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The Impact of E-Mobility on The Italian Electricity System

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Abstract

This paper investigates possible scenarios of electric cars introduction and their impact on the Italian electricity system. Given the foreseen increased number of cars until the year 2030, three different scenarios in terms of penetration of electric vehicles have been considered, namely 10%, 20% and 40%. A detailed bottom up energy model of the Italian car fleet has been developed. The car fleet is analyzed in terms of energy consumption, carbon emissions and externalities costs. The analyzed scenarios suggest that the introduction of electric cars would always lead to primary energy savings. In particular, the increase of the penetration corresponds to a decrease of primary energy consumption, carbon emissions and externalities costs.

*Keywords:*e-mobility; electric vehicles; private cars;

1. Introduction

Transportation is one of the main energy consuming sectors (IEA, 2017) and it is facing important challenges due to the rapid depletion of fossil fuels, the environmental and health associated problems, and the globalization of trade with its increasing international transport volume. To cope with these issues, the interest in renewable energy systems is growing rapidly as they could replace polluting combustion engines (Donateo et al., 2015). In light of this, the electrification of the transportation sector may offer important opportunities in order to increase its sustainability, considering the increasing rate of electricity generated by renewables. Electric vehicles are a key

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element in transport sustainable development as they could reduce its energy and carbon intensity, as well as the associated pollutant emission.

In this sense, the European Union has issued many directives to encourage its member countries to promote clean and energy efficient road transport vehicles by strengthening their sales (2009/33/CE) and by establishing a single market capable of reducing space, congestion, total energy consumptions and CO_2 emissions (2009/28/CE).

Italy has been strongly influenced by the European directives and issued some guidelines (AEEG, 2010) with the aim of building a framework of incentives and tax reduction for low emission vehicles including electric ones.

As a result of an analysis of national surveys, the Italian Mobility Research Centre states, that the three main important factors influencing the diffusion of electric vehicles are related to the image of modernity and the reduced environmental and acoustic pollution (ANIASA, 2013). The same study reports that the high selling price is a major obstacle to electric vehicle sales. In this sense, support policies including incentives over the long-term would be extremely important (Comodi et al., 2016).

The present paper aims at estimating to what extent is the primary energy consumption reduced in Italy if EV are introduced, how much carbon emissions can be saved and to what extent are externality costs reduced.

A bottom up model is implemented for assessing the forecasting of the vehicle stock, analyze the necessary electricity supply and check the consequent emissions. In this way, it is possible to test different scenarios in terms of car fleet development, electricity generation mix and specific consumption of the vehicles.

The model is composed by three main modules, namely forecasting and definition of the vehicle stock, electricity supply module, and the energy and emissions calculation module. The first two modules allow to calculate the input for the third one. In this way, it is possible to test different scenarios in terms of car fleet development, electricity generation mix, specific consumption of the vehicles, etc.

Furthermore, possible externality savings deriving from the introduction of electric vehicles are estimated and an analysis of the energy consumption and carbon emissions till the year 2030 is developed. Three different scenarios in terms of penetration of electric vehicles have been considered, namely 10%, 20% and 40%.

The paper is structured as follows: section 2 introduces the case study of the Italian car fleet, section 3 describes the methodology used, including basic model description and data used. Results and are presented in Section 4 and discussed in Section 5. Section 6 concludes the paper.

Nomenclature

a	Gompertz curve adjustment parameter	i	year
b	Gompertz curve adjustment parameter	j	percentage of electric cars penetration
BAU	business as usual scenario	S(t)	scrappage rate
C	cars' stock	t	vehicles at age

2. Case study: Italian car fleet

The Italian car fleet is composed by ~38 millions of vehicles and data shows that an increase of the number of vehicles was steadily registered in the period 2000-2015. The growth of the Italian car market is proportional to the growth of the GDP (Perujo et al., 2010). In fact, in the period 2010-2015 a reduction of the growth was observed, probably due to the economic crisis while from 2000 until 2010, the average growth rate was approximately constant and equal to 1.3% per year.

In terms of compliance to European emission regulations, approximately 50% of the vehicles are compliant only with Euro 0-1 (25%) and Euro 2-3 (25%) regulations, which are the oldest ones. This means that, in average, the circulating cars in Italy are characterized by higher pollutant emissions.

