

ASSESSMENT OF ELECTRIC MOBILITY ADEQUACY AND ENERGY REQUIREMENTS BASED ON REAL WORLD DATA

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Abstract

In a context of high energy and environmental impacts of the transportation sector, alternative vehicle technologies, such as electric vehicles, appear as an adequate option. This paper addresses the suitability of these vehicles to drivers' mobility patterns and quantifies the potential energy requirements that result from different recharging scenarios. For that purpose, a tool was developed to assess, through real-world monitoring, the impacts of shifting to electric mobility considering driving patterns, hourly availability to recharge and electric vehicle characteristics. The main results indicate that between 45 to 77.5% of the studied drivers have an adequate mobility pattern to electric mobility and possible recharging patterns are anticipated. Furthermore, the developed tool provides accurate results for hourly energy grid requirements when compared with real-world charging scenarios.

Keywords: EV (electric vehicles), charging, on-board, driver

1 INTRODUCTION

The transportation sector plays a crucial role in people's quality of life. However, over the last decades, the issue of the negative environmental impacts associated with the transportation sector has been focus of much attention, in particular regarding the trade-off between the benefits in terms of the mobility provided to the passengers and or freight versus being a dominant source of pollutant emissions and energy consumption [1]. In 2013, the transportation sector was responsible for 32% of the final energy consumption in Europe [2], while CO₂ emissions from the transportation sector have reached 20% in the EU27 in 2012 [2]. As a result, this sector is facing new challenges related to its increasing energy consumption and emissions profiles [3].

The main strategies to address these issues have focused mainly on improvements in energy efficiency [4], namely with the development of alternative vehicle technologies, such as the hybrid electric vehicle (HEV), full electric vehicle (EV) and plug-in hybrid electric vehicle (PHEV). These technologies are mostly targeted for tackling urban mobility challenges, since they are approximately 3 times more efficient [5], they eliminate local emissions and reduce noise significantly [6]. However, the share of these vehicles in the market is still generally low and the impacts of these technologies tend not to be immediate, due to the slow fleet turnover associated to fleet renewal [7].

Furthermore, the concept of electric mobility matches very well in the smart cities concept, which has gained a lot of importance in the last years [8, 9]. Promoting an integrated energy efficiency strategy that is able to communicate data flows and information may be the way forward for numerous cities.

Nevertheless, such propulsions technologies are still not as established as conventional ones, with several weak points that inhibit them from being true alternatives. For example, the acquisition costs of EVs are still higher when compared with similar vehicles with conventional propulsion technologies [10-12]. This fact is very important, since it makes it more difficult for the EV business model to be appealing to consumers, which further hinders its wider adoption [13]. Even accounting for the reduced running costs of electric vehicles, on a total ownership cost analysis the differential is still not favorable to electric vehicles [14]. Moreover, there is still some uncertainty regarding the price of electricity if electric mobility becomes global [10]. In this sense, the high purchase cost is reported to be the major issue postponing the widespread adoption of electric vehicles [15-17]. Furthermore, technical limitations of EV such as limited range, speed, increased weight and reliability may also contribute to the low adoption levels [13], in spite of the fact that these limitations may be soon resolved through technological improvements. Several studies have focused on the improvement of the electric components, such as batteries [18, 19] or energy management [20, 21]. However, the assessment of adequacy and limitations of electric mobility based on real word data is still scarce or based on simulations. When studying EV usage suitability it is important to take into consideration aspects such as driving context, type of electric mobility (e.g. EV, PHEV and/or HEV), driving behavior and household attributes. A study simulating driving cycles from GPS travel data of 227 instrumented conventional vehicles in the US, comparing conventional, HEV and PHEV concluded that, when compared to other technologies, PHEV achieved up to 50% less fuel consumption even in aggressive operating conditions [22]. A technology comparison was also performed in a case-study in the city of Beijing using real-world GPS driving data of 112 vehicles, with results revealing a greater fuel consumption benefit of electric mobility than in the US due to different driving conditions and ranges, with PHEV with smaller batteries appearing as the preferred type demand of most drivers and with less extra cost [23]. The application of EV technologies in urban logistic transport has also been assessed, with electric mobility rising as an economically viable solution and presenting advantages regarding energy consumption, energy dependence, pollutant emissions (CO_2 , HC, NO_x and CO) and human health [24]. Savings between 30% and 100% concerning the environmental impacts of adopting EV can be achieved depending on the electricity production mix and costs per kilometer might also be reduced up to 95% [25]. In Lisbon, a high potential replacement of conventional vans with small-size electric vehicles in a city logistics operational context was found when the alternative technology is able to maintain the delivery capacity, with EV presenting better performances at a street level rather than city level [26]. Real-world data on driving cycles are crucial for evaluating electric vehicles and contributing to future design and components improvements. Additionally it is also important to take into consideration the end-user expectations and adaptation to such technologies.

