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Potential Impact of Electric Vehicles on the Electric Supply System

A case study for the Province of Milan, Italy

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Summary

Mobility of persons and goods is an essential component of the competitiveness of European industry and services as well as an essential citizen right. The goal of the EU's sustainable transport policy is to ensure that our transport systems meet society's economic, social and environmental needs.

The transport sector is responsible for about 30% of the total final energy consumption and for about 25% of the total CO2 emissions. In particular the contribution of road transport is very high (around 80% and 70% respectively). These simple data shed light on the necessity to move towards a more sustainable transportation system, but also suggest that a technological/systemic revolution in the field will positively impact the overall world's sustainable development.

From a technological point of view, a lower dependency from not renewable energy sources (i.e. fuel oil) of the road transport is the main anticipated change. In particular electric engines possibly represent the natural vehicle evolution in this direction. Indeed they have much higher energy efficiency (around three times that of internal combustion engines, ICE) and do not produce any kind of tailpipe emissions. How the electricity will be supplied to the vehicles is still unpredictable due to the too many existing uncertainties on the future development, but the electrification of the drive train will contribute to having alternative energy paths to reduce the nearly total dependency on crude oil. In particular, vehicle range and performances allowed by the different possibilities will play a key role on the debate.

At the moment a great attention is attracted by electric vehicles, both hybrid and not, that will allow users to recharge their vehicles directly at home. This kind of vehicle can represent a real future alternative to the ICE vehicles in particular for what concerns the daily commuting trips (whose range is quite low). It is therefore important to understand what might be the impact on the electric supply system capabilities of this recharging activity.

In this light the present study carries out an analysis of this impact for the Province of Milan (of particular relevant due the very high daily commuting trips) at a 2030 time horizon. Key issue of the analysis is the estimation of a potential market share evolution for the electric vehicles. The results obtained show that even with a very high future market penetration the impact of the vehicles on the annual energy consumption will be quite negligible. On the contrary they also show that without an appropriate regulation (e.g. the intelligent integration of electric vehicles into the existing power grid as decentralised and flexible energy storage), they could heavily impact on the daily electric power requirements.

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Introduction

Mobility of persons and goods is an essential component of the competitiveness of European industry and services; mobility is also an essential citizen’s right. The goal of the EU's sustainable transport policy is to ensure that our transport systems meet society's economic, social and environmental needs, as highlighted by the mid-term review of the 2001 White Paper, 'Keep Europe moving' (EU, 2006). Effective transportation systems are essential for Europe's prosperity, having significant impacts on economic growth, social development and the environment.

In 2004 the transport sector consumed 30% of the total final energy consumption (of which 82% is due to road transport) and it was responsible for 25% of CO2 emissions (EU-25). In 2003 road transport constituted about 80% of total transport demand. Road transport accounts for 71% of transport related CO2 emissions and passenger cars constitute 63% of these road transport related CO2 emissions. Road transport is also nearly totally dependent of fuel oil making it very sensitive to foreseeable shortage of crude oil (security of energy supply).

At present the reciprocating internal combustion engines (ICE) either as homogeneous charge spark ignition (gasoline engines) or stratified charge compression ignition (diesel engines) dominates the drive trains of road vehicles. The market shares of these two technologies at present is about 50/50, however the market share of diesel vehicles is likely to further increase in the near future because of their better fuel economy. Gains in energy efficiency are still possible, however after years of large gains presently small incremental improvements are foreseen by technical development of this current state-of-the-art technology. The above mentioned sensitivity of present technologies to shortages of crude oil and the necessity to reduce Greenhouse Gas (GHG) emissions, without loosing the competitiveness of the European industry is forcing a demand of new technological approaches to secure sustainable future mobility. In road transport, vehicles running with Biofuels blend already exist and modified and new power-trains concepts are underdevelopments to accommodate a high degree of Biofuels. Well-to-Wheel (WtW) and Life Cycle Assessments (LCA) studies need to be considered in selecting the future energy sources, the feasible fuels and the vehicle technology.

Electrification of drive trains might offer a step change technology based on its excellent WtW energy efficiency; an ICE car requires an average of 40kWh/day versus the 10kWh/day for an electric vehicle, (MacKay, 2009). This tendency will also open the possibility to use alternative energy paths to secure mobility (security of energy supply) making the road transport more independent from crude oil. Also the intelligent integration of electric vehicles into the existing power grid as decentralised and flexible energy storage (V2G concept, e.g. see http://www.smartgrids.eu/) might offer new possibilities to the global management of electric energy offer and demand.

However, one could wonder what might be the impact of the electrical vehicle market penetration in the electrical energy and power requirements of the European electrical grid. Further, is their penetration a possible issue for utility providers and grid operators in terms of generating and distributing capacity?

Previous studies on this topic has forecast a very optimistic (in the opinion of the authors) market penetration for this type of vehicle in the 2030 horizon. The present study aims to define a methodology to calculate the possible impact of electric vehicles in the European electrical grid in terms of energy and power requirement adopting three different hypotheses on the market penetration of these vehicles. Indeed since too many degrees of freedom affect the problem, the basic idea is to use, as a reference, the market evolution of a category of vehicles which can appear to the possible customer very similar to electric vehicles; i.e. the methane (CNG) and Liquefied Petroleum Gas (LPG) powered vehicles and then hypothesize different correlated scenarios. As a first step and as testing benchmark the case study of Milan and its hinterland (the province of Milan) has been taken as subject of the study. Further model refining and access to real data of other European metropolitan areas will make possible to extend the present study to a European-wide approach with a better and realistic study of the possible impact to the European electrical grid in terms of energy and power requirements.

Battery Electric Vehicles – Available fleet and potential market

Key issues for estimating the potential impact of electric vehicles on the electrical grid and in particular on the whole electric consumption are: i) the identification of the main technical features for the available (short to medium term) fleet of vehicle and ii) the estimation of the potential market penetration evolution of these vehicles in the next years. Because of the data available at this stage are very limited due the very few vehicles using the full electric technology, all the conclusions that can be drawn should be taken with the appropriate reservations. In addition, depending also on the future market response, new developments in the electric vehicles technological (e.g. on the battery performances, on the vehicles efficiency and so on), as well as on alternative technologies, can also substantially modify future trends in unexpected ways.

Despite all the possible uncertainties, there are several works claiming a very favourable market development of electric vehicle (actually at the moment this regards mainly PHEVs, i.e. the Plug-in Hybrid Electric Vehicle, but with the increasing of the distance range of battery electric cars –BEV-, the same can be expected also in this case). In this study all the works carried out during the last years will be taken in consideration, even if the results that will be presented will follow an autonomous path.

Available Electric Vehicles – Main technical features

The analysis of the technical features of the electric vehicles already available or that will be available in the next years, is fundamental in order to understand their potential penetration in the market. Information like their distance range, battery capacity, energy consumption and others, are important to define which kind of commuters can be attracted to using them. In particular, one of the main limitations for full electric cars is the distance they are able to cover without the need of recharging (operation that at the moment requires several hours). At the moment this distance very hardly reaches the 150km and this, connected to their unlimited possibility of use in the centre of the main European cities, makes them particularly suitable for urban utilization. At the same time the main cities and their metropolitan areas are also the most electric energy consuming areas and therefore they are the one which can particularly suffer from the electrical energy requirements of these vehicles. This is also the reason why, in this study, the Province of Milan has been chosen as case study, being one of the most important urbanized area in Italy.