The remaining 50% is represented by cars compliant with Euro 4 and Euro 5-6 regulations. In Fig. 1, it can be seen that, roughly, Euro 5-6 cars replace mainly Euro 2-3 cars, whereas Euro 1-2 cars are quite stable. Since it seems that the owners have not the willingness to substitute them, it can be considered that the remaining share of Euro 1 cars will be replaced at a very slow rate.

In terms of fuel, in the early 2000s, almost ~75% of the Italian cars was fueled with gasoline. This trend was probably due to the fuel price evolution as, in the 2000s, diesel was cheaper than gasoline. In the following years a relevant increase of diesel price was also observed and many users switched to diesel cars and increased the engines and fuel demand. In fact, in 2015 approximately 50% of the cars were fueled by gasoline, ~40% by diesel and the rest by other fuels, in particular LNG and LPG. The number of users who decides to switch to these alternative fuels is increasing also because existing gasoline cars can be easily adapted.

Approximately a half of the gasoline fleet is represented by small cars, with engine dimensions in the range of 0-1200 cc., whereas the other relevant share is represented by middle cars, 1200-1600 cc., finally large cars, 1600-2000 c.c., represent only a marginal share as they compose the large majority of the diesel stock. In fact, Italian users choose gasoline for “city cars” as they consume less fuel thanks to their reduced dimension. In line with this, it can be observed that the average dimension of the engines tends to decrease probably due to the sensibility of the Italian customers to the cost of fuel.

Finally, in terms of emissions regulation, the average age of diesel fueled cars is not as high as gasoline cars, since it is a recent phenomenon and most of them are compliant with Euro 4 and Euro 5-6 regulations. Cars compliant with Euro 0-1 and Euro 1-2 represent about 30% of the total in 2015 with respect to the ~50% of the gasoline cars.

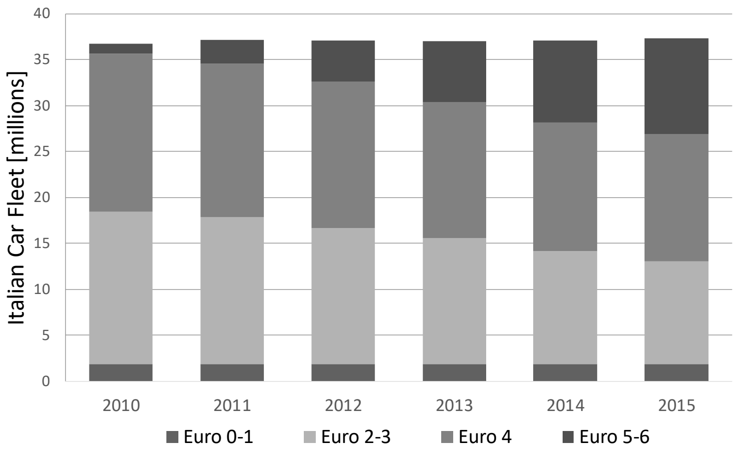

Fig. 1. Italian car fleet.

3. Methodology

A bottom up model has been developed to determine the impact of the introduction of electric cars on the Italian energy system. Firstly, an estimation of the amount evolution of cars in Italy is led and the fuel consumption associated is calculated. Then, the electric vehicles increasing introduction is analyzed determining the related primary energy consumption, carbon emissions and externalities per different typologies of cars.

The first input data were the historical number and typologies of cars circulating in Italy. The fundamental hypothesis of the model is that electric cars will affect the market shares of only small and medium (e.g. 0-1200 c.c. and 1200-1600 c.c.) gasoline and diesel cars. With the support of the LEAP (Long-range Energy Alternatives Planning) platform for the stock forecasting it was possible to estimate the number of cars available, C_i, per each year, *i*, till in 2030.

The scrappage rate was estimated according to the Gompertz curve (Dias et al., 2014) and then introduced in LEAP:

$$S(t) = e^{-e(a+bt)} \tag{1}$$

where *t* is the vehicle's age, *S(t)* is the fraction of scrapped vehicles at age *t*, and *a* and *b* are curve adjustment parameters.

The increase of the number of cars from 2016 up to 2030 is considered equal to the increase of cars registered in the previous 14 years. The assumption is justified by the fact that from 2000 up to 2010 the growth rate of the car market was constant. The future stock of cars obtained in LEAP is then decreased by assumed percentage of the electric vehicles (2):

$$C_j = C_i - j \times C_i \qquad (2)$$

Where i is the considered year and j is the penetration percentage considered in the scenarios, namely 10%, 20% and 40%. C_j represents the expected stock whose primary energy consumption and emissions are calculated. Given the average consumption of the existing cars of medium dimension (Comodi et al., 2016), it is assumed that small cars will consume 20% less than medium ones. The battery capacity and the corresponding mileage (Table 1) are estimated by considering approach suggested in literature (Perujo et al., 2010).