As a result, two crucial aspects must be evaluated in what concerns electric mobility: first, adequacy quantification of shifting from conventional to an alternative vehicle propulsion technology; and, secondly, anticipating the possible impacts of its adoption in mobility patterns, energy consumption and emissions. The current paper addressed these two topics taking advantage of real world vehicle monitoring data for the city of Lisbon, Portugal.

2 METHODOLOGY

2.1. Data sample considerations

An on-road monitoring trial was performed to characterize driving patterns in the metropolitan area of Lisbon, Portugal. An on-board monitoring unit (OBU) tool was used to collect data on mobility patterns and driving performance: the intelligence to drive – i2d device. A group of 40 drivers were monitored for a period of 6 months August 2014 to January 2015. Table 1 presents a characterization of the participants of the study, in terms of gender, age and driving experience.

Table 1: Participants descriptive statistics characterization.

N	Gender (N)		Age (Years)		Driving Experience (Years)	
	Female	Male	Mean	Std. Deviation	Mean	Std. Deviation
40	18	22	43.4	12.2	23.7	11.8

A total of 5352 days were monitored (data for all drivers), during which drivers made a total of 25629 trips, travelling a total of approximately 285000 km in 7150 hours of driving. The participants used their own vehicles throughout the monitoring periods. Most of the vehicles were diesel (65%) with less than 10 years (Euro 4 or newer). Regarding the vehicles type, it ranged from small city cars to sport utility vehicles (SUVs), with family cars (40% of the vehicles) being the most common.

The i2d device used for the study is a technology promoted under a R&D project supported by FAI (the Portuguese Innovation Support Fund for Energy Efficiency) developed by an IT SME Portuguese company (ITDS) in a partnership with a research center (IDMEC - IST) with a high technological demonstration component. Figure 1 presents the i2d device and its installation in a vehicle.



Figure 1: i2d (intelligence to drive) on-board unit device.

The i2d provides a non-intrusive system that monitors all the main variables with an 1 Hz frequency that characterize vehicle usage (location, vehicle dynamics, road grade and engine management) with specific dedicated sensors such as GPS, altimeter, accelerometers and OBD connection. Based on the collected data, i2d calculates accurate relevant indicators needed to characterize the use of vehicles. In order to ensure confidentiality, at any moment, only the driver or an identified user has access to the driver's own information on the website. All communications are secure on a 24/7 basis, based on a Machine to Machine (M2M) network, from the OBD port to the cloud directly. For research purposes, a separate platform can be accessed in which it is possible to download the data collected.

2.2. EV adequacy modeling tool

For the purpose of quantifying driver adequacy in shifting from conventional to an alternative vehicle propulsion technology and of anticipating possible impacts of its adoption, an EV adequacy tool was developed. The overall EV adequacy modeling tool schematics is presented in Figure 2.