	Brand	Model	Capacity (kWh)	Range (km)	Consumption (kWh/100km)	Classification	Data Source
Cars	Renault	Twingo Quickshift E	21.45	129	16.60	Medium	http://www.atea.it/twingo-elettriche.htm
	Fiat	Panda	19.68	120	16.40	Medium	http://www.atea.it/panda-elettriche.htm
	NICE	Mega City	10.50	80	13.05	Small	http://www.nicecarcompany.co.uk/
	FIAT	500	22.00	113	19.53	Medium	http://www.italiaspeed.com/
	Mitsubishi	i-MIEV	20.00	160	12.50	Medium	http://www.mitsubishi-motors.com
	MINI	MINI-E	35.00	180	19.44	Big	http://www.miniusa.com/minie-usa/
	TESLA	Roadster/Model S	55.00	300	18.33	Big	http://www.teslamotors.com/
	CODA	CODA-EV	33.80	180	18.78	Big	http://www.codaautomotive.com
	Lighting	GTS	35.00	175	20.00	Big	http://www.lightningcarcompany.co.uk/
	MILES	ZX40S/ZX40ST	10.00	105	9.56	Small	http://www.milesev.com/
	Phoenix	SUV/SUT	35.00	209	16.73	Medium	http://www.phoenixmotorcars.com/
Light Duty Vehicles	AIKè	ATX	8.40	70	12.00	LDV	http://www.alke.com/electric-vehicles.html
	Piaggio	Porter	25.74	110	23.40	LDV	http://www.ch.vtl.piaggio.com/porter_el.htm
	LDV	Maxus Electric		160		LDV	http://www.ldv.com

Table 1 Main features of the fully electric vehicles (cars and light duty vehicles) already present in the market

A non exhaustive list of available vehicle models is reported in Table 1.

By analyzing the vehicle features, it was possible to roughly individuate three main car categories based on their battery capacity and on their distance range. This is important because data concerning the composition of the Milan's vehicular fleet are available and thus in the evaluations, the different features of the different classes have been taken into consideration. These features are summarized in Table 2.

	Size	Capacity (kWh)	Range (km)	Consumption (kWh/100km)	Recharging time	
					Standard* (h)	Industrial ** (min)
Cars	Small	10	100	10.00	5	10
	Mid-size	20	130	15.38	5	10
	Large	35	180	19.44	5	10
Light Duty Vehicles		20	100	20.00	5	10

* For these data the expected technological improvement have already been considered

** Information provided by the AltairNano for the NanoSafe batteries already on Lighting and Phoenix cars

Table 2 Simplified classification for the Electric Vehicles

In this table is reported also the expected recharging time. This is very important to evaluate the electric power required by the vehicle fleet. However this information varies from model to model. An average value of 5 hours has been considered in this study to take also into account the future technological developments. In addition the AltairNano (http://www.altairnano.com) has presented a new technology allowing a 10 minutes charging time, without affecting the battery performances and duration, by means of an industrial plug-in system. Such system is already available in some of the car models listed in Table 1 and thus it represents something more than a simple future perspective. Since it can also influence the electric power required by the vehicular fleet, this fast-charging option will be included in the evaluations.

The data presented are in line with both; what is declared by the manufacturer and what can be found in the open literature, apart from what is presented in Clement et al., (2007). Indeed in Clement et al., the vehicles consumption has been estimated to be in the interval 20-35kWh/100km which is much higher than what is possible to find elsewhere. This is probably due to a possible mistake of the authors that convert the energy from litre of gasoline equivalent/100km to kWh/100km assigning the half part to the electric consumption. These data, for PHEVs are usually evaluated measuring the fuel consumption while the battery level remains approximately constant and thus the conversion would be not acceptable. Nonetheless the estimates provided result excessively high.

Finally, it is necessary to consider the efficiency of the battery charger. For the calculation an efficiency of 90% has been considered for the recharging phase (see Clement et al., 2007). Actually also the discharging phase is characterized by a certain efficiency. This efficiency has been taken into account while setting the distance range of Table 2.

	Size	Power required to the grid	
		Standard (kW)	Industrial plug-in (kW)
Cars	Small	2.2	66.7
	Mid-size	4.4	133.3
	Large	7.8	233.3
Light Duty Vehicles		4.4	133.3

Table 3 Estimated electric power required by each vehicle category to be recharged

At this point it is necessary to define the power needed by each single vehicle to be recharged and to hypothesize the way all the vehicles overlap the request of electricity. An estimate of the electric

power required is reported in Table 3. Data presented highlight also that normal houses with 3kW Italian electric supplier will not be sufficient anymore, requiring the owner of a car to change the agreement made with the electric energy supplier. This will then cause the increase of the energy cost to take into consideration for the electric vehicles market penetration estimation.
Hypothesizing that all the electric vehicles go back home in the hour interval 4.00-7.00pm and that the probability of arriving is constant on this interval, the main electric power demand will be in the interval 7.00-10.00pm in which all the vehicles will be recharging. In case of industrial plug-in the identification of the power request is much more difficult to be forecasted. Making assumptions on the probability distribution of the plug-in time, it would be possible to use a Monte Carlo simulation to estimate a probability distribution of the power demand. In the present study this estimate has not yet been carried out.

As a final consideration, it is important to remark that in the present study, the impact of the Plug-in Hybrid Vehicles has not been considered. The main reason is connected to the fact that for the kind of trips we are considering (mainly commuter trips on short distances), also the hybrid vehicles will move mainly as fully electric ones, thus requiring the same energy. For this reason in the fleet evolution evaluation, all the different typologies of electric vehicles are considered all together as a whole.

Potential electric vehicle market penetration and its evolution

The main uncertainty of the study is without any doubt the estimation of the future electric vehicle market penetration. Some studies have been already carried out on the topic, even if they focus mainly on the Plug-in Hybrid Electric Vehicles (PHEV). The many degrees of freedom of the problem (e.g. the petroleum price, the national incentives schemes, the development of new alternatives technologies, etc.) affect the reliability of any attempt of forecasting. In addition the strong dependence of the electric energy production from not renewable sources makes the electric cars also less green as one can expect considering that a full electric car, by itself, does not produce any kind of tail-end pollution (of course during its operations and not from a life-cycle perspective, in which, for example, the batteries production and disposal play an important role). This also influences the willingness of the governments to strongly push towards this direction.

In the field open literature it is possible to find studies in which the market penetration estimation is very optimistic. In Clement et al. (2007-2008), PHEVs reach the 28% of the total Belgian vehicle fleet in 2030. The estimation has been obtained by using the TREMOVE model (Logghe et al., 2006), which is widely used in the European Commission to support environmental transport policies. In Hadley and Tsvetkova (2008), it has been estimated that by the year 2020, PHEVs will achieve a constant 25% market share, reaching the number of 50 million of vehicles in 2030 in the USA. Other studies also confirm these estimations. However, as already stated above, the problem has too many degrees of freedom (as outlined also in Simpson, 2006) and, therefore, in the present study three different assessments (scenarios) have been carried out based on the following three different assumptions:

1. In 2010 the 0.5% of the vehicle fleet is made up of electric vehicles. Then the number of vehicles evolves in time assuming that the forecasted market share follows a logistic trend calibrated on the trend that methane (CNG) and Liquefied Petroleum Gas (LPG) powered vehicles have had in the period 2000-2009. This assumption is based on the idea that from the consumer perspective the electric technology has fairly the same appeal as the other “alternative” ones.
2. In 2010 the 1% of the vehicle fleet is made up of electric vehicles. Then the number of vehicles evolves in time assuming that the forecasted market share follows a logistic trend double than the one calibrated on the trend that CNG and LPG powered vehicles had in the period 2000-2009. This assumption is based on the idea that from the consumer perspective the electric technology has fairly the same appeal than the other “alternative” ones apart from the fact that

electric vehicles do not suffer from the limited availability of service stations (the plug-in can be made at home albeit the need for an increase power availability – see previous chapter).

