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Assessing electric mobility feasibility based on naturalistic driving data

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ABSTRACT

In a context where electric mobility is gaining increasing importance as a more sustainable solution for urban environments, this work presents an analysis of electric mobility feasibility and adequacy based on private users' naturalistic driving data. Several scenarios were tested to evaluate different charging event opportunities and their impacts on electric mobility feasibility. In more detail, scenario 1 considered that vehicles would recharge whenever they are stopped for 2, 4 or 6 h, either on weekdays or weekend days; scenario 2 tested the hypothesis of recharging only during the night period; and scenario 3 assumed that vehicles would recharge during the day on weekdays. Furthermore, the potential energy impacts of electric mobility at a city level, by applying a driver and street level approach, were also estimated.

Results revealed that electric mobility is highly feasible for weekday urban trips, while weekend trips due to their higher average distance are less suitable to be performed by EVs. Scenario 1, due to its higher recharging opportunities was found to be the best-case scenario. In this case, the percentage of eligible trips was found to be equal to or higher than 94% and 88% on weekdays and weekend days, respectively. Results showed also the lower electric mobility feasibility if considering only daytime charging, on weekdays (scenario 3). However, if considering night charging (scenario 2), the electric mobility eligibility was found to improve significantly. When considering a street level analysis, the potential reduction in energy consumption ranges in average from −60 to −70%, enabling the visualization of higher EV potential, with increasing potential for reducing energy consumption for increasing road grades.

Concluding, since electric mobility is particularly suited for urban driving and most households detain 2 or more vehicles, there is a high potential to replace at least one ICEV by an EV. In this case, people may adapt their driving behavior, using the EV for their day-to-day urban driving while the ICEV would be used for longer trips. Nonetheless, the capacity to recharge during night plays a significant role on trips eligibility. Therefore, the availability of home-charge set-ups or a much higher deployment of public charging stations at residential locations are required in order to incentivize drivers to shift towards electric mobility.

1. Introduction

The transport sector is accountable for considerable externalities, mostly at urban level with consequences in terms of traffic, energy consumption, air quality and noise problems. For example, road transport in the UE-28 was responsible in 2015 for 33% of the final energy consumption and 26% of greenhouse gas emissions (EEA, 2017; European Commission, 2017). These facts justify the need to consider alternative solutions in this sector.

The major alternatives to mitigate these impacts have focused mostly on improvements in energy efficiency. Among several alternatives, the shift to electric mobility, focusing on urban centers, is regarded as one of the most promising approaches (Egbue and Long, 2012). In fact, urban environment can provide a suitable

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niche for alternative vehicle technologies (such as battery electric – BEVs – and plug-in hybrid electric vehicles – PHEVs) since it is mostly characterized by lower trip distances (posing fewer restrictions in terms of range anxiety) and a higher potential for availability of a concentrated network of public charging points (International Energy Agency, 2016). But, above all, urban areas are typically affected by high levels of pollution representing a public health risk.

In this context, the introduction of alternative vehicle technologies can provide significant improvements in urban air quality, lowering the pollutants concentrations to which the urban population is exposed. With this positive effect in mind, most vehicle manufacturers are developing and/or selling electric vehicles (EVs). While in 2017 around 155 EV models were available, it is expected that in the next 5 years this value can double (Bloomberg and McKerracher, 2018). However, such technologies are still not as established as conventional ones, mainly due to consumers concerns regarding autonomy and recharging limitations but also due to the higher purchase cost (Carley et al., 2013).

Literature on consumer adoption has focused on several factors affecting the adoption of these alternative technology vehicles (Carley et al., 2013; Egbue and Long, 2012; Jensen et al., 2013; Rezvani et al., 2015; Zhang et al., 2011). Egbue and Long (2012) applied a survey to technology enthusiasts and potential EV owners in order to identify the barriers to widespread acceptance of EVs. The authors found that attitudes, knowledge and perceptions related to EVs differ across gender, age, and education groups. Furthermore, results suggested that although playing a major role on EVs adoption, sustainability and environmental benefits are ranked behind cost and performance. Carley et al. (2013) also applied a survey to examine consumer stated intent to purchase a plug-in electric vehicle. Adult drivers from large US cities were surveyed before vehicle manufacturers and dealers began marketing campaigns. Therefore, results concern early impressions on this vehicle technology. Overall, the stated intent to purchase or lease electric vehicles was found to be low. Those consumers revealing some interest in adoption such technology were typically educated, previous owners of conventional hybrids, environmentally sensitive, and concerned about dependence on foreign oil. However, issues related to purchase cost, recharging and driving range revealed diminished interest in plug-in vehicles.