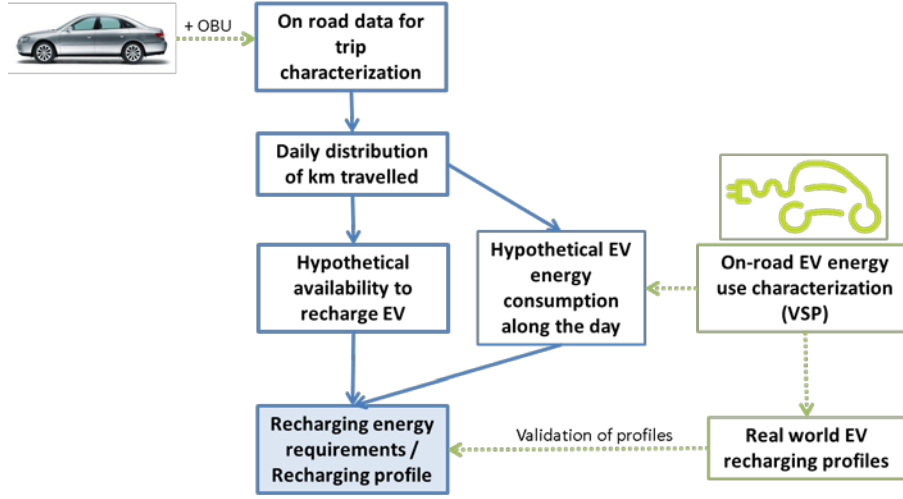


Figure 2: Overview of the applied methodology

In a first step, the real-world vehicle data collected with the i2d device enabled the trip characterization of the different drivers, allowing to assess different indicators concerning vehicle usage, namely:

- Day and time of trip;
- Distance travelled;
- Average speed; and
- Driving power distribution (based on 1 Hz vehicle speed, acceleration and road grade), following Vehicle Specific Power (VSP) methodology [27].

Using the VSP methodology distributed by 14 modes [28], it is possible to calculate the second-by-second driving power demand for each of the monitored vehicles. VSP can be calculated according with Eq. 1.

$$VSP = v \cdot (1.1 \cdot a + 9.81 \cdot \text{grade} + 0.132) + 3.02 \cdot 10^{-4} \cdot v^3 \quad \text{Eq. 1}$$

Where VSP is vehicle specific power (m^2/s^3); v is instantaneous vehicle speed (m/s); a is instantaneous acceleration (m^2/s) and grade is road slope. The VSP distribution in 14 modes is computed at a trip level building a fingerprint of the power distribution of each driver vehicle usage.

Furthermore, the collected data allows considering other trip indicators, which are combined with the previously mentioned, namely average daily hourly distribution of the distance travelled. This hourly basis distribution of the distance travelled by each driver enables the assessment of recharging possibilities throughout the day (considering both week and weekend days). Recharging opportunities are considered by the model, whenever the vehicle is stopped for two consecutive hours.

For estimating hypothetical EV energy consumption (i.e. what would be the energy consumption footprint if the conventional vehicle mobility profiles was fulfilled by an EV), representative EV models were considered (with battery capacity between 16 and 24 kWh). To estimate EV energy needs in the real world driver mobility patterns, the developed EV adequacy model combines the modal energy use of a specific EV (previously collected under on-road conditions in other studies [29]) with the VSP modal time distribution obtained with the data collected for each driver, allowing estimating the energy requirements of each driver profile according with Eq. 2.

$$\text{Total Energy} = \sum_{i=1}^{14} \text{Energy}_i \times t_i \quad \text{Eq. 2}$$

Where i corresponds to the 14 modes, Energy_i the energy use on VSP mode i and t_i the time on VSP mode i .

Taking into consideration all the information obtained by the model, it is also possible to estimate the evolution of vehicle battery state of charge, as well as the recharging voltage and current in a minute by

minute basis. Finally, all this information generates EV recharging energy requirements, which translate into recharging profiles.

The EV adequacy model is applied to the driver profile in a weekly basis analysis combining variables related to driving performance (VSP time distribution, distance travelled, average speed), availability to recharge (hourly distance distribution) and EV characteristics (VSP modal energy use, battery capacity and charging characteristics). For this case, the properties of typical EVs commercially available (and already characterized under on road conditions) have been tested.