3. Without considering a specific future trend, the impact of different percentages of electric vehicles on the whole fleet at a 2030 time horizon has been evaluated (from 10 to 30%). This evaluation was carried out in order to show the impact on the electric supply system of a wider penetration of electric vehicles on the vehicle market, also according to the scenarios forecasted in Clement et al. (2007-2008) and in Hadley and Tsvetkova (2008).

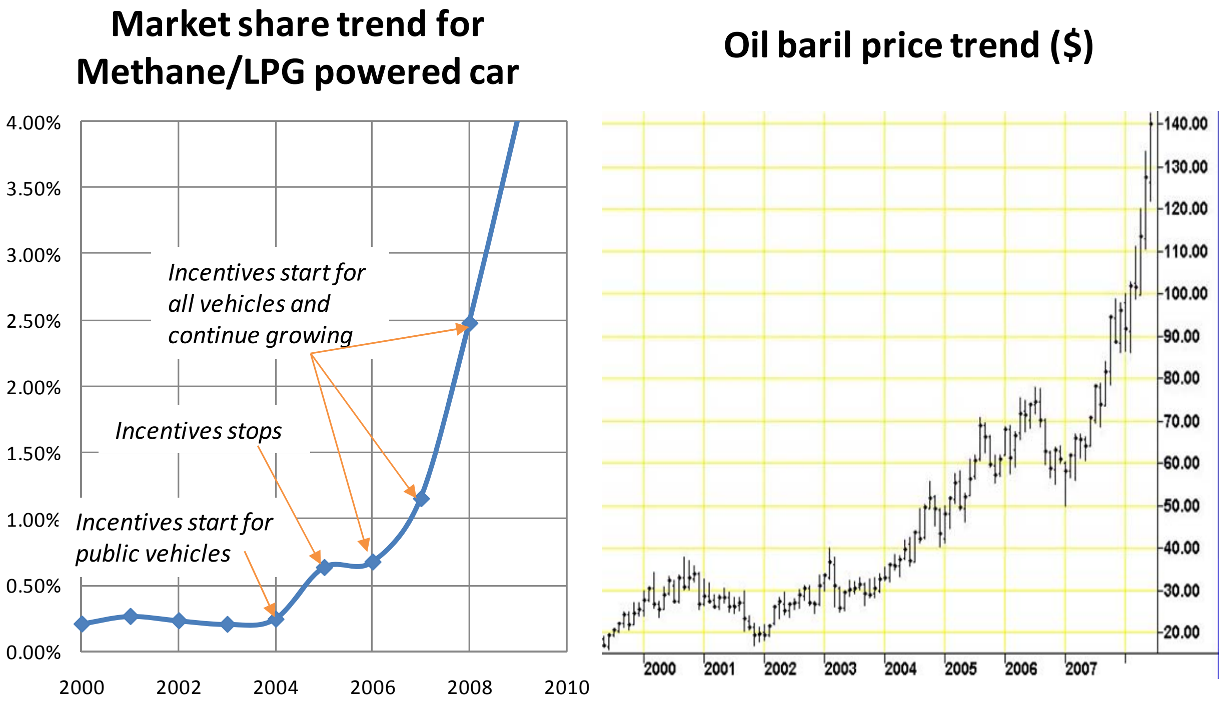

Figure 1 Market share evolution for Methane/LPG powered cars (source ACI, 2000-2008) and impacts of oil price and Italian national incentives

It is worth noting that in the first two assumptions the forecasts are based on real data colected (by the Automobil Club Italiano) in the study area (the Province of Milan). It is quite certain that the market evolution of electric vehicles will not resemble that of the CNG+LPG ones, but at least these data contain information about the citizens' appeal to "green" vehicles and, in addition, their reaction to the petrol price evolution and national incentives. In Figure 1 it is possible to appreciate the linkage between the CNG+LPG vehicle trend in Italy, the oil price and the Italian national incentives policy. In this light the decision to consider a scenario with an evolutionary trend double than those of CNG and LPG vehicles is also influenced by the belief that national governments will push more urgently towards electric vehicles also because of the potential for vehicle-to-grid applications (i.e. the opportunity of using vehicles connected to the electric supply network as additional storage unit; see Jenkins and Rossmaier, 2008, as a reference).

In Figure 2 the previously mentioned estimated market share trend for CNG+LPG powered car for the Province of Milan is showed. As it is possible to recognize it requires 15 years to reach the maximum value of approximately 10% of the market share.

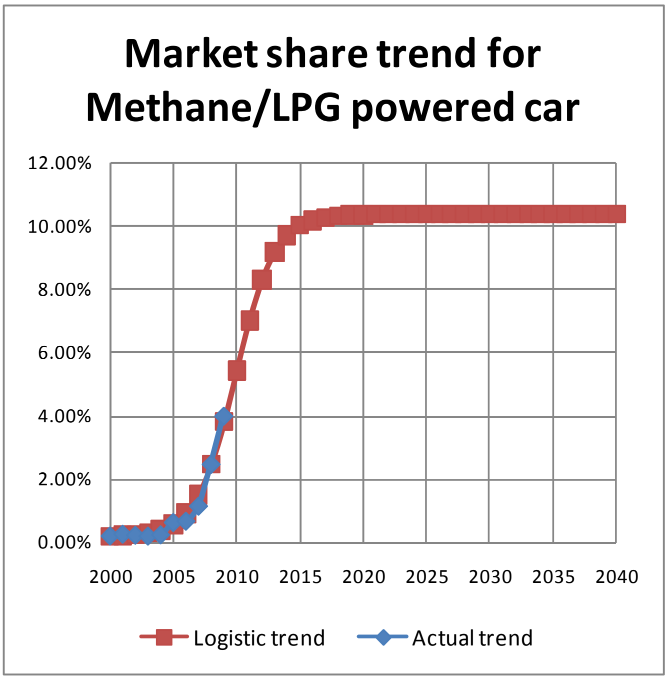

Figure 2 Actual (source ACI, 2000-2008) and estimated trend for the Methane/LPG powered car market share

Apart from the market share evolution it is necessary to understand which is the number of vehicles in the study area to take into consideration. Since the study focuses on the commuters' behaviour, it would be necessary to retrieve data about the daily trips that have origin and/or destination in the Province of Milan. This information is usually not very easily accessible. Fortunately the Italian National Statistic Institute (Istat) during the ten-yearly population census has collected also information concerning the daily commuting trips and the transport mode used. These data are freely available on-line (SIDT, 2005) and allowed us to perform a more detailed evaluation of the potential use of electric vehicles, since these trips are those which can be more easily attracted by the lower consumption, the possibility to access every part of the cities etc. In Table 4 the car Origin/Destination matrix for the Province of Milan is reported.