Table 1. Typologies of cars: dimension, consumption and mileage.

		cc	Consumption	Mileage (2016)	Emissions factor
Gasoline	Small cars	0-1200	14 km/l	109.221 Mkm	0,0693 t/GJ
	Medium cars	1200-1600	11,6 km/l	112.864 Mkm	
Diesel	Small cars	0-1200	17,4 km/l	2.205 Mkm	0,0741 t/GJ
	Medium cars	1200-1600	14,5 km/l	95.703 Mkm	
Electricity	Small cars	0-1200	0,10 kWh/km	0	Considering the Italian Energy Mix:
	Medium cars	1200-1600	0,179 kWh/km	0	- Natural gas 0,0555 t/GJ - Coal 0,0951 t/GJ - Oil 0,0741 t/GJ

After the calculation of the fuel consumption of all vehicles, the carbon emissions are estimated by considering the appropriate fuel emissions factors (Table 1). Then, the externalities connected with the corresponding emissions level and primary energy consumption are estimated.

Electric emissions strictly depend on the electricity generation mix of the country. The Italian electricity generation mix was considered to estimate the primary energy consumption from electric cars: thanks to the electricity generation module, it is possible to establish the generation mix and analyze the impact of different scenarios.

4. Results

Three scenarios of electric cars penetration are considered, namely 10%, 20% and 40% and compared to the Business as Usual (BAU) scenario. In all scenarios, it is assumed that 50% of electric cars belong to the small category and the other 50% to the medium one. The aim of testing these scenarios is to estimate the maximum potential for energy savings and emissions reductions, as well as a realistic estimation of achievable results in short-medium period.

Firstly, the BAU scenario is built by assuming that from 2016 to 2030 the sales share of new cars is equal to 2002-2016. The shares between the different categories are kept constant.

The impact of different scenarios is analyzed in terms of primary energy consumption and CO_2 emissions: small gasoline, medium gasoline and medium diesel cars have very similar shares in the energy consumption and carbon emissions. If the electric cars substitute gasoline medium, gasoline small or diesel medium cars, there is no difference in terms of energy consumption and carbon emissions since they have the same weight.

In fact, the substitution between electric and traditional cars is convenient if the electricity generation mix of the countries, as Italy, is less carbon intensive than the direct use of gasoline and diesel in internal combustion engines. In this analysis, only fossil fuels are considered as the contribution of renewable energy does not represent a "primary energy" source.

In the scenario case of 10% penetration of electric cars in the stock, the introduction of electric cars determines a primary energy savings of 62 PJ. The carbon emissions show a reduction of 5 Mt and externalities cost decrease as well. If the penetration increases to 20%, the same phenomena are observed: there is a decrease in primary energy consumption equal to 125 PJ, a reduction of carbon emissions of 10 Mt, and a saving in the externality cost of 819 M€. This trend is further amplified in the case of a penetration of 40%: it can be observed that 250 PJ of primary energy, 21 Mt of carbon emissions and 1.638 M€ of externalities can be saved. Savings results are shown in Fig. 5, Fig. 6, Fig. 7 respectively per primary energy, carbon emissions and externalities cost.

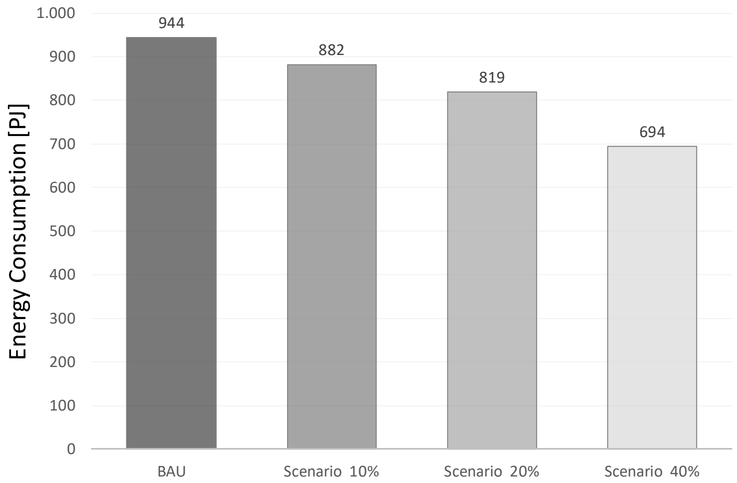

Figure 5. Primary energy consumption comparison between BAU and scenarios in the year 2030.