2.3. EV recharging scenarios

In order to test the applicability of the EV adequacy model, three different scenarios of EV charging were tested:

1. Recharging whenever possible;
2. Afternoon/night charging (after 1 p.m.); and
3. Night charging (between 2 and 6 a.m.).

The first scenario considers that whenever there is an opportunity to recharge (vehicle stopped for 2 or more consecutive hours), there is infrastructure available and the EV will be recharged. A second scenario was defined taking into account a mobility profile where the vehicle is used mostly during the morning and recharged afterwards. This type of profile can be adequate for private or commercial purposes, namely in logistics applications, very highlighted lately in the literature [30, 31]. Lastly, the third scenario is more related with private vehicle usage, in which the vehicle is exclusively recharged during nighttime and at home.

The three scenarios tested have been observed under real-world operation in three different applications [32]. These three real world EV adopters' usage patterns were used for comparison and validation purposes. For each case, standard slow recharge (on Schuko sockets) was taken into consideration in the analysis, since it is the most observed reality, as well as to maintain coherence between the model results and real-world operation.

3 RESULTS AND DISCUSSION

Based on the sample of 40 drivers in Lisbon area, it was possible to evaluate the adequacy of EV to their mobility patterns. Figure 3 presents an overall characterization of the sample drivers' mobility patterns, showing that 60% of the drivers analyzed travel up to 30 km per day, either under commuting trips (private use) or for daily usage. The percentage of driver using their vehicle for more than 60 km is low (5%).

In this section, a first characterization of the sample hourly availability recharge will be addressed; secondly, three different charging strategies will be assessed regarding the adequacy of the mobility profiles of the sample. From the drivers that are able to change to electric vehicles, a comparison between simulated and real-world recharging datasets (with similar charging strategies, for each scenario) will be performed, allowing to compare the magnitude of energy charged as well as the hourly charging profiles.

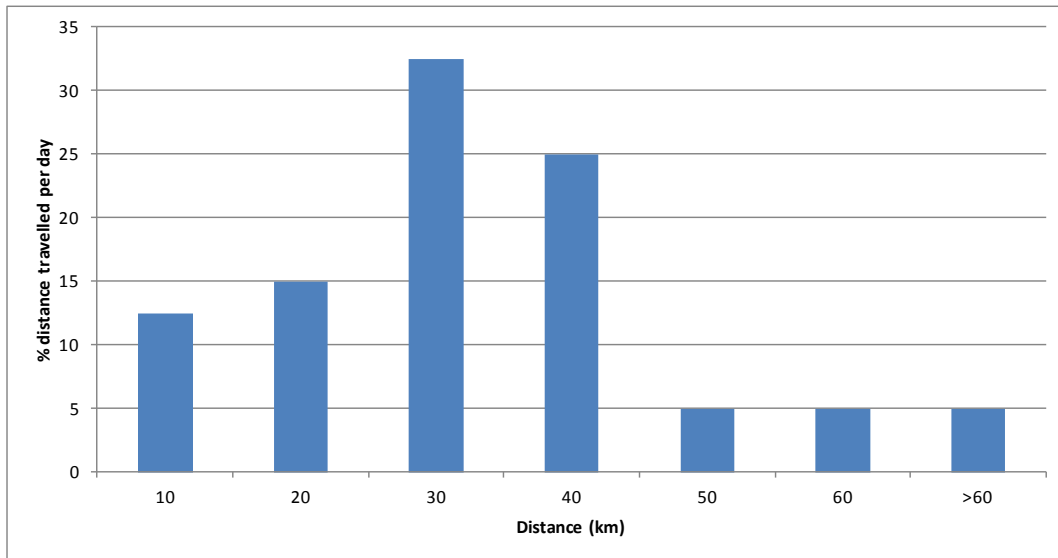


Figure 3: Distribution of the daily distance driven for the sample of 40 drivers studied

Based on the developed EV adequacy model, it was possible to evaluate the recharging availability for all the considered sample, by considering the hourly mobility characterization of each driver. Figure 4 shows an almost total availability (near 100%) to recharge between 0 and 7 a.m. Furthermore, on weekdays during daytime, the availability to recharge is generally over 40% outside the peak periods (morning, between 8-10h and afternoon, between 16 and 21 h). Therefore, the total sample of 40 drivers studied has some opportunities to recharge not only over night, but also during the day for some of the drivers.

