers), there will always be a place for the vehicles to recharge. Considering recharge time, some batteries can recharge for only 20 minutes with a regular plug and then be able to cover a certain mileage with that charge. This way, the concept of EVs is a matter of a behavioral pattern change for the people, where the driver will have to potentially plan for the daily trips before the smart charging stations will appear around the city. This smart charging system will allow for a less than 15 minute full recharge of the standard electric light vehicle battery and also allow for charging the customer to his monthly electricity bill (Reimann pers. comm. 2011). This technology is still under development, yet it has great prospects for the urban setting charging options.

Finally, people need to be educated about the emissions their diesel and petroleum cars generate at the moment in order to care more about the surrounding environment. This awareness will speed up the transition from gasoline to electric vehicles, especially if the state incentives will be in place such as trading petroleum vehicles in for the discounts on the electric vehicles for example. Top-bottom regulation and active participation of the

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Government will make the EV technology more successful and will facilitate the transition process.

9.3 Market aspect

As it was already mentioned, the market infrastructure for EVs and charging infrastructure will have to advance significantly in Hungary within the next several years. At the moment no incentives are in place to promote the participation of local and international vehicle and battery manufacturers in the development of EV technology. The best tactics to improve the market would be to investigate and adopt the most successful experiences of the electric technology forerunners to the urban setting of Budapest.

9.4 R&D

The R&D section was discussed intensively by all of the experts mentioned in this paper due to the fact that modern technology still needs to advance in order to put the EVs on the same level of reliability as the diesel and petroleum vehicles. According to Ms. Reimann, electric vehicles have a very promising future, where the range of the vehicles with nickel metal hydride and lithium ion batteries at the moment can already compete with the regular vehicles in terms of range, speed and recharging time (Tesla roadster, etc.). Despite the rapid development of electric technology, the ELMU experts still allocate about 10 to 20 years before the electric vehicles will be able to take over their diesel counterparts. Within the foreseeable future petroleum vehicles will probably have the same demand from the population, yet the number of electric vehicles will rise given appropriate infrastructure and various incentives from the manufacturers and the Governments. Finally, at the moment the most advanced "bridge technology" between petroleum and electric vehicles is the hybrid vehicles, which provide the combination of gasoline and electric engines in order to give a better mileage to the car and to abate at least some of its emissions. Once people will feel comfortable with the hybrids, they might express an increased interest in the pure EVs.

9.5 Policy aspect

The final overarching theme, well-written policy can serve a major trigger to the successful EV implementation within Budapest (Reimann pers. comm. 2011). There is certainly a need for the top-bottom regulation from the state, which would benefit from the e-mobility in along term given its responsibilities towards the "European Strategy on Clean and

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Energy Efficient Vehicles" that came out this year (COM (2010) 186). Additionally, the environmental policy that has been improving throughout the years will eventually address the emissions from the road transport, which could be eliminated by the advanced EV technology introduction (Reimann pers. comm. 2011). There is also a need to stimulate the electric battery producers to increase the capacity of the already existing technology and to make the mass production of the batteries possible that would not rely only on the rare earth metals. As it was previously discussed, the need to intensively utilize the rare earth metals in mass production of electric batteries could cause a resource security issue, where more than 90% of these metals are located in China (Harrop and Das 2011). Thus, more research should be targeted towards making the EV technology less dependent on rare resources. Last but not least, the national policy could affect the road rules for different transportation modes by, for example, donating a separate lane just for the electric vehicles in order to make sure it has the privilege in driving during busy hours. All of the above-mentioned needs will need to be satisfied in order to ensure the success of the technology in the city of Budapest within the next coming decade.

9.6 Cooperation between the city of Budapest and the Budapest airport

There is much work that needs to be done by the Government and local authorities in order to allow for a successful EV integration into the life of Budapest citizens, particularly invest into careful planning and originate pilot projects that would show the current perception of the EVs by the people. One such project could involve the Budapest airport, which has expressed significant interest in the electric vehicle technology and would consider investing into recharging infrastructure. The local municipality could provide financial incentives for the airport to install the charging infrastructure outside both Terminal I and II and to allow for free parking of the electric and plug-in hybrid vehicles there. Thus, the availability of the infrastructure could influence the taxi park of the airport, where the fleets could be converted into hybrid or even pure electric engines since they could utilize the new charging stations located at the airport and at the ELMU office. Thus, the airport could serve a good opportunity to demonstrate both international and local people the advantages of the EV technology and charging stations, which would have a direct impact on their overall perception of the e-mobility in Europe. The cooperation between the authorities of the city of Budapest and the Budapest International Airport will produce a steady platform for the successful integration of the EV technology.

