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

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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 CO2 emissions (2009/28/CE).

Italy has been strongly influenced by the European directives and issued some guidelines (AEEG, ARG/elt242/10) 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. 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, Caresana).

The present paper aims at estimating how various shares of private electric vehicles penetration in Italy reduce the primary energy consumption and the carbon emissions level. 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.

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.

Nomenclature

BAU	business as usual scenario
S(t)	scrappage rate
t	vehicles age

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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, Ciuffo). 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, as reported in Table 1, 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.

Table 1. Euro categories and European Union Directives

Regulations	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Year	Before 1992	1992	1995	2000	2006	2009	2014
European Union Directives	-	91/441/CEE 91/542/CEE	91/542 CEE 6.94/12 CEE 96/1 CEE 96/44 CEE 96/69 CE 98/77 CE	96/69 CE 98/77 CE 1999/96 CE 1999/102 CE 2001/1 CE 2001/27 CE 2001/100/CEA 2002/80/CE A 2003/76/CE A	98/69 CE B 98/77 CE 1999/96 CE B 1999/102 CE 2001/1 CE 2001/27 CE B 2001/100 CE B 2002/80 CE B 2003/76 CE B	1999/96/CE 2001/27/CE 2005/79/CE 2006/51/CE	

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, gasoil was cheaper than gasoline. In the following years a relevant increase of gasoil price was also observed and many users switched from gasoline to gasoil cars and increased the demand of diesel engines and gasoil. In fact, in 2015 approximately 50% of the cars were fueled by gasoline, ~40% by gasoil 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 gasoil 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.
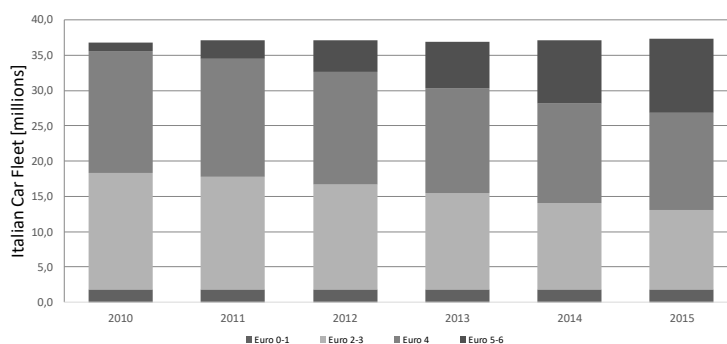

Fig. 1. Italian car fleet.

3. Transportation Model

A bottom up model has been developed to determine the impact of the introduction of electric cars on the Italian energy system. The model aims to analyze the impact of the introduction of electric cars within 2030 in terms of energy consumption and carbon emissions.

With the support of the LEAP platform for the stock forecasting, the model has been implemented in a spreadsheet and it has a flexible structure so that it can be easily adapted to different contexts. Therefore, it is not specific for the case of Italy. 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, 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).

3.1. Estimation of the evolution of the car fleet in Italy

The starting point for the development of the model is represented by the historical data related to the 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 gasoil cars.

To estimate the number of cars available in 2030, a comprehensive model of the Italian transport sector was developed in the LEAP (Long-range Energy Alternatives Planning) platform.

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 scrappage rate was estimated according to the Gompertz curve (Dias et alii):

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

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.

Given the average consumption of the existing cars of medium dimension (Comodi, Caresana), it is assumed that small cars will consume 20% less than medium ones. The battery capacity and the corresponding mileage are estimated by considering approach suggested in literature (Perujo, Ciuffo).

To estimate the primary energy consumption from electric cars it is necessary to consider the electricity generation mix: thanks to the electricity generation module, it is possible to establish the generation mix and analyze the impact of different scenarios.

Once calculated the fuel consumption of all vehicles, the carbon emissions are estimated by considering the appropriate fuel emissions factors. Then, the externalities connected with the corresponding emissions level and primary energy consumption are estimated. 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. are not taken into account.

3.2. Scenario analysis

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 gasoil cars have very similar shares in the energy consumption and carbon emissions. If the electric cars substitute gasoline medium, gasoline small or gasoil 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 gasoil 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. 2, Fig. 3, Fig. 4 respectively per primary energy, carbon emissions and externalities cost.
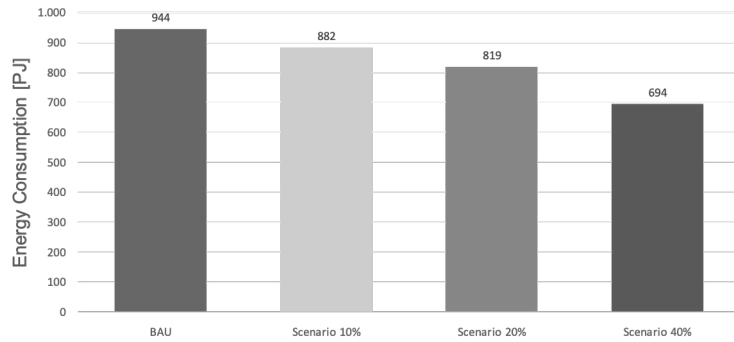

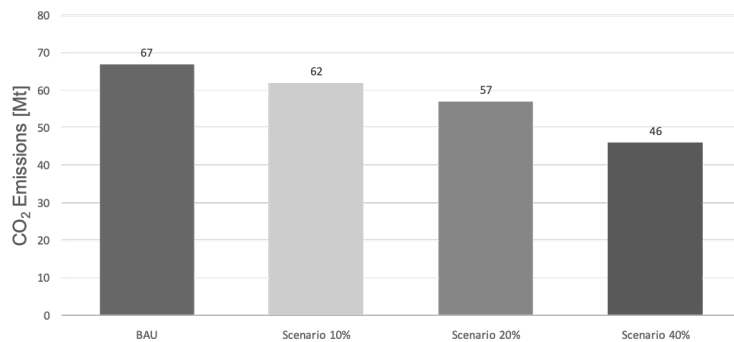Figure 2. Primary energy consumption comparison between BAU and scenarios in the year 2030.

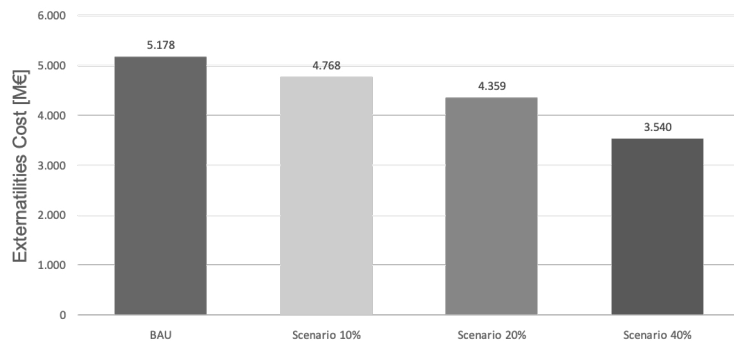Figure 3. Carbon emissions comparison between BAU and scenarios in the year 2030.

Figure 4. Externalities cost comparison between BAU and scenarios in the year 2030.

3.3. Results

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.

4. Conclusions and future perspectives

A literature review on electric vehicles analysis has put in evidence that most studies focus on technical issues separately related to transport planning, car manufacturing or energy consumption. The present paper investigates the impact of the introduction of electric cars in the Italian car fleet and its impact on the energy system. Indeed, the objective of this study is to introduce a multidisciplinary analysis of the electric vehicles.

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, a scenario analysis has been developed by 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, Tomasoni). 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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