Jensen et al. (2013) assessed consumers preferences before and after a real experience with electric vehicles. A stated preference survey was applied to drivers who experienced an electric vehicle for three months. Results revealed a significant change on individual preferences after driving an electric vehicle. In more detail, driving range was found to be a major concern. Furthermore, it was found that these concerns about low driving ranges are not due to misconceptions, but a true mismatch between the range drivers wish to have available in their everyday lives and what EVs provide. Furthermore, in accordance with previous studies, findings revealed that environmental concern has a positive effect on the preference for EVs both before and after the test period.

In a review study performed by Rezvani et al. (2015), the author resumed these and other studies mentioning that, consistently, across literature, purchase cost and limited range are well-known barriers to adoption while environmental awareness and lower running cost are shown to be drivers. In this context, it is possible to conclude that, overall, there are two main limiting factors for the adoption of EVs, namely the purchase cost and the limited range. While the former restriction can be offset in the short-term, either through taxation and other financial benefits or through a better marketing on the reduced ownership costs over conventional vehicles; the last is highly dependent on technology developments (e.g. increase batteries energy capacity). Therefore, the adequacy of alternative technologies to the users' mobility profiles still corresponds to one of the major challenges in the massification of these alternatives. A potential approach to overcome this issue is to perform in-depth analyses on real world driving patterns based on real world drivers. Such analyses allow to evaluate the potential of EVs to meet day-to-day mobility requirements, which may provide a helpful tool to support public authorities on encouraging the transition of private users towards zero-emission vehicles. The increasing use of information and communication technologies (ICT) to characterize conventional vehicle's usage makes possible to obtain detailed data on driving behavior and vehicle dynamics from real world driving conditions (naturalistic driving data), that were not available until these technologies have emerged. These data provides additional opportunities such as in the assessment of the potential adoption of EVs, with some research appearing focused on this thematic. For instance, Fraile-Ardanuy et al. (2018) used GPS taxi traces to evaluate the possible adoption of EVs in a real taxi fleet from San Francisco (USA). By applying an EV consumption model derived from the physical relationship between the forces acting on the electric vehicle, the authors concluded that the *electrificability* rate of the analyzed taxi fleet was of 74.3% of the total trips, using a 2015 Nissan Leaf. Furthermore, results revealed that more than 65% of the fleet trips were compatible with the operation of a typical EV used as taxi. Considering the economic analysis, purchase costs were found to increase by 10%; however, service, maintenance and repairs and fuel costs showed a potential for reducing by 77% and 84%, respectively, resulting in a reduction of 20.9% in overall costs.

Focusing on GPS traces from internal combustion engine (ICE) light vehicles, De Gennaro et al. (2014) evaluated the potential of EVs to meet the mobility demand in two different Italian cities. In this study, instead of using a dynamic model, the potential electric energy demand was calculated based on fixed consumption values obtained from car manufacturers or from the US Environmental Protection Agency (EPA) tests, depending on the type of EV that was considered. Main findings showed that more than 80% of the urban trips are eligible to be covered by electric vehicles and that an urban fleet share of up to 28% could be replaced by electric vehicles without any change in their driving patterns. Greaves et al. (2014) used driving data recorded by GPS technology to assess the extent to which car travel needs can be met by EVs. Similarly to the previously referred studies, an energy consumption model based on characteristics of the vehicle and on speeds was used to determine the charge used, while a battery recharge function was used to determine charging times. Results revealed that EVs with a range of 60 km and a simple home-charge set-up would be able to accommodate over 90% of day-to-day driving. Moreover, the authors concluded that even if EVs are not suitable for long, high-speed journeys without having recharging alternatives, they are particularly suited for the majority of day-to-day city driving trips.

Even though there are some studies addressing the feasibility of electric mobility, these studies focus mainly on public transport fleets or professional vehicle use, which have mobility patterns quite distinct from those of private fleets, or instead use fixed consumption values, not accounting for the influence on energy consumption of road grade, traffic and weather conditions or even of aggressive driving behavior (including speeding and hard acceleration), among others. In this sense, considering the low availability of studies focusing on private fleets, in addition to the use of not very detailed and representative data, the aim of this paper is to assess electric mobility feasibility based on private users' naturalistic driving data. Expanding this driver analysis to a city level scale enables a much wider characterization of potential energy impacts of electric mobility. Moreover, this study provides new insights related to usage and recharging requirements for the