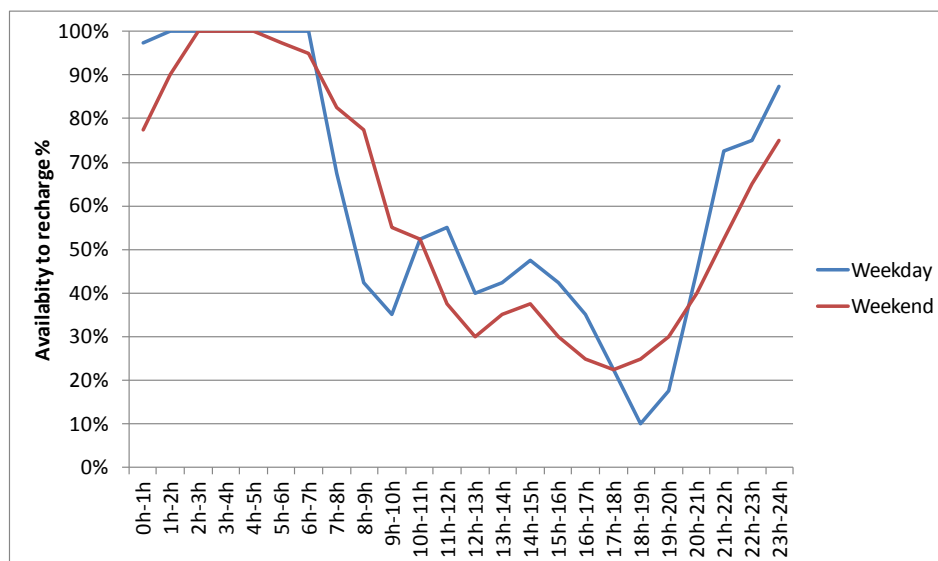


Figure 4: Hourly availability to recharge for the sample of 40 drivers studied

Considering the sample of 40 drivers, three recharging scenarios were tested and compared when possible with real-world recharging datasets from 3 EV adopters (not included in the sample of drivers studied) that present similar charging strategies. For all the scenarios studied, the simulation considered a vehicle with battery capacity and charging characteristics (voltage and current) similar to the one vehicle used in the real case.

Regarding Scenario 1, which considers recharging whenever possible, the modeled recharging profile is presented in Figure 5. There are some differences to the real recharging profile, mainly at night, due to the fact that this user always charged during the day, but would not do it always at night. However, the results obtained indicate that there is some consistency in the magnitude of the energy charged, suggesting as well as a predominance of energy charging during day and the remaining at night. For Scenario 1, 24 of the 40 drivers would be able to shift to electric mobility. The remaining drivers presented driving profiles that did

not allow for a change to electric mobility, either due to high distances driven or lack of recharging availability.