O/D (n. of cars)	Milan Province	Outside	*Total*
Milan Province	772,945	57,960	*830,905*
Outside	117,436	--	*117,436*
Total	*890,381*	*57,960*	*948,341*

Table 4. Origin/Destination car matrix for the Province of Milan in the year 2001 (source: Istat, 2005. Data refer to people who made the trip with their own car as a driver)[1]

In addition, the analysis has also considered that a part of Light Duty Vehicles (LDV) fleet could probably be converted to electric technology. However at this stage the available data were not enough to give a reliable estimation of this amount and for this reason the authors made the choice to simplistically evaluate the total number of LDV as the 10% of the total number of electric vehicles (percentage usually accepted for this kind of studies).

Table 4 data refer to the year 2001 and for this reason it is necessary to foresee a possible evolution law. In transportation studies, the traffic evolution is usually simplistically connected with the growth of the Gross Domestic Product (GDP). During the last years, however, this relationship has become weaker, since the GDP growth has significantly started to decrease in the Italian context without a correspondent remarkable reduction in the mobility growth. For this reason the future trend for the

[1] These informations are not readily available on-line but required some elaborations. The authors are thankful to Maria Teresa Borzacchiello, of the University of Napoli who retrieved these information.

traffic in the Province of Milan has been linked to the evolution of the total number of cars in the Lombardy Region (ACI, 2001-2008). In Figure 3 this trend is shown, appearing approximately linear.

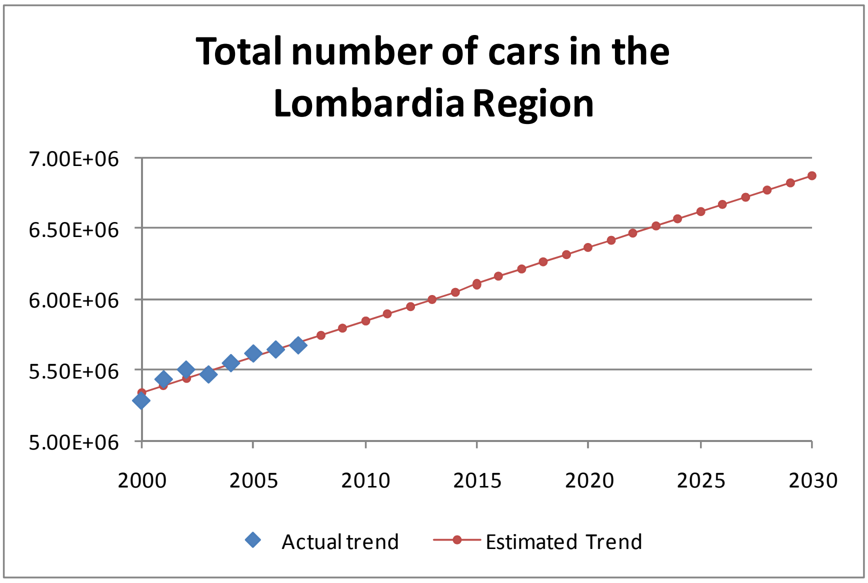

Figure 3 Car fleet evolution in the Lombardia Region (source ACI, 2000-2008)

For what concerns the composition of the car fleet (with respect to the engine dimensions), according to the data provided by the ACI (2001-2008) it is possible to consider the composition reported in Table 5. These data will be used, together with those of Table 3 for the evaluation of the electric energy required by the whole vehicle fleet.

Car size	% of the car fleet
Small	30.0
Mid-size	62.9
Large	7.1

Table 5 Car fleet composition by engine size (source: ACI, 2001-2008)

Expected impact of the electric vehicles fleet on the electric consumption of the Province of Milan

Demand of electricity and its evolution in Italy and in the Province of Milan

In order to assess the electric vehicles impact on the energy supply system it is necessary to have detailed information about the electric grid capacity, the yearly energy consumption and the time dependent electric power required in the geographical area under investigation. In Italy these data are collected and published by the society TERNA S.p.A. (http://www.terna.it/) which is one the Italian electric provider. Unfortunately available data are not very detailed for what concerns the Provincial Scale. However, data regarding the total electric energy consumption for the last year is available at that scale, while the past energy consumption trend is available at a Regional scale and the power required to the grid (for the current year and also an estimate for the following 10 years) is available only at a National level (Terna 2007a,b,c,d).

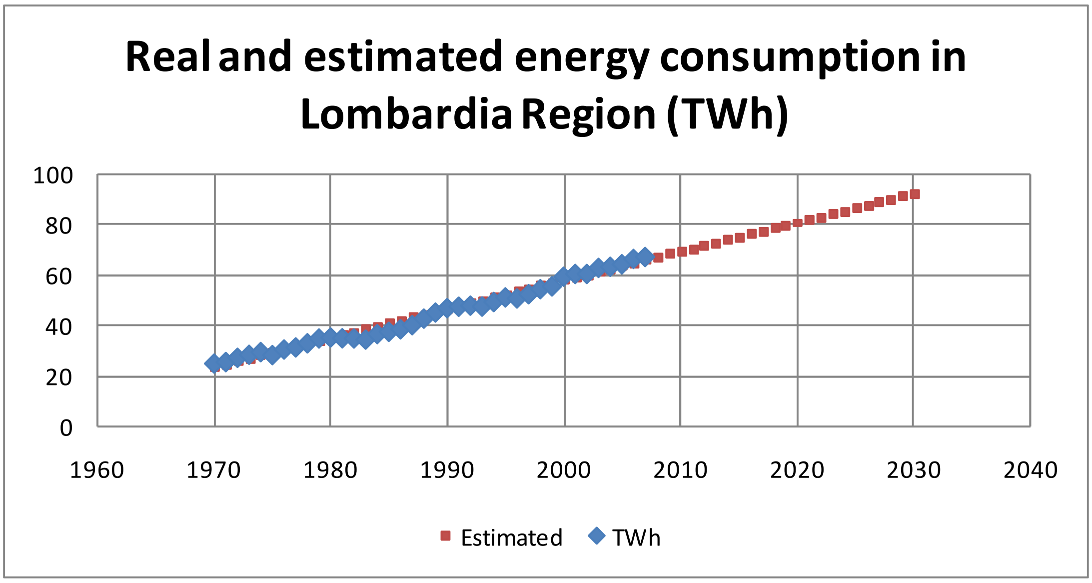

Figure 4 Actual and estimated yearly energy consumption for the Lombardia Region (source: Terna, 2007b)

Starting from the available data it was possible to estimate the future trend for the yearly electric energy consumption of the Lombardy Region (see Figure 4) and of the entire Italy. Then the same trend has been applied to the Province of Milan. By using the ratio between the Milan and Italian yearly electric energy demand and the peak power requested to the Italian grid, the peak power requested by the Province of Milan has been also estimated.

In the same way also the power peak trend for the Province of Milan has been obtained starting from the available trend of the peak power required for Italy. In Figure 5 the daily trend of the electric power requested to the grid is showed per each month of the year 2007. It is very interesting to notice that, apart from the summer months (in which the use of the car is much more differentiated and thus the impact of the electric vehicles on the grid would be more difficult to estimate), the peak power load is requested to the network during the time interval 4.30-6.00pm in which, it is possible to hypothesize, there will be also an high power request for the vehicles battery charging (commuters coming back home and plugging-in the vehicle to get it ready to be used the day after). For this reason the calculated value of vehicle electric power request has been compared with this peak value.