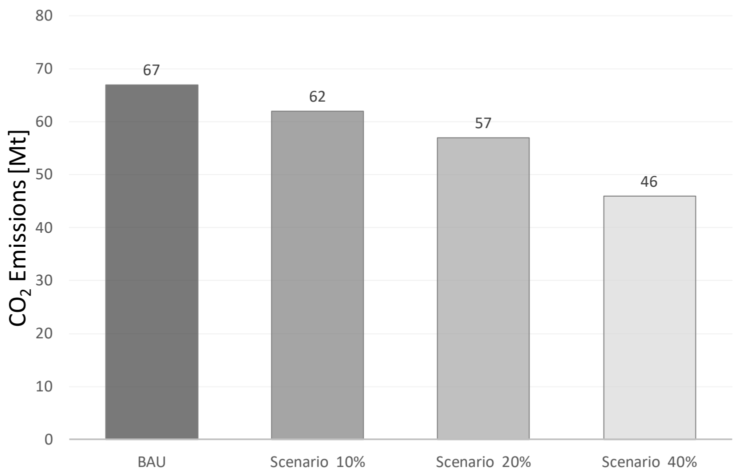

Figure 6. Carbon emissions comparison between BAU and scenarios in the year 2030.

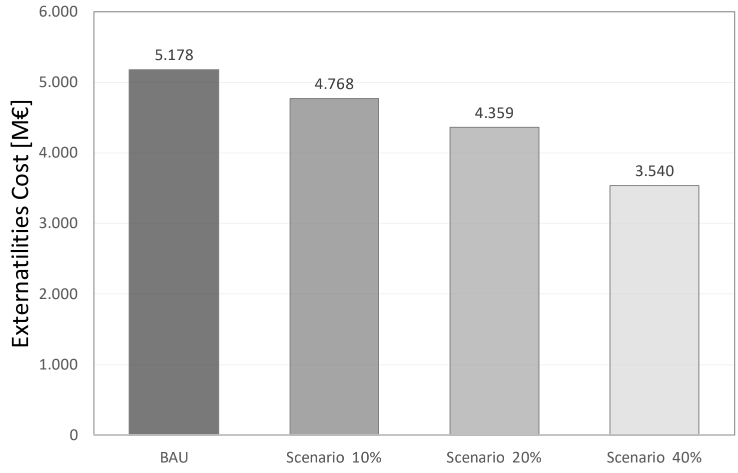

Figure 7. Externalities cost comparison between BAU and scenarios in the year 2030.

5. Discussion and limitations

Results show that the transport sector shift to electricity will boost energy consumption and carbon emissions, driven by the joint variations in time-use and consumption patterns. This leads to a reduction of the carbon intensity of the Italian cars fleet. On this basis, it can be said that the electric cars penetration could be advantageous for the Italian energy system, since the carbon intensity would be reduced and primary energy would be saved. Savings of primary energy have relevant policy implications, because the reduction of utilization of primary energy increases energy independence and, consequently, energy security.

Furthermore, it can be noticed that the introduction of electric cars provokes a reduction of the externalities cost and saving could be utilized to define incentive schemes in support of the diffusion of electric mobility.

In its current form, the model represents a first version and it will be improved further by implementing a more accurate approach for the estimation of the future market including socio-economic factors, and a more detailed description of specific energy consumption for the different car categories (e.g. by considering the volume dimension and the emission regulation). In this paper, only externalities cost connected with the energy consumed for mobility is considered, whereas externalities due to the batteries, noise, recycling of the cars, etc. could be integrated.

4. Conclusions and future perspectives

The present paper investigates the impact of the introduction of electric cars in the Italian car fleet and its impact on the energy system.

A specific bottom up model has been implemented in order to estimate the future development of the car fleet till 2030, the penetration of electric cars and the corresponding effects in terms of primary energy consumption, carbon emissions and externalities savings.

Furthermore, three scenarios have been analyzed considering penetration levels of electric cars equal to 10%, 20% and 40%. The analysis of the scenarios highlights that the introduction of electric cars determines positive effects on the Italian energy system. In fact, primary energy, carbon emissions and externalities costs are reduced. This determines a reduction of the carbon intensity of the car fleet and financial savings in externalities cost.