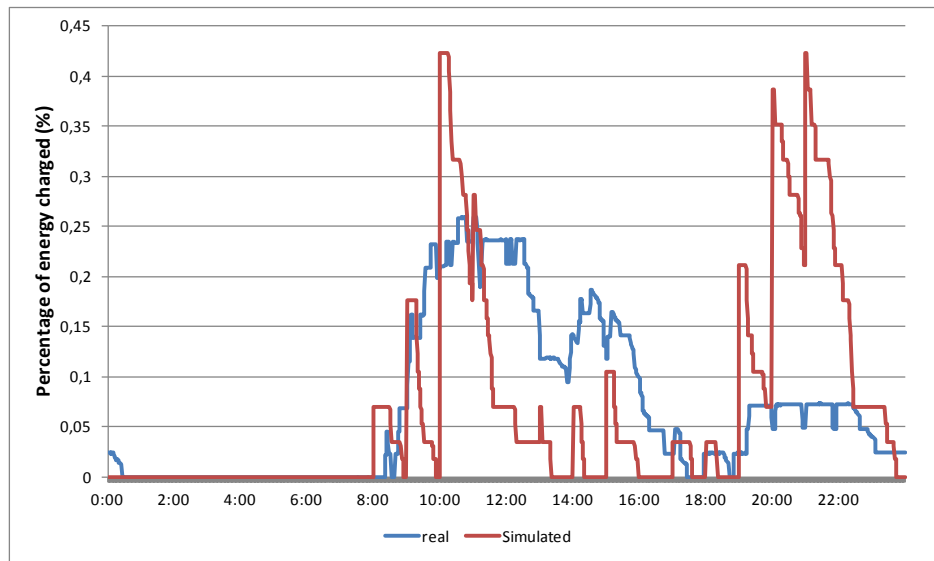


Figure 5: Electric vehicle real and modeled energy charging profiles for Scenario 1 for 24 adequate drivers

Based on the possibility of using EV mainly during the morning period (a.m.), a second option was tested, evaluating the possibility of recharging afterwards, as presented in Figure 6. Once again, the differences found are justified by the different type of mobility profiles under comparison: private usage (18 drivers) versus the real recharging profile (which represents a commercial usage). The reduced availability to recharge between 4 and 8 p.m. is the main responsible factor for the differences found between simulated and real charging profile, as well as a high availability of the simulated profiles to recharge around 1 p.m. Therefore, the modeled data tends to present a large amount of energy charged in the beginning of the considered period instead of the homogeneous real profile. For this recharging scenario, only 18 of the 40 drivers would be able to change to electric vehicles.

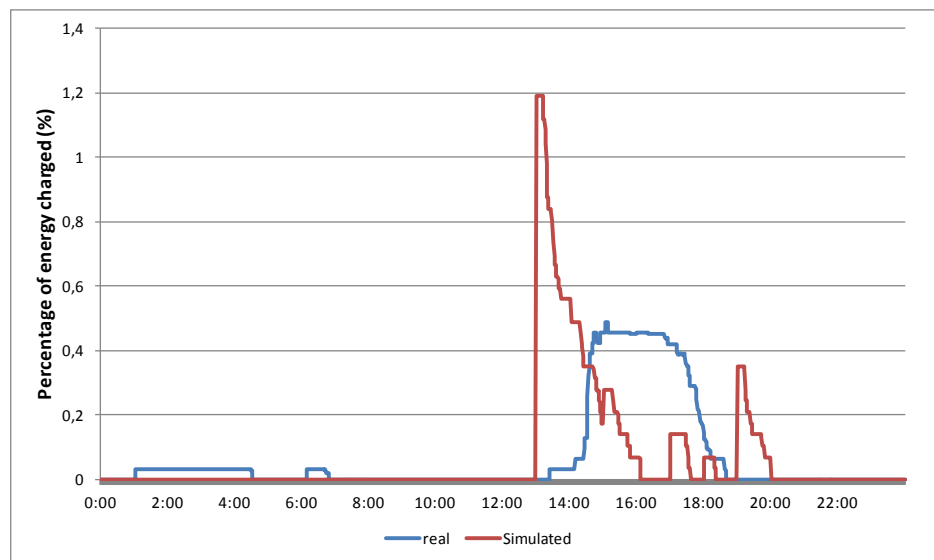


Figure 6: Electric vehicle real and modeled energy charging profiles for Scenario 2 for 18 adequate drivers

For a night charging scenario, Figure 6 presents the percentage of energy charged along the day, depicting a good agreement between the estimated and the real charging data. As shown in Figure 7, the availability to recharge is very high during the night for the sample of 40 drivers studied. Furthermore, the possibility of overnight recharging seems to be little influenced by the different mobility patterns of the sample of drivers studied, since they have sufficient time to fully charge the vehicles' batteries during night. This result indicates that the model provides good results when the conditions for these comparable conditions.