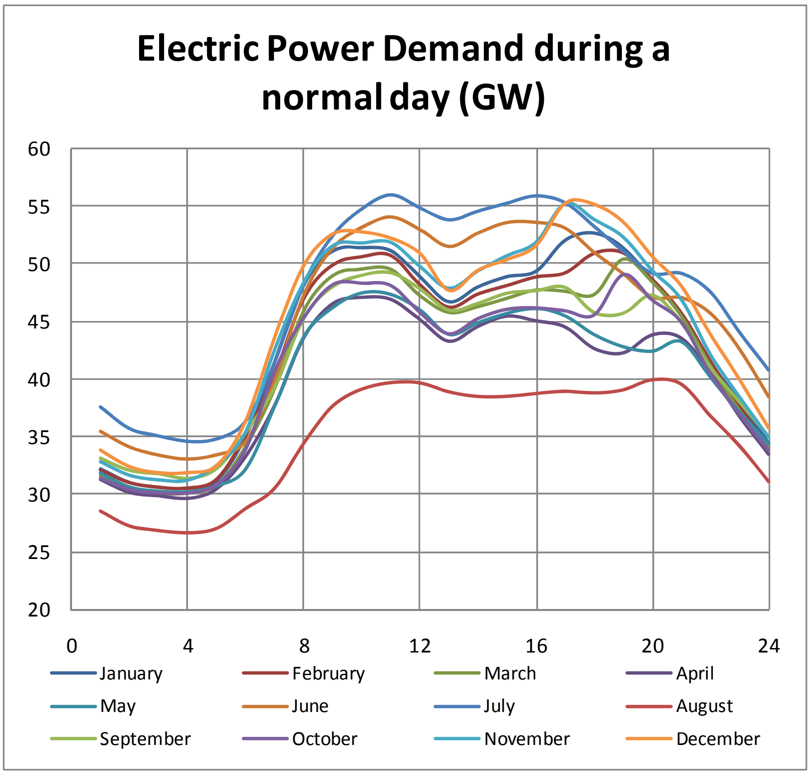

Figure 5 Average daily trend for the Electric Power load on Italian grid per each month(source: Terna, 2007c)

Year 2007	Electric energy consumption (TWh)	Electric energy consumption (%of the national)	Peak of Electric Power (GW)
Province of Milan	21.5851	5.99%	*3.31*
Lombardy Region	67.413	18.72%	*10.34*
Italy	360.171	100.00%	55.22

Table 6 Absolute and relative electric energy consumption in the Province of Milan, Lombardia Region and Italy (source: Terna, 2007a,b,c; in italics data estimated by the authors)

Electric energy required by the electric vehicles fleet to the electric grid of the Province of Milan

The final part of the work was then devoted to set-up a calculation model for the electric consumption of the estimated electric vehicle fleet. First element in this calculation is the estimation of the average daily distance covered by the vehicles. The National Institute for Training and Research on Transport (Isfort) publishes every year a report summarizing the Italians' mobility behaviours. In this report the following data have been summarized.

Vehicle	Context	Average distance covered (km)
Cars	Italy	40.00
	North-West Italy	38.30
	Big Cities	29.70
	Estimation for Milan	**28.44**
LDV*	Estimation for Milan	60.00

* No statistics were available for Light Duty Vehicles. The reported value refers to Clement et al. (2007)

Table 7 Average distance travelled in different geographical context (source: Isfort, 2008). In bold typeface the values estimated by the authors.

For what concerns Light Duty Vehicles, no data were available. For this reason it has been considered the value reported in Clement et al. (2007) for the Belgian context (the value for the cars was also very similar).

Year			Fleet consistency (number of cars)		Electric Vehicles share (%)
2030			1,206,612		***1.55%***
Vehicle		Number	No. of charges per day and per vehicle	Total number of charges per day	Average required energy per day (kWh)
Cars	Small	5,605	0.284	1,593.936	17,533
	Mid-size	11,730	0.219	2,565.960	56,451
	Large	1,325	0.158	209.333	8,059
LDV		1,866	0.600	1,119.600	24,631
			Daily Total (kWh/day)		106,670
			Yearly Total (kWh)		**38,936,358**

Table 8 Electric vehicles energy consumption in the Province of Milan for the year 2030 – Scenario 1

Year			Fleet consistency (number of cars)		Electric Vehicles share (%)
2030			1,206,612		***3.09%***
Vehicle		Number	Nb of charges per day and per vehicle	Total number of charges per day	Average required energy per day (kWh)
Cars	Small	11,211	0.284	3,188.156	35,070
	Mid-size	23,460	0.219	5,131.920	112,902
	Large	2,651	0.158	418.825	16,125
LDV		3,732	0.600	2,239.200	49,262
			Daily Total (kWh/day)		213,360
			Yearly Total (kWh)		**77,876,078**

Table 9 Electric vehicles energy consumption in the Province of Milan for the year 2030 – Scenario 2

In Table 8 and in Table 9 the electric vehicles energy consumption is reported. The model operates in the following way. Based on the year, a certain fleet consistency and a certain percentage of electric vehicles are used (with respect to the previously mentioned trends and the evaluation scenario considered). Then using the percentages of Table 5, the number of small, medium and large cars are calculated and then the number of LDVs. On the other hand, using the distance range of Table 2 and the average covered distance of Table 7, the average number of charges per day and per vehicle is considered (i.e. not all the vehicles recharge the batteries the same day). Then it is possible to calculate the total number of charges per day by multiplying the number of charges per day and per vehicles by the number of vehicles. Multiplying the obtained value by the capacity of the battery of each vehicle category and dividing by 0.9 to take into account the recharging efficiency, it is possible to evaluate the average total daily electric requirement. Multiplying this value for the number of days in one year it is possible to calculate the total yearly electric requirement. In this case the number of days in one year would have been, the number of working days (around 250), since the study refers to commuters trips. However, in order to consider also the energy consumption for the other days and to keep a safety margin, the daily value has been multiplied by 365 days.

The total yearly electric energy required by the electric vehicles can appear a very high value. Actually it represents less than the 0.3% of the electric energy consumption of the province of Milan (which, in 2030 will be around 30×10^9 kWh). Even using the same electric vehicle fleet evolution until 2050 the situation does not change significantly never exceeding the value of 0.5% of the total energy consumption. For this reason despite all the approximations made during the study, the authors are confident about the reliability of the magnitude of the results presented so far. In this light, the impact of electric vehicles on the total electric energy consumption could be considered quite negligible. The problem that will be examined in the next section will be related to “when” this energy is needed, i.e. on the electric power demand which is requested to the grid.

In the next table the main results about the incidence of electric vehicles on the electric energy consumption are summarized for all the scenarios at the time horizon 2030.