This analysis represents a preliminary work, which is to be further developed by improving the forecasting model and some related hypothesis.

Italy is an energy importing country, therefore most of fossil fuels, in particular oil and natural gas, are imported from third countries. Thus, Italian transport sector is largely influenced by the stability of the supply energy countries (Bianco et al., 2018). The reduction of primary energy consumption in the transport sector would mean to decrease these impacts, which are out of the influence of the country itself.

Transport and energy policies face various technical and economic issues as well as political challenges and barriers (Delponte et al., 2010). A cleaner transport sector, car fleet in particular, would be determinant for the decrease of the pollution, especially in cities and urban areas where it is concentrated the largest number of cars. Scenarios should be taken into account in national energy policies to manage and modify national transport planning as part of geopolitical and economic strategy. Awareness of the scenarios allows to better choose appropriate policy elements through multicriteria and long-term emission assessments.

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References

AEEG (Autorità per l'Energia Elettrica e il Gas), 2010. ARG/elt242/10. Special provisions for electricity transmission, distribution and measurement and dispatching supply service for testing low-voltage charging stations in public areas.

ANIASA (Associazione Nazionale Industria dell'Autonoleggio e Servizi Automobilistici), 2013. Mobility Lab, La mobilità elettrica e gli italiani.

Bianco, V., Scarpa, F., 2018. Impact of the phase out of French nuclear reactors on the Italian power sector. Energy 150, 722-734.

Comodi, G., Caresana, F., Salvi, D., Pelagalli, L., and Lorenzetti, M., 2016. Local promotion of electric mobility in cities: guidelines and real application case in Italy. Energy 95, 494-503.

Delponte, I., Tomasoni, L., 2010, Transport and energy: urban strategies for planning. TemaLab 3, 47-54.

Dias, M.V.X., Haddad, J., Nogueira, L.H., da Costa Bortoni, E., da Cruz, L.A.P., Yamachita, R.A, and Goncalves, J.L., 2014. The impact on electricity demand and emissions due to the introduction of electric cars in the São Paulo Power System. Energy Policy 65, 298-304.

Donateo, T., Licci, F., D'Elia, A., Colangelo, G., Laforgia, D., and Ciancarelli, F., 2015. Evaluation of emissions of CO_2 and air pollutants from electric vehicles in Italian cities. Applied Energy 157, 675–687.

European Commission Directorate-Generalfor Research, 2003. External Costs − Research results on socio-environmental damages due to electricity and transport.

Gompertz, B.,1824. On the nature of the function expressive of the law of human mortality and on the new mode of determining the value of life contingencies. Phil. Trans. Royal Soc. A115,513–580.

Hao, H., Wang, H., and Ouyang, M., 2011. Fuel conservation and GHG (Greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet. Energy 36, 6520-6528.

Huzayyin, A.S., Salem H., 2013. Analysis of thirty years evolution of urban growth, transport demand and supply, energy consumption, greenhouse and pollutants emissions in Greater Cairo. Research in Transportation Economics 40, 104-115.

IEA, 2017. Key world energy statistics.

Jochem, P., Babrowski, S., Fichtner, W., 2015. Assessing CO_2 emissions of electric vehicles in Germany in 2030. Transportation Research Part A, 78, 68–83.

Ou, X., Zhang, X., Chang, S., 2010. Scenario analysis on alternative fuel/vehicle for China's future road transport: Life-cycle energy demand and GHG emissions. Energy Policy 38, 3943–3956.

Perujo, A., Ciuffo, B., 2010. The introduction of electric vehicles in the private fleet: Potential impact on the electric supply system and on the environment. A case study for the Province of Milan, Italy. Energy Policy 38, 4549-4561.

Puksec, T., Krajacic, G., Lulic, Z., Vad Mathiesen, B., Duic, N., 2013. Forecasting long term energy demand of Croatia transport sector. Energy 57, pp. 169-176.

Santos, G., 2017. Road fuel taxes in Europe: do they internalize road transport externalities?. Transport Policy 53, 120-134.

Seixas, J., Simoes, S., Dias, L., Kanudia, A., Fortes, P., Gargiulo, M., 2015. Assessing the cost-effectiveness of electric vehicles in European countries using integrated modeling. Energy Policy 80, 165-176.

Zhao, S.J., Heywood, J.B, 2017. Projected pathways and environmental impact of China's electrified passenger vehicles. Transportation Research Part D, 53, 334-353.