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GIS-driven analysis of e-mobility in urban areas: An evaluation of the impact on the electric energy grid

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HIGHLIGHTS

- Two GIS driving patterns databases are analysed.
- The urban travel behaviour in two Italian provinces is derived.
- Two BEV models and five recharging strategies are assumed.
- Results show that an urban fleet share between 8% and 28% can be driven only electric.
- The electric energy demand of this fleet share stays below 5% of that of the province.

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ABSTRACT

This paper investigates the potential of electric vehicles to meet the mobility demand currently met by conventional fuel vehicles and explores the application of GIS datasets to geo-reference the electric energy demand resulting from their deployment on large geographical areas. The study is based on driving patterns collected from conventional fuel vehicles in the Italian provinces of Modena and Firenze by means of on-board GPS systems. The analysis is carried out over one month, considering approximately 28,000 vehicles and 36 million kilometres. Two types of battery electric vehicles and five recharging behavioural models are considered, to evaluate the trips and the fleet share suitable to be served by EVs, by following all the trips and parking sequences in the databases. This allows deriving the impact on the electricity grid of the electrification of urban vehicles in terms of additional electric energy demand and its geographical distribution. The results show that more than 80% of the urban trips can be covered by electric vehicles and that an urban fleet share between 8% and 28% could be replaced by the current generation of electric vehicles without any change in their driving patterns. The derived electric energy demand increase remains below 5% of the total electric energy demand, and below 20% of the domestic electric energy demand in the analysed areas. The geographical analysis shows in detail how this additional demand is distributed over the areas analysed, and how it compares with the already available recharging infrastructures in the two provinces. A complete description of the model developed is provided, focusing on the potential of GIS datasets to address the integration of electric vehicles in urbanised areas.

1. Introduction

The potential of applying Geographic Information Systems (GIS) is well recognised in many fields of research. With respect to the analysis and modelling of transportation systems, an increasing adoption of GIS data has been noticed over the last decade, in order to integrate travel surveys [1,2] with better data acquisition techniques. In general GIS data are more accurate and reliable than those from surveys, as the latter might be affected by personal interpretations and errors by the interviewed people [3].

GIS data have been already used to observe mobility paths and corridors in congested areas, with the purpose to optimise traffic flows and reduce transportation time, as per [4–6]. However the accuracy of GIS datasets, together with the possibility to automatize the data acquisition and processing, has enabled to collect large amounts of data, extending mobility analysis to a number of different objectives. For instance, GIS data have been used to

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Nomenclature

Acronyms

AC	alternating current
BEV	battery electric vehicle
DC	direct current
EPA	environmental protection agency
EU	European Union
EV	electric vehicle
GIS	geographic information systems
GPS	global positioning system
HEV	hybrid EV
HVAC	heating, ventilation and air conditioning
IEC	International Electrotechnical Commission
LDV	light duty vehicle
PHEV	plug-in hybrid EV
REEV	range extended EV
SOC	state of charge
SUV	sport utility vehicle
V2H	vehicle-to-home
V2G	vehicle-to-grid

model the traffic-related air pollution [7,8], expansion of urban conglomerates and networks developments [9,10] as well as travel mode detection [11]. Recently GIS data have been also used to investigate the potential of the deployment of new individual road transport technologies. Notably the public acceptance and usability of Electric Vehicles (EVs) was addressed in [12–14], dealing with the energy distribution infrastructure impact and optimisation for Plug-in Hybrid EVs (PHEVs) [15–17], the effects on electricity market of Vehicle-to-Grid (V2G) applications [18–20] and market potential of EVs [21].

Beyond these recent applications, GIS datasets have even more potential, not yet fully explored in literature. As presented in this work, the geo-referenced mobility analysis of large scale samples of vehicles and the integration of the transportation and behavioural models with digital mapping systems enable to precisely depict the impact of the introduction and deployment of new technologies. With respect to e-mobility, different aspects can be investigated, from the impact of present and future policies to usability and market penetration of new vehicle technologies, and short and long-term environmental aspects of EVs. The target of this paper is to explore the use of GIS datasets to investigate, in detail never reached before, the potential of EVs to meet the individual road mobility demand currently met by conventional fuel vehicles, and derive the geo-referenced electric energy demand resulting from their deployment in mid-sized European cities and the surrounding provinces.

To this purpose our Institute purchased two databases from the private company Octo Telematics [22]. This company is specialised in collecting geo-referenced driving patterns of vehicles by means of GPS devices installed on-board. The databases purchased stemmed from the Octo Telematics data pool and were chosen in order to represent the average fleet sample over one month (May 2011) in two Italian provinces, namely Modena and Firenze. These areas are identified by the province boundaries, and they are both characterised by a number of close urban conglomerates connected by an inter-urban road network. The article refers to this as urban environment. Analysing the data, it was possible to accurately derive the mobility behaviour of the vehicles (i.e. number of trips undertaken per vehicle, distances travelled, parking duration and geographical distribution of trips and parking) and evaluate the share of the mobility demand that could already today be met with EVs. Moreover the electric energy demand arising from the electrification of different fleet shares has been evaluated, enabling to also understand their impact on the current electric energy distribution grid. The time-dependency of the electric energy demand over the week, and its geo-referenced distribution in the province area have then been addressed.

The results can be extended to investigate the future development and sustainability of the EVs in urban conglomerates, evaluating the impact of transport policies [23] as well as design the recharging infrastructure network. The authors foresee the extension of the analyses to different EU countries, addressing the urban mobility and electrification of transport on a continental scale.

2. Methodology

2.1. Description of the activity databases

This study is based on the analysis of two activity databases from the Italian provinces of Modena and Firenze. These databases contain mobility data of conventional fuel vehicles in these areas, collected during a GIS data acquisition campaign which involved 52,834 vehicles in the province of Modena and 40,459 vehicles in the province of Firenze, respectively 12.0% and 5.9% of the whole fleet of Light Duty Vehicles (LDVs) in these provinces. These vehicles were equipped with an acquisition device that recorded time, GPS coordinates, engine status, instantaneous speed and cumulative distance. The acquired data enabled to derive the duration, length and average speed of the sequence of trip and parking events of the vehicles over a period of one month (i.e. May 2011) with no interruptions. Approximately 91% of the analysed vehicles were registered in the name of physical persons while the remaining part of the vehicles was registered in the name of a commercial activity. The age distribution of the private vehicle holders reflects the typical age distribution of the Italian drivers according to the data documentation from [22], while no further information concerning the vehicle and engine technology was provided with the data. The data were preliminary processed by filtering out the vehicles which had made more than 50% of the trips out of the province boundaries, reducing the databases to approximately one-third of their original size. The objective was to focus on the vehicles which show a predominant local usage that, in this specific context, can be considered mainly as urban driving. This is of particular interest for the analyses presented in this article, being the short-to-midterm deployment of EVs most likely going to happen in urban areas. Then the data underwent a cleansing and consistency check procedure, to remove possible errors from the records, due, for example, to the poor quality of the GPS signal. This procedure reduced the count of the records of the databases of approximately 5% [24].

The final size of the databases, after this preliminary data processing, reduced to 16,223 vehicles for Modena (30.7% of the original size, 3.7% of the fleet in the province) and 12,422 vehicles for Firenze (30.7% of the original size, 1.8% of the fleet in the province). The analyses presented in this paper have been carried out on these filtered and cleansed samples (considering private as well as commercial vehicles).

Table 1 provides general data of these provinces. They are comparable in terms of population, population density and registered vehicles per person, as per [25]. Table 2 provides details of the