Year 2030	Yearly electric energy consumption in the Province of Milan (kWh) 30,261,152							
	Scenario1	*Scenario2*	*Scenario 3*					
Fleet Share (%)	1.55%	3.09%	5%	10%	15%	20%	25%	30%
Electric vehicles consumption (kWh)	38,936	77,876	125,885	251,771	377,659	503,547	629,433	755,321
Incidence of electric vehicles on energy consumption (%)	0.13%	0.26%	0.42%	0.83%	1.25%	1.66%	2.08%	2.50%

Table 10 Electric vehicles energy consumption in the Province of Milan for the year 2030 – All Scenarios

In Table 10 it is possible to notice that even in the extreme event of electric vehicle accounting for the 30% of the vehicle fleet, the energy consumption will not represent more than the 2.5% of the total amount, thus confirming what previously stated.

Electric power required by the electric vehicles fleet to the electric grid of the Province of Milan

The evaluation of the power required by the electric vehicles needs the definition of a time interval in which the vehicles' batteries are charged. As already stated above, according also with the results of the study presented by Isfort (2008), it is here hypothesized that all the vehicles will go back home in the time interval 4.00-7.00pm, then plugging-in their batteries.
The definition of the peak of required electric power depends on the precise plug-in time of each vehicle. For this reason it should be treated as a random variable. Making assumption on the distribution of the vehicles arrival time, it is possible, by using a Monte Carlo simulation, determining the probability distribution of the energy peak. However, at this stage, the analysis has considered only the average hourly electric power request. Considering that the arrivals are equally distributed in the time interval 4.00-7.00pm, the maximum of the power request will be in the time interval 7.00-9.00pm (as presented in Table 2 the recharging time for all the vehicles is assumed to be equal to 5 hours).

In addition two different values have been considered:

- the *average electric power request*, i.e. the values considering that the vehicles have not to recharge their battery every day (see what stated in the previous paragraph), but that in each day the same average percentage of vehicle recharges its battery;
- the *maximum electric power*, i.e. the power required to the grid in the improbable, but not impossible, extreme event that all the vehicles recharge in the same day.

The first statistic is important to understand the power that every day will be additionally asked to the grid, while the second gives an estimate of the maximum request the grid could have.

Year 2030	*Scenario1*	*Scenario2*	*Scenario 3*					
Fleet Share	2%	3%	5%	10%	15%	20%	25%	30%
Average incidence on the electric power request (%)	0.40%	0.83%	1.34%	2.67%	4.01%	5.34%	6.68%	8.02%
Maximum incidence on the electric power request (%)	1.69%	3.51%	5.67%	11.35%	17.02%	22.69%	28.36%	34.04%

Table 11 Incidence of the electric power peak daily request by the electric fleet for the year 2030 – All Scenarios

In Table 11 the average and the maximum incidence in terms of power request by the electric fleet is presented for the year 2030. It is worth noting that in both the Scenario 1 and 2 the incidence is quite low. It reaches very high values only in case electric vehicles would exceed the 15%. To understand the possible effect on the daily trend, it is possible to examine the following figures.

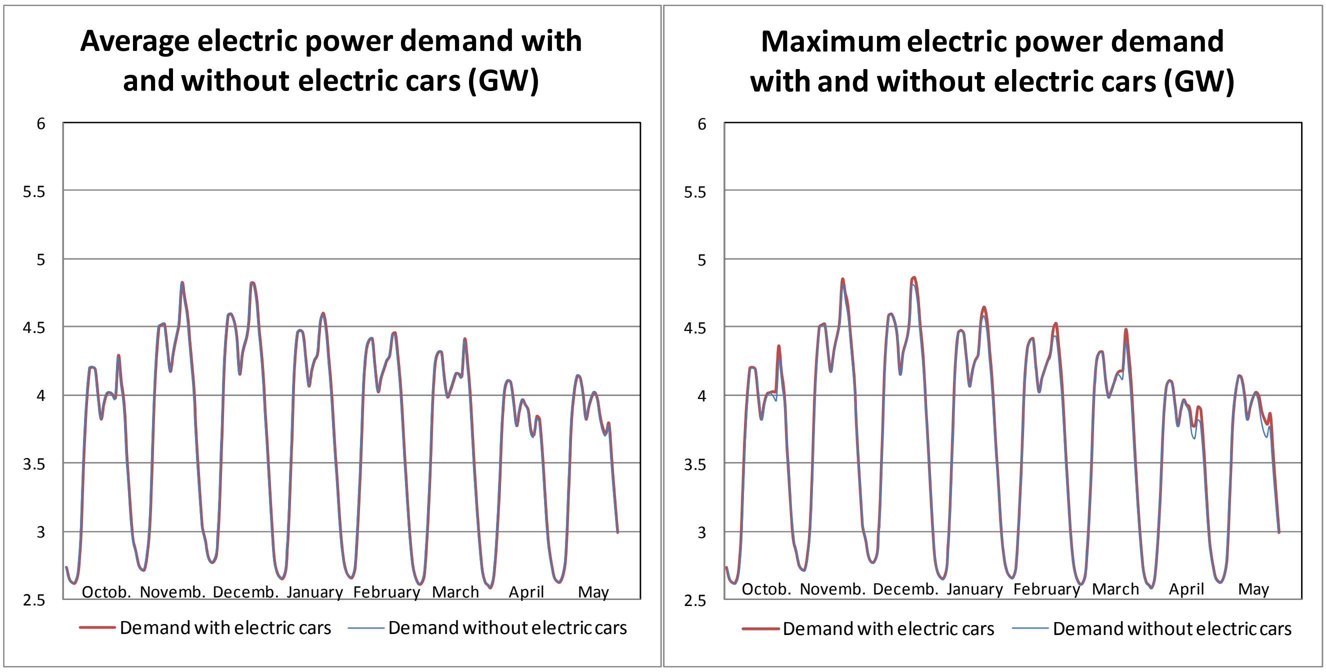

Figure 6 Average and maximum impact on the electric power request profile during the winter months. Scenario 1