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10. Recommendations for the Budapest International Liszt Ferenc Airport

The analysis of the case study airports and the Budapest airport demonstrated that the present situation at the Budapest International Airport is rather suitable for the integration of EVs, yet much effort and initiative will have to come from the airport itself in order to physically test the technology and assess its feasibility. At the moment the Hungarian Government does not prioritize e-mobility concept over other issues and thus no significant incentives are offered by the State. However, this does no mean that the incentives will never be there. From the experience of the Frankfurt and Vienna International Airports it is obvious that the financial aspect is the key concern for the integration of e-mobility into specific transportation sectors such as short distance – low speed GSE. Thus, before the Hungarian Government becomes interested in promoting EVs throughout urban areas, the airport can provide for a number of steps to build a platform for the e-mobility integration at its premises, especially given the demand from the Malev and Celebi GH Companies. Recommendations are provided below.

10.1 Purchasing EVs for the airport and the GH use:

1. Purchasing light vehicles for the departmental services: according to the Frankfurt airport the light commercial vehicles for the use by ramp agents or by the airport managers will most probably not pay the initial investment cost back within their lifetime (as is the case for the Mitsubishi iMiev). It would be much more cost-effective to wait with this purchase for a couple of years when the prices for the second-hand market vehicles could make the EV technology more available. Another incentive to lowering the market prices will happen only due to the development of the economies of scale. However, no sudden reduction in the market price of electric vehicles is expected within the next several years and thus the airport could probably invest more time into the following:

(1) seek a good incentive from the vehicle manufacturer, who would be interested in selling several vehicles at a time with a good discount rate,

(2) aim to request or negotiate the State subsidies based on the fact that the eventual carbon neutrality of the airport will contribute to reduction of the national GHG emissions,

(3) negotiate the prices of the future purchase of light vehicles with the airport management board since eventually the investment on vehicles would be returned due to the cheap prices of electricity.

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2. The airport should clarify the question about the application of the GSE emissions produced by the GH operations and figure out whether the emission credits will go to either the airport, the airlines or just to GH Companies. This question should probably be addressed to the ACA scheme since both of the case study airports discussed previously have their own GH services and thus heavily invest into the sustainable fuel to save money.

3. If the GH emissions are included into the airport's overall carbon footprint, the airport should consider testing new electric equipment for the GSE sector and simultaneously look into potential refurbishing of the recently purchased diesel vehicles with electric engines. Potentially, some Hungarian companies would refurbish the diesel vehicle into the electric one for a cheaper price compared to the initial investment cost of the new electric GSE equipment.

3. Even if the GH services are counted separately from the airport in terms of their emissions it is still in the airport's interest to address the GH company's request to install different charging infrastructure options around the terminals. The airport can also cooperate with the GH services in order to critically analyze the GSE equipment and identify areas that would yield the most savings for the fuel if converted into the electric vehicles according to the strategy used by the Frankfurt and Vienna airports. The airport will need to test various capacity vehicles from the identified sector (short-distance or long-distance) in order to make calculations and determine whether it would be feasible for the GH Company to purchase the entire vehicle fleet of just one electric vehicle type.

4. The airport can work towards establishing close cooperation with other Hungarian airports or with the closest international airports in order to perform the market screening on electric vehicles, share the experience and identify the best supplier of the equipment within the geographical boundaries of partner airports' location.

5. The airport should request each specific type of electric GSE equipment from one provider (potentially together with other airports) to yield the best discount rates for the purchase.

10.2 Charging infrastructure assessment

1. In order to allow for the GH services to purchase electric units of GSE, the airport will have to design locations for potential plugs that could be accessed all the time by the electric vehicles. The foreign experience of the Frankfurt and Vienna airports demonstrates that the regular electric plugs located within the premises of the aircraft hubs would be the best initial solution that would allow for 24/7 charging opportunities for the vehicles that work constantly around the aircraft. Additionally, it would allow for both the airport and the GH services to

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adjust to potential modifications within the vehicle operations and train staff to plan ahead for the periodical recharging of the vehicles when they are not in use.

2. Once the simple plug-in charging system is established, it would be able to supply most of the vehicles during their operations. For the night time, the same analogy could be made for the parking lots where most of the GSE is located during the non-operating hours. The airport could either look into the previously discussed induction charging or simply install weather-protected plugs next to the parking spaces where the vehicles could easily access the charging system.

3. Meanwhile, the airport and the GH companies could determine the best location for the central quick charging station that could serve more than 1 vehicle at a time and have recharge time of less than 15 minutes. Even with the refuelling diesel truck, the procedure of refilling the entire fleet's tanks usually takes about 2 to 3 hours, so the quick electric charging could compete with that timing.

