Energy xxx (2016) 1–10

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Adoption barriers for electric vehicles: Experiences from early adopters in Sweden

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ARTICLE INFO

Article history:
Received 25 February 2016
Received in revised form
12 November 2016
Accepted 21 November 2016
Available online xxx

Keywords:
Electric vehicle
Consumer behavior
Market uptake
Smart grid
Distributed energy resources

ABSTRACT

Electric vehicles are considered as one of the most effective technologies for reducing current greenhouse gas emissions from the transport sector. Although in many countries, local and national governments have introduced incentives and subsidies to facilitate the electric vehicle market penetration, in Sweden, such benefits have been limited. Results from a survey carried out among private owners of electric vehicles are presented in this paper, including the analysis of the respondents socio-demographic characteristics, reasons for choosing an electric vehicle, charging locations and driving preferences, among others. The main results characterize current electric vehicle drivers as male, well-educated, with medium-high income; electric vehicles are used mainly for private purposes and charged at home during night time. Furthermore, the paper presents an analysis of the impact of large-scale penetration of electric vehicles on existing power distribution systems. The findings presented in this paper provide important insights for assuring a sustainable large-scale penetration of electric vehicles by learning from the experiences of early adopters of the technology and by analyzing the impact of different EV penetration scenarios on the power distribution grid.

1. Introduction

In 2009, the transportation sector was responsible for 25% of the worldwide carbon dioxide (CO_2) emissions, out of which 75% was produced by cars and trucks [1]. In the European Union (EU), road transportation contributes to one-fifth of the total CO_2 emissions which has led the European Commission to set targets such as 10% renewable transport fuels by 2020 [2]; or adjusting the CO_2 emission limits for all new cars from 130 g of CO_2/km to 95 g of CO_2 by 2020 [3]. Not surprisingly, with the increasing concerns regarding rising GHG emissions and secure oil supply, the development of low-carbon and carbon-free technologies for transportation has been given a high priority for policy makers and different authorities worldwide [4]. Alternative fuel vehicles have increasingly gained attention due to their potential for reducing greenhouse gases (GHG) emissions and their ability to increase the penetration of renewable sources into the transportation sector. Development of cost-competitive second and third generation biofuels as well as large-scale market penetration of Electric Drive Vehicles (EV) for commercial and private use, have become the main focus of investments in Research, Development and Demonstration programs [5].

Although electric vehicles have been around since the 1800s [6], it was not until 2011 when commercial EVs gained high interest, mainly due to environmental concerns, as well as advances in batteries and electric drive-train technologies (e.g. regenerative breaking) [4].

Typically, the term *EVs* refers to different types of vehicles, for instance plug-in hybrid electric vehicles (PHEVs), extended-range battery electric vehicles (E-REVs), battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs). This paper will focus on the owners of BEV, thus excluding all the hybrid models.

Regarding the EV market uptake, their penetration levels are strongly dependent on the consumers acceptance. On one hand, potential changes in travel behavior, governmental support and the environmental and economic concerns are some of the additional key factors that have acted as barriers to rapid and successful EV market uptake. On the other hand, higher price than conventional vehicles, is one of the main reasons for the weak demand in many countries. Additional concerns, such as the so called range anxiety,

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http://dx.doi.org/10.1016/j.energy.2016.11.119
0360-5442/

referring to the anxiety caused by the limited driving range of the batteries versus the range offered by their internal combustion engines (ICEs) counterparts, batteries charging time and lack of charging infrastructure versus the use of fossil fuel stations [7] also limit mass adoption of EVs. However, a study carried out in UK, evaluated the charging behavior of EV drivers, and found that the initial range anxiety would fade overtime since knowledge and confidence developed through driving for an extensive period of time [7], [8].

Zubaryeva et al., summarized different criteria affecting the success of EVs market penetration: demographic criteria (e.g. early adopters usually have high income; wealthier countries will adopt earlier); environmental criteria (e.g. temperature variations); energy criteria (e.g. including electricity mix; energy security); and transport criteria (e.g. market penetrations might be facilitated if it targets consumers interested in purchasing a second car) [9]. To identify and understand the main driving forces that explain the variables and the thought process of early EV adopters, could help develop better strategies and incentives to help increase its market penetration.

The aim of this paper is to identify the main factors responsible for motivating the use of EVs and to understand the thought process of early EV adopters, in order to shape the strategies and define better incentives that could help increase the market penetration of electric vehicles in Sweden. This country has been ranked several times as one of the most innovative countries in the world as well as environmental front-runner and pioneer [10], moreover, it has several characteristics that make the country very suitable for large-scale electric vehicle adoption, for instance, stable production and high capacity transmission of electricity, large share of renewable energy sources, with 44.1% generated by hydro [11], possibility for easy access to charging, etc. [12].