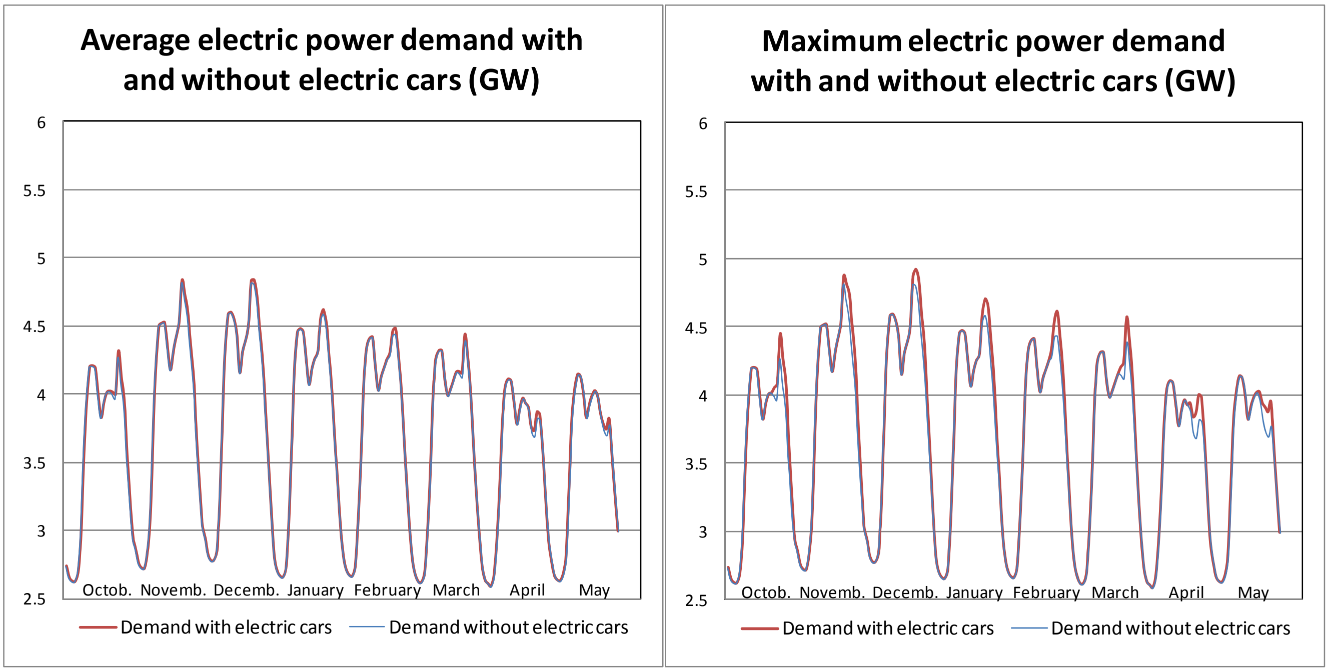

Figure 7 Average and maximum impact on the electric power request profile during the winter months. Scenario 2

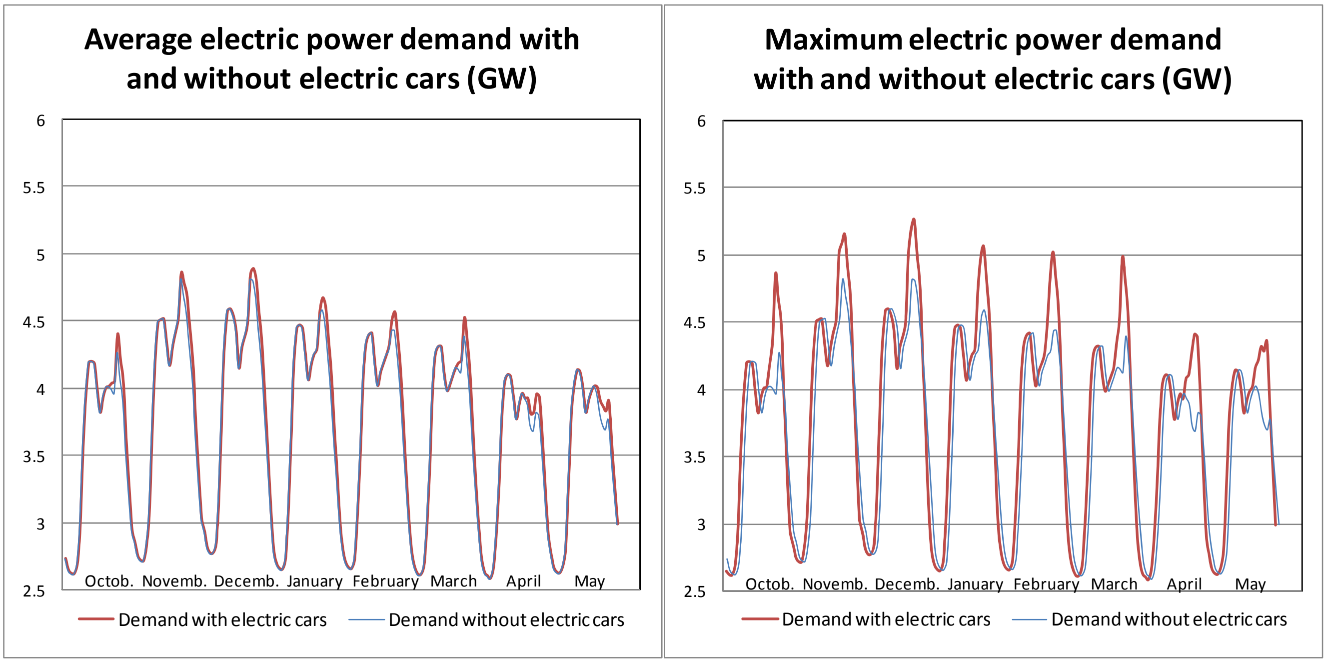

Figure 8 Average and maximum impact on the electric power request profile during the winter months. Scenario 3 – Electric fleet share = 5%

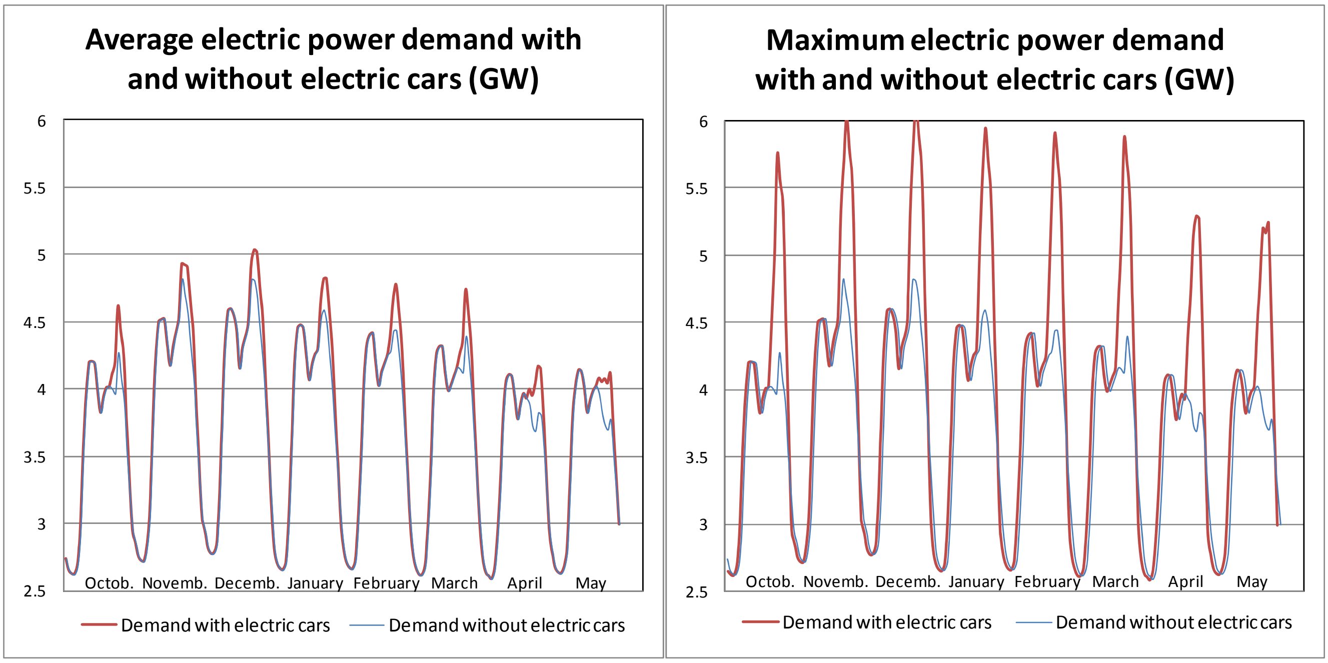

Figure 9 Average and maximum impact on the electric power request profile during the winter months. Scenario 3 – Electric fleet share = 25%

From Figure 6 to Figure 9 it is possible to appreciate the impact of the electric vehicles market penetration on the incidence of the electric power required during the average day of each winter month. As the percentage increase significantly it is necessary to adopt strategies in order to avoid the potential damages created to the grid capacity. In particular, creating an "intelligent" grid, able to decide "when" providing power to the batteries (there are several studies on this topic, see, e.g. Jenkins et al., 2008), it would be very fruitful in order to shift the power request on hours in which this is lower avoiding all the possible problem of network overloading. This concept is at the basis of the "Vehicle to Grid" (V2G) strategy, according to which the vehicles can represents additional element capable of storing electric energy to be used during the peaks of demand (if the vehicles are connected to the network).