4. The price of the quick charging infrastructure could be discussed and negotiated with the electricity provider company (either E.ON or potentially ELMU) that would be willing to install it on the airport's premises. In case the electricity provider is not inclined to negotiate the price, the airport could address the Hungarian municipality to join the airport's efforts in providing an electric charging station for the general public just outside the Terminal I and then Terminal II. The State authorities could provide effective incentives to support the airport's initiative given their growing interest in sustainable transport and thus the airport could come back to the negotiations with the electricity and infrastructure provider about the price of the charging infrastructures claiming the discounts on the bulk purchase. Thus, the airport could really benefit from this strategy and install both the internal and public use recharging stations once it obtains the State support.

10.3 Behavior and attitude towards e-mobility

1. Both the airport and the GH Companies when working with integration of the e-mobility into the GSE sector will have to educate the staff about the benefits of the electric equipment compared to the diesel counterpart in order to promote the excessive use of the electric GSE. Measures could be taken straight away given the Celebi GH company already utilizes the e-forklifts.

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10.4 Cooperation with the local municipality and the city of Budapest authorities

1. It is essential for the airport to request the State's attention to its interest towards e-mobility integration based on the fact that Hungary is also involved in the overall European GHG reduction plan and integration of the electric vehicles that would lead into the consequent development of the renewable energy sources and serve good for the country.

2. The municipality of Budapest can provide both significant financial and promotional support for the charging infrastructure inside and outside the Budapest airport area, which would attract the owners of EVs in a long term. Potentially the airport could sign a deal with the State authorities for installing one charging infrastructure at the outside premises where the charging station inside the airport territory could come at a smaller price since the airport provides its services to the municipality in promoting the idea of EV integration.

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11. Conclusions

This work focused on the key objectives of facilitating the exchange of experience between the three EU international airports. The two successful case study airports of Frankfurt and Vienna provided crucial information about the EV integration into their daily work and this information was further communicated to the Budapest Airport in this thesis. It was crucial to assess the international airports with a successful history of EV development since they helped identify the major drivers and barriers of the electric vehicles used at the airport premises. Another objective was to provide a platform for the successful EV integration at the Budapest airport based on the information provided by the case study airports and by the different experts at the Budapest airport itself. Finally, the last objective was to provide an in-depth insight into the potential of the Budapest airport in terms of the EV experience.

This thesis covered all of the mentioned objectives and presented an exhaustive list of recommendations for the Budapest airport in terms of designing a strong platform for integrating the EVs into its daily life. The key outcome of this work is the fact that the effectiveness of the electric vehicles, just like every other technology, would depend on the approach of the Budapest airport towards this innovation. The airport should start small by testing different types of vehicles that have been already tested by the two other case study airports in order to adapt to the new mode of transportation. This switch will result in less behavioral changes and ability to distribute the major financial investments through longer time, which according to the predictions of other airports is easier in terms of the amortization and is justified in a long term by the vehicle efficiency. The Budapest airport will have to prioritize the e-mobility project and seek additional incentives to make the investment costs less painful.

Thus, the key research question of the thesis – "*Does the EV technology respond to the requirements of the Budapest Liszt Ferenc International Airport for adequate reduction of Greenhouse Gas emissions (GHG) from the ground transportation fleet and feasible elimination of financial burden associated with conventional fuel consumption of the fleet?*" - *w*as answered as "yes, it can, but it depends on the personal experience of the airport with this technology". This response was based on the experiences of the two major international airports in Europe such as the Frankfurt and Vienna airports, which pointed out that not every technology can be equally well used in different settings. The Budapest airport will need more

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time to test the new electric vehicle technology and to realize whether it suits the needs of the airport and whether the airport will be able to adapt to some changes that the technology might introduce.

The rest of the sub-questions stated in the introduction of this paper will be answered by the following short summary of the key findings from all three airports.

11.1 Financial aspect

* Generally, the airports view the EVs as a potential reduction of financial costs before they consider the potential reduction of the emissions from this technology. Significant reduction in the market price has to be acquired before the airport can start using light commercial vehicles for the ramp agents. At the moment only certain types of GSE equipment have a short payback period (forklifts, e-loaders, conveyor belts, hybrid tow trucks and potentially solar – powered passenger stairs).

* More incentives are needed from the state, vehicle or battery manufacturers in order to accelerate the process of e-mobility integration into the airport operations. The high cost of the e-vehicles still remains a barrier to introduction of this technology.

11.2 R&D

* EVs with lead acid batteries have so far successfully penetrated the short distance-low speed GSE sector. However, the airports are generally sceptical about the EV range, speed and overall reliability of the battery capacity for the long-distance sector at the airport where predictability of the technology is essential. The lead acid battery is currently the best option for the short distance - slow speed GSE sector at the airports. There is a potential for the NiMH to substitute some of the lead-acid batteries for some equipment, yet this will need more research and time to come about.

