ROAD TRANSPORT ELECTRIFICATION, A NEW HIGHWAY TO ENERGY SAVING

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Abstract

Mobility of people and goods is achieved through different means of transport; among them "on the road" transport, with vehicles powered by internal combustion engine, is undoubtedly the most practiced. This is true despite the drawback, due to thermal traction, that road transport is less efficient and more polluting than most other modes of transport, comparing specific fuel consumption and harmful emissions.

As a matter of fact, electric traction is 3-4 times more efficient than thermal one. The advantage is such as to largely compensate the losses occurring during the electricity production and distribution, losses greater than the correspondent ones in refining and distributing liquid and gaseous fuels.

By comparing, for example, a trolley bus and a 18 m articulated bus, the electric vehicle consumes 53% less, in terms of primary energy. Achilles's heel of the electrified road transport are the batteries; recent huge progresses in electric storage systems can overwhelm the handicap of battery's weight. The current high cost of storage system, instead, is expected to decline in the coming years. The paper deals with a benchmark between electric traction vehicles and thermal ones, based on a big data set available in ENEA.

1. Introduction

The transport sector, consuming about 39.69 Mtoe (Source: National Energy Balance 2016), accounts for about one-third of the total final energy consumption and is responsible for the Italian dependence on oil; indeed, while other sectors such as the industrial and energy sectors have been converted to alternative fuels, transport has so far not differentiated energy sources, remaining anchored to fossil fuels which continue to be responsible for the prevalent (about 92%) of final consumption of the sector.

It is well known that the conversion efficiency of fuels energy in mechanical energy is much higher in a thermoelectric power plant than in an internal combustion engine (ICE), considering the average efficiency - in real use - of such power plant in a vehicle; the efficiency of a thermoelectric power plant is so higher, even the double with respect to the average of an ICE, to largely offset the losses occurring during the distribution of electricity and the on-board, final conversion of electric energy in mechanical energy (tank-to-wheel, TTW).

This is true in general, but even more true in our country. Indeed, thanks to the efficiency improvement of the national electricity system (see Figure 1), the so called well to tank (WTT) efficiency of a "pure" electric vehicle (BEV) have been substantially improved in recent years, though is still much lower than that one occurring to refine and distribute liquid and gaseous fuels. The increase in average efficiency is mainly due to the diffusion of combined cycle systems and cogeneration plants, for the combined

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production of electricity and heat. The thermoelectric CO_2 emission factor also declined, from 708 g CO_2 / kWh in 1990 to 488.9g CO_2 / kWh in 2015 [1].

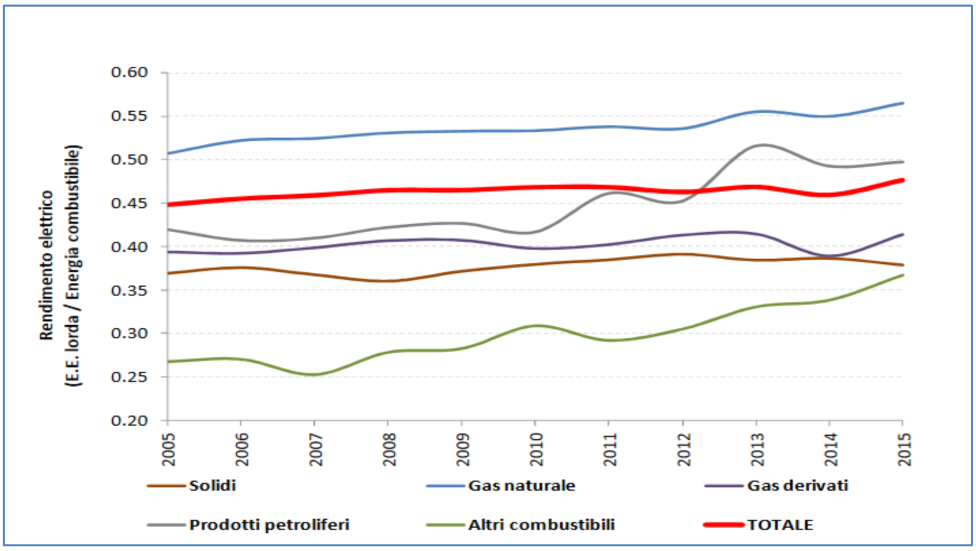


Figure 1: Generation efficiency for electric energy by fossil fuel (ISPRA)

These factors favor the electric vehicle in comparison with the conventional vehicle; for example, in Italy a B-segment car, the VW Golf, may have a primary energy saving reduced of about 50% compared to its petrol version.