It is necessary to underline that the creation of an additional “intelligent” network represent a not negligible investment, whose costs and benefits need to be taken into consideration more carefully. In addition the V2G strategy can result in an additional degree of freedom of the problem. Indeed it could be an additional incentive to the electric vehicles, if, for example, the energy moved from the vehicles to the network is paid by the electric energy supplier at a higher value than it is sold (the equivalent of the feed-in tariff for PV in many European countries). On the other hand it could have a negative outcome if, for example, the vehicles’ owners loose the possibility to have their car always ready in case of necessity of use (the grid “intelligence” should for example give the possibility of choosing if making available the vehicle capacity to the grid or not).

Concluding remarks and further research

Electric vehicles represent an important opportunity for pursuing a sustainable development not only of the transportation system but for the entire society. Indeed their Well to Wheel efficiency is indeed very high and this will allow a considerable step forward in the reduction of the overexploitation of resources.

Among the possible alternatives, the electric vehicles, both hybrid and not, are deserving particular attention at the moment also in light of the apparent simplicity of their diffusion (they can be recharged directly at home using the normal electric grid).

Actually the diffusion of this technology will increase the demand of domestic electric energy for recharging the vehicle's batteries. In particular, due to the common habits of many people and to the still long recharging time required, it is necessary to evaluate the possible impact that the contemporary plug-in of thousands of cars can have on the electric grid.

The present study has tried to evaluate this impact on the grid of the Italian Province of Milan at a 2030 time horizon. The model used to calculate the electric energy and power required has been very simple, but, being based on as detailed as possible real data, it is able to provide a reliable estimation.

In particular the main uncertainty of the whole model is the future evolution of the electric vehicles market share. Several studies have tried to give an estimate of such a trend, but the results presented, due to the many degrees of freedom affecting the problem have also been very different. For this reason, in the present study, the basic idea has been to use, as a reference, the market evolution of a category of vehicles which can appear to the possible customers, very similar to electric vehicles, namely the methane (CNG) and Liquefied Petroleum Gas (LPG) powered vehicles. Then, on the basis of their actual past trend, different correlated scenarios have been hypothesized.

Results obtained show that even with a very high future market penetration the impact of the vehicles on the annual energy consumption will be quite negligible. On the contrary they also show that without an appropriate regulation (e.g. the intelligent integration of electric vehicles into the existing power grid as decentralised and flexible energy storage), they could heavily impact on the daily electric power request. Actually this is true only considering very high (in the authors' opinion unrealistic) future electric vehicles market share (20-25%) in 2030.

As a conclusion of the study, it is the authors' opinion that electric vehicles can really represent a realistic alternative to ICE vehicles, also in terms of the available capacity of the electric grid. Further analyses are however required in order to extend the results to a wider and more complex context and, in particular, to better individuate a more reliable future trend for this vehicle category.

References

ACI, Automobil Club Italiano. (2000-2008). http://www.aci.it/index.php?id=54. Autoritratto 2000-2008.

http://www.alke.com/electric-vehicles.html

http://www.altairnano.com

http://www.atea.it/twingo-elettriche.htm

http://www.atea.it/panda-elettriche.htm

http://www.ch.vtl.piaggio.com/porter_el.htm

Clement, K., Van Reusel, K., Driesen, K. (2007). The consumption of Electrical Energy of Plug-in Hybrid Electric Vehicles in Belgium. *European Ele-Drive Conference*. Brussels, Belgium

Clement, K., Heasen, E., Driesen, K. (2008). The Impact of Charging Plug-in Hybrid Electric Vehicles on the Distribution Grid. *Proceedings 2008 - 4th IEEE BeNeLux Young Researchers Symposium in Electrical Power Engineering*. Eindhoven, The Netherlands.

http://www.codaautomotive.com

European Commission, DG-TREN (2006). Keep Europe moving – Sustainable mobility for our continent. http://bookshop.europa.eu/eubookshop/download.action?fileName=KO7606127ENC_002.pdf&eubphfUid=494666&catalogNbr=KO-76-06-127-EN-C

Hadley, S. W., Tsvetkova, A. (2008). Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation. Oak Ridge National Laboratory. Oak Ridge, Tennessee, U.S.A.

Isfort (2008). La domanda di mobilità degli italiani. http://www.isfort.it/

Istat (2005). 14mo Censimento Generale della Popolazione e delle Abitazioni – 2001. Final Report. http://dawinci.istat.it/

http://www.italiaspeed.com/

Jenkins, S. D., Rossmaier, J. R., Ferdowsi, M. (2008) Utilization and Effect of Plug-in Hybrid Electric Vehicles in the United States Power Grid. *IEEE Vehicle and Propulsion Conference*. Harbin, China.

http://www.ldv.com

http://www.lightningcarcompany.co.uk/

Mackay, D.J.C. (2009). Sustainable Energy — without the hot air. UIT Cambridge Ltd, Cambridge, England

http://www.milesev.com/

http://www.miniusa.com/minie-usa/

http://www.mitsubishi-motors.com

http://www.nicecarcompany.co.uk/

http://www.phoenixmotorcars.com/

Simpson, A. (2006). Cost-Benefit analysis of Plug-in Hybrid Electric Vehicle Technology. *22nd International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exhibition*. Yokohama, Japan. http://www.nrel.gov/docs/fy07osti740485.pdf

http://www.smartgrids.eu/

Terna S.p.A. (2007a). Dati Statistici sull'energia elettrica in Italia – Dati Storici. http://www.terna.it/

Terna S.p.A. (2007b). Dati Statistici sull'energia elettrica in Italia – L'elettricità nelle regioni. http://www.terna.it/

Terna S.p.A. (2007c). Dati Statistici sull'energia elettrica in Italia – Carichi. http://www.terna.it/

Terna S.p.A. (2007d). Previsioni della domanda elettrica in Italia e del fabbisogno di potenza necessario. Anni 2008 2018. http://www.terna.it/

http://www.teslamotors.com/

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Abstract

The study analyses the impact of the electric vehicles' recharging activities on the electric supply system for the Province of Milan with a 2030 time horizon. In particular, the impact is seen both in terms of total electric energy consumption and in power requested to the grid. Because of the long recharging time required by the cars batteries, the probability to have thousands of cars contemporary plugged-in is not negligible.

The key issue of the study is a more plausible (in the authors' opinion) estimation of the potential electric vehicles market share evolution in the time period considered.

The results obtained clearly show that without an appropriate regulation (e.g. the intelligent integration of electric vehicles into the existing power grid as decentralized and flexible energy storage), electric vehicles could heavily impact on the daily requested electric power.

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