When it comes to the current levels of EV penetration in Sweden, the total amount of electric vehicles, including plug-in hybrid vehicles was of 8668 in February 2014, out of which 39% were fully electric and 61% plug-in hybrid vehicles [13]. Although there was a 142% increase between 2014 and 2015, Sweden still lags behind in comparison to other European countries, as for instance Norway, France or Germany.

The main gaps identified in research literature (and not based on hypothetical data) from EV drivers are the lack of studies using representative samples that include the experiences from EV early adopters as identified by Refs. [14,15]. A better understanding of EV drivers behavior is essential to determine the impact of EVs and to promote a successful and sustainable integration of EVs into current societies and infrastructures and to facilitate future EV market development and growth.

Moreover, filling these gaps would help determine changes in electricity demand necessary to estimate future infrastructure requirements and maximize existing resources, specially non-dispatchable renewable electricity. Integrating electric vehicles with existing power systems poses several challenges besides the economic and regulatory challenges, such as the technical limitations of the existing networks and the increase in distribution losses due to EV charging peaks.

In order to cover some of the research gaps and help eliminate some of the market barriers that explain the slow EV penetration in Sweden, this paper focuses on identifying and evaluating EV early adopters characteristics and experiences. The results are expected to provide important insights for policy development, marketing strategies and infrastructure requirements for a successful large-scale EV adoption. Additionally, other countries with similar characteristics can improve their initial EV implementation stages from the learned experiences in Sweden. To achieve this, a detailed survey was sent out to all the private electric vehicle owners in Sweden, gathering insightful information regarding their characteristics, driving experiences and suggestions for future improvements.

Additionally, in order to estimate the possible impacts on the existing electricity infrastructure, the information from the survey, regarding charging habits and average daily driving patterns, together with EV adoption forecasts [5], were used to analyze the impact of EVs on the existing power infrastructure. Moreover, studies and simulations from several researchers on this particular issue [16,17] were also presented and discussed. Finally, a simple simulation model was built to determine the technical implications on the local electric distribution infrastructure of the expected EV growth in Sweden.

1.1. Relevance of EVs

Electric vehicles have been proposed as one of the most effective alternatives to internal combustion engines (ICEs) to reduce CO_2 emissions and allow countries to increase their sustainability [18]. From an efficiency point of view, ICEs reach 28–30% conversion efficiency while electric motors can achieve up to 95% [19]. From an environmental point of view, when comparing the operation phase of ICEs and EVs, LCA analysis shows that gasoline vehicles cause a higher environmental impact. However, battery production is considered as the most critical component, depending on the type of materials needed for the manufacturing. As an example, when manufacturing Lithium-Ion batteries, CO_2 levels of 2.7 MT per battery have been estimated by Ref. [20]. In addition to the previously mentioned impact, Faria et al. have identified that the elevation profile, user driving style and the auxiliary equipment affect heavily the overall energy consumption of the electric vehicles [21]. Moreover, the electricity generation mix is also one of the decisive factors affecting the EV impacts on GHG emissions. With the current share of renewable sources in the electricity mix of many European countries, led by Norway with close to 100%, followed by Austria and Sweden with approximately 60% in 2012 [22], EVs would contribute to a substantial reduction of GHG emissions in these countries, with emissions expected to continue decreasing due to the continuous integration of renewable sources.

Another important aspect to consider is the impact that different penetration levels of EVs will have on the power system. Large penetration of EVs would not affect the power transmission and distribution systems, for as long as they are managed as active components of the whole power grid. With highly increasing use of renewable energy sources, Finn et al. demonstrated that, by combining renewable production with demand response management of EVs, grid operators and consumers would maximize renewable self-consumption, reduce the peak demand and minimize demand on conventional generation [23]. To minimize the impacts on the power system and avoid investments on new generation and transmission capacity, Madzharov et al. analyzed several scenarios of EV penetration, with controlled and optimized charging in different power systems, demonstrating the potential benefits with using controlled charging [24]. The idea behind *Smart Charging*, is that the EV or the charging station it is connected to, would communicate with the network operator and then it would send back information about how much power it could draw at any given time. This approach has been reported to help improve the integration of intermittent sources of energy into the electric grid [25]. An additional approach is to provide with *vehicle-to-grid* (V2G) functionalities, where EVs are allowed no only to recharge from the electric grid, but also to supply power from their batteries when required. V2G would allow EVs to play an important role in increasing the flexibility of the distribution power system and to facilitate the integration of fluctuating distributed energy sources

Please cite this article in press as: Vassileva I, Campillo J, Adoption barriers for electric vehicles: Experiences from early adopters in Sweden, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.11.119