Considering that i) in a large urban area (Rome) 40% of the vehicles does not exceed 100 kilometers per week (corresponding to the range of an average electric car rechargeable in 30’, at ultra-fast charging station of 50 kW or more), ii) in this way it is possible, in urban use, to replace these cars with equivalent electric vehicles, iii) annual primary energy consumption for cars and taxis in cities in 2014 is around 8.9 Mtoe and, finally, estimating an average energy consumption reduction of about 30% (petrol-diesel-weighted value), there would be a 10% reduction in imported fuels consumption. Even greater is the reduction of greenhouse gas emissions, thanks also to the progressive penetration of renewable sources that have a zero emission. As a matter of fact, electricity from renewable sources, considering hydroelectric production too, rises in 2014 up to 37% , more than doubling with respect to 2005 (17%). Finally, the (local) emission of harmful and acoustic emissions would be total.

In the following, the energetic issues will be deepened with regard to individual transport only, passenger cars, using a big data set about the real urban use of cars developed by ENEA, but similar considerations can also be made for road freight transport, with reference to urban and periurban tracts.

2. The Italian situation

From the AEA [2] database, in 2015, in Italy more than 1.57 million passenger cars have been sold, more than 55% diesel-fueled, and an appreciable fleet of hybrid cars

(HEVs), in particular petrol-fueled vehicles (**Errore. L'origine riferimento non è stata trovata.**).

Fuel	**Car registrations (total 1.573.729)**	**CO_2 (g/km)**	**Fuel Consumption (g/km)**	**Energy Consumption (Wh/km)**
Diesel	55,4%	115,50	37	439
Petrol	31,2%	117,99	38	461
LPG	7,7%	118,99	40	509
Natural gas	4,0%	98,44	49	480
Diesel-Electric	0,04%	113,46	36	431
Petrol-Electric	1,57%	86,23	28	337
Petrol-Electric Plug-In	0,04%	50,37	16	335
Electric	0,09%	0,00	0,00	147

Table 1: Car registrations, emissions and consumptions – Year 2015

Specific fuel consumption FC (g/km) and energy consumption EC (Wh/km) were estimated for the new vehicles sold in 2015, disaggregated for different fuels, using the National CO2 Emission Factors (Mg CO_2Mg fuel and Mg CO_2/MJ fuel) published by ISPRA in the GHG Inventory Report [3]. In the case of CNG, only the EC was available, so that the FC was estimated by converting this data on the basis of the Inferior Calorific Power declared by the National Energy Balance and the CNG density established by UN/ECE Regulation N. 101 [4].

1.1 Comparison between different power-train

Since the energy performance of vehicles depends to a large extent on the weight and power of the vehicle itself, in the following the normalized characteristics (per unit of weight) of the best-selling diesel fuelled cars. The analysis allows to compare vehicles with similar characteristics and different power train (Table 1).

Type	**Weight (kg)**	**Power (kW)**	**CO2 (g/km)**	**FC (g/km)**	**EC (Wh/km)**	**EC/weight (Wh/kg-km)**
FIAT 500L	1.399	68	111,97	36	425	0,304
FIAT 500X	1.429	88	115,42	37	438	0,307
VW GOLF	1.360	78	103,73	33	394	0,290
RENAULT CLIO	1.165	58	91,54	29	348	0,298
NISSAN QASHQAI	1.406	84	104,61	33	397	0,282
average	**1.627**	**87**	**115,26**	**37**	**439**	**0,304**

Table 1: Clockbusting models characteristics (Year 2015)

The same was made for different powertrains, results are reported in Figure 2 and Figure 3.