For this scenario, 18 drivers were able to shift to electric mobility, because starting at 2 a.m. would not recharge the vehicle's battery enough to guarantee the next day mobility patterns. However, if the night recharging scenario contemplates charges between 8 p.m. and 6 a. m., 31 drivers (77.5% of the sample) would be suitable to change the electric vehicles, since this schedule is particularly adequate to the sample's hourly availability to recharge.

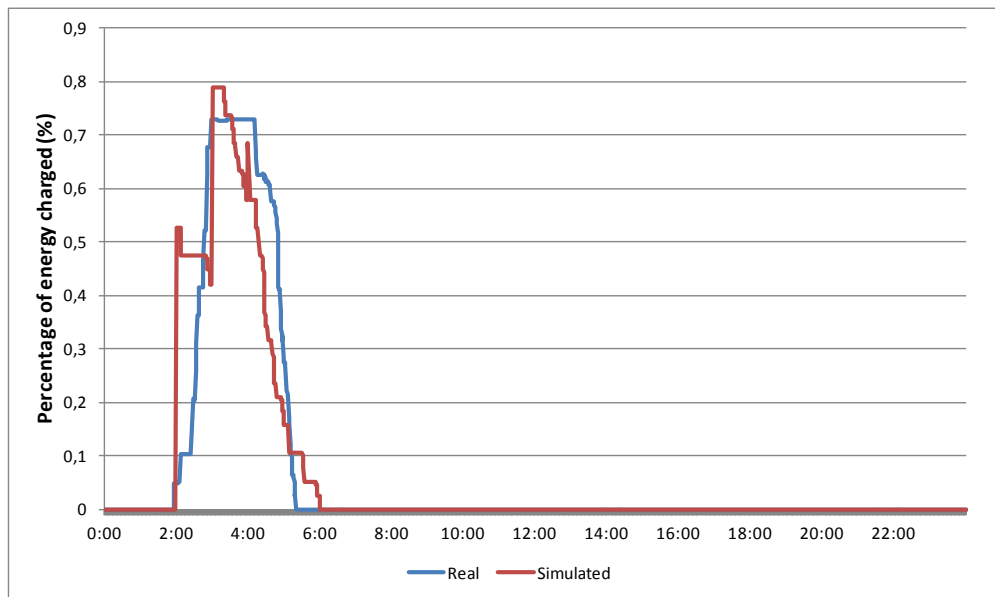


Figure 7: Electric vehicle real and modeled energy charging profiles for Scenario 3 for 18 adequate drivers

4 CONCLUSIONS

In a context of high energy and environmental impacts associated to the transportation sector, alternative vehicle technologies, such as electric vehicles appear as a suitable option. Electric vehicles are mostly targeted as a means to tackle urban mobility challenges due to their higher efficiency, local emissions elimination and significantly reduced noise. However, the share of these vehicles in the market is still low, mostly because of the reluctance associated with autonomy and charging. Consequently, the adequacy and performance of electric mobility is still uncertain. This paper focus on this issue by analyzing the adequacy of electric vehicles to a sample of 40 drivers. These drivers were monitored in their conventional vehicles under real-world operational context, allowing to assess driving patterns including their modal power distribution, hourly availability to recharge and distances driven.

For this purpose, a tool was developed to analyze through real-world monitoring, the impacts of shifting to electric mobility considering driving patterns and electric vehicle characteristics (such as battery capacity, modal energy use and recharging properties). Three scenarios were tested (recharging whenever possible, afternoon/night charging and night charging) and compared with three real-world recharging datasets compatible with each recharging strategy studied. The EV adequacy tool provides estimates of minute-by-minute energy requirements to the grid according with driver mobility patterns and vehicle inputs.

The main results indicate that different charging scenarios allow including between 45 and 77.5% of the studied drivers and that the tool developed can provide accurate results of hourly energy grid requirements when compared with real-world charging scenarios. This is particularly demonstrated in Scenario 3 where the charging conditions are very similar.

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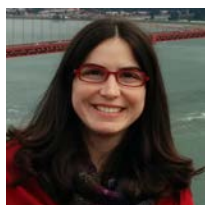
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