* R&D is needed in order to tackle the further integration of the EVs into the airport daily operations in different transportation sectors.

11.3 Charging infrastructure

* Integration of the EVs into the airports involves minor changes within the infrastructure if there are not many vehicles. The simplest charging option is the conventional plug that is protected from the weather conditions by a lid and can recharge any type of electric vehicle within 6 to 8 hours, with a potential for short charging time.

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* In case of more advanced charging infrastructure, there is a demand for standardization of the plugs and the need to have more rapid charging options (under 15 minutes) for the EVs to be highly competitive compared to the diesel vehicles

11.4 Behavioral change and Organizational benefits

* Integration of EVs into the airports does not involve much behavioral change either where the staff has to simply remember to plug the equipment in once it is not in use and make sure it has enough capacity to operate the peak hours. Little planning usually does the best job for taking care of the battery charge.
* Cooperation between the airports and planning mass purchases in advance from the same provider of equipment has a positive effect on the manufacturer's discount rates since ordering the equipment in bulk usually results in reduction of the overall price.

11.5 Policy and Subsidies

* If Governmental subsidies do exist, they still need to increase in order to cover the airport's demand for the electric vehicles integration.
* European policy framework on e-mobility has to significantly develop in order to trigger major EV integration into the airports and urban areas. Additionally, stronger policies would yield more progress from the vehicle and battery manufacturers where the prices for the vehicles could significantly drop over time.
* Cooperation between the airport and local authorities is crucial for the successful integration of the EVs both outside the airport premises and on the inside due to possibility of obtaining the State support such as financial incentives.

11.6 Future research

Conclusively, all of the future research and marketing screening will have to be done by the Budapest International Airport in order to adapt the electric vehicle technology to its needs and receive the maximum benefits from it. Since I participated in the original meetings with the representatives from the Budapest airport and the GH Companies, I was able to observe the demand from both the airport and the GH side for the more efficient vehicles on the apron. Since the Budapest airport has already established the "e-mobility movement" that includes the airport managerial staff and representatives from the GH companies, I am certain the cooperation will yield the best strategy that would target successful EV integration. The

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future research for the best fuel efficiency could also incorporate hydrogen fuel cells, biofuel and other options that both the Frankfurt and Vienna International Airports are also considering in parallel with the electric vehicles.

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Appendix I

Methodology. List of semi-structured questions:

- Can you tell me about the original plan of electric vehicle (EVs) integration and how it has evolved, if at all, along the way?
- What vehicles were (or will be) introduced/modified (heavy-duty or passenger fleet)?
- What would you say have been the most influential elements leading to this program?
- How would you describe the differences between electric and regular gasoline vehicles?
- How has the program been working? Are there lessons learned that you think might be helpful for others wanting to do something similar?
- How would you describe the receptivity to the program?
- What are the most critical issues for implementing EVs at the airports?
- What do you think is the further scenario for EVs at the airports in EU?
- What new policies would make a significant improvement in this area?
- Do you have a public outreach campaign regarding the program? If so, can you describe it?

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EV traction battery overview

***Table 3**. Comparative scheme for different type of already existing batteries (or last stage of research) (Sources: Harrop and Das 2011; Kobayashi et al. 2009; Van den Bossche et al. 2005).*

	Lead acid	NiCd	NiMH	Zn Air	Sodium Sulfur	Zebra NaNiCl	LiCoO2	LiMn2 O4
Release	1881	1958	1990	1997	1960	1982	1992	1999
Voltage (V)	2	1.2	1.2	1.15	2.1	2.58	3.7	3.6
E by weight (Wh/kg)	30-40	40-60	30-80	200	110	100	90-140	160
Specific Power (Wh/l)	180	150	250-1000	80-140	150	150	760	1800
Max discharge	10C	n/a	20C	n/a	n/a	n/a	40C	40C
Charging rate (hrs)	>10	8	6	n/a	n/a	n/a	< 3	< 3
Monthly self-discharge	3-4%	20%	30%	n/a	n/a	0	5-10%	5-10%
T range	n/a	-40 to +60C	-20 to +60C	n/a	n/a	n/a	-20 to +60C	-20 to +60C
Charging specifics	Const voltage	Const current	n/a	n/a	n/a	n/a	Const voltage/ current	Const voltage /current
Cycle life	500-800	2000	1500	200	1000	1000	>1000 (3000 max?)	>1000 (3000 max?)
Cost $/kWh	150	400-800	250	80	n/a	300	>300	>300
Range PEVs/HEVs	<40 miles		HEVs 40-50 miles				40-250 miles	

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