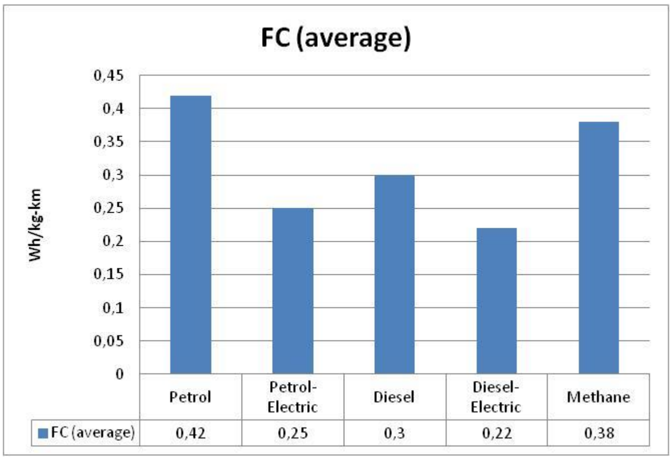


Figure 2: Specific (per weight and distance unit) consumption (Year 2015)

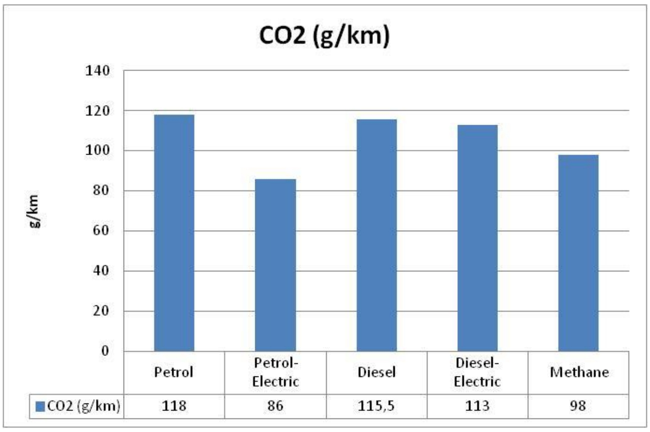


Figure 3: Specific CO_2 emissions

It is worth of note that the majority of petrol models are city-cars, their displacement is below 1400 cc, except for a 7% of models, notwithstanding they show a consumption 30% higher than that of diesel. The hybridization opportunity is therefore much greater for petrol cars, because it allows to compensate for their lower performance compared to a diesel engine, more energy efficient thanks to its much higher compression ratios. Moreover, for a hybrid diesel car the cost of engine, that has to be added to the cost of the hybridization, is higher than the cost of spark-ignited engine (i.e. petrol fuelled). As a matter of fact, a diesel engine is more "loaded", because of the higher pressures it is subjected to, and needs to be heavier. And a hybridized petrol car doesn’t suffer the issues related to the emission of nitrogen oxides, which were the origin of the "diesel gate".

The electric cars sold in Italy (2015) according to the AEA were 1458, but only 6 models, out of 19, exceeded 100 registrations (Table 2).

Type	Sold (n)	Weight (kg)	Power (kW)	EC (Wh/km)	EC/weight (Wh/kg-km)
NISSAN LEAF	386	1.542	80	150	0,097
RENAULT ZOE	328	1.502	43	146	0,097
CITROEN C-ZERO	164	1.140	35	126	0,111
SMART FORTWO	152	977	35	145	0,148
TESLA MODEL S	134	2.205	123	181	0,082
BMW I3	111	1.270	-	129	0,102
average	**210**	**1.479**	**58**	**147**	**0,099**

Table 2: Average characteristics of "pure electric cars" sold in Italy (2015)

In Table 2 their characteristics and average values are reported, and it can be noticed that the offer significantly increased with respect to a recent past, ranging throughout all market segments, from classic citycar such as SMART to Model S of Tesla.

1.2 Pure" electric vehicles and "plug in" hybrids (BEV & PHEV) vs. conventional ones

To overcome the differences, in weight and power, in the characteristics of the different commercialized vehicles, it is proposed to compare the energy consumption of different versions for the same car model, the VW Golf. For this model there are on the market three different kind of power train: gasoline, hybrid gasoline (HEV), plug-in hybrid (PHEV). To consider pure electric (BEV) too, a car of the same manufacturer (Jetta) that has similar characteristics, was considered. Below there are the specific consumption data declared by the manufacturer (Table 3) for different technologies, with the distinction between electric energy consumption and gasoline consumption for plug-in hybrids. Consumptions are measured according to the homologation cycles, in which urban cycle mileage is significantly lower than extra-urban mileage (3,9 km vs. 6,9 km).

FC (FUEL CONSUMPTION) IN L/100 km	Petrol	HEV	PHEV	BEV
Urban	**6,20**	**4,4**		
Extraurban	**4,40**	**3,90**		
mixed	**5,10**	**4,1**	**1,70**	
EEC (ELECTRIC ENERGY CONSUMPTION) (Wh/km)				
mixed			**124**	**139**
TOTAL ENERGY CONSUMPTION (Wh/km)				
FC			**124**	**139**
EEC	**467**	**375**	**156**	
Total (mixed use)	***467***	***375***	***280***	***139***

Table 3: Well-to-Tank energy consumption for a Golf (different models).

As the plug-in hybrid are chosen by people used to drive in the city (otherwise, their high investment cost is not justified with respect to a diesel car), we recalculated FC and

EC according to real-use percentages as resulting in a study by ENEA, to better estimate the balance between electric engine and ICE use (Figure).

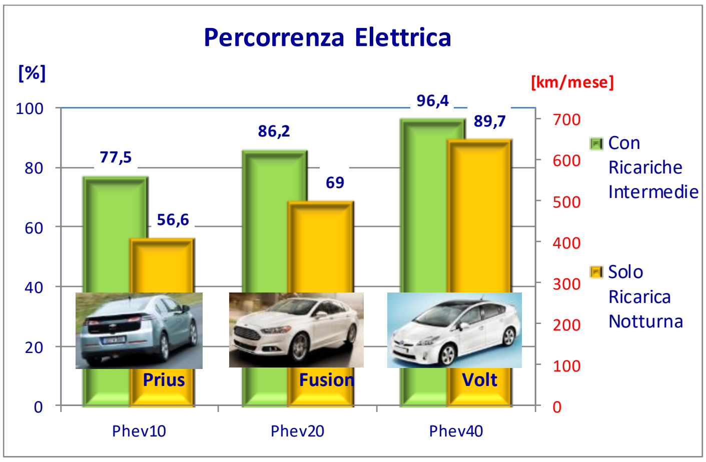


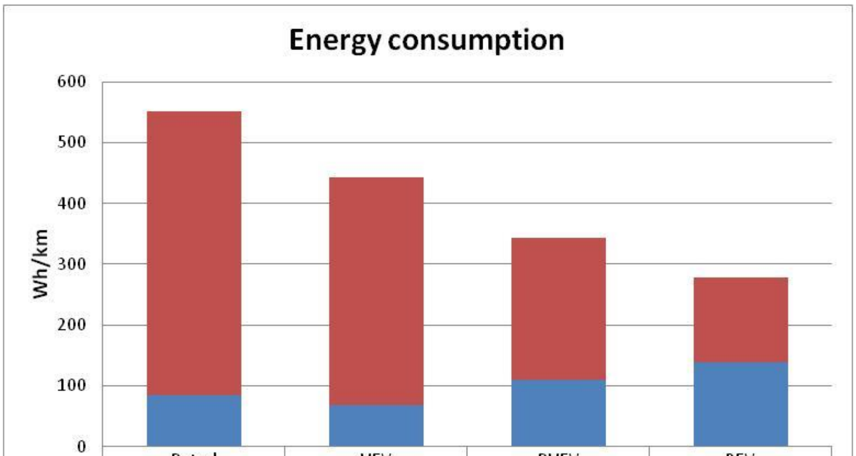
Figure 4: Monthly mileage in electric mode for three PHEV Font ENEA [5]

The study is based on a big-data set obtained from the actual daily travels recorded for a sample of 15,000 vehicles equipped with onboard units in the city of Rome [5].

It was also assumed that the plug-in hybrid consumes like the hybrid petrol car when it works with the thermal engine, and like the electric car when it moves into electrical.

2. Results

On the basis of these hypotheses, WTT(well to tank) and TTW(tank to wheel) specific energy consumptions were estimated for the different fueled versions of the same model (**Errore. L'origine riferimento non è stata trovata.**).



	Petrol	HEV	PHEV	BEV
TTW	467	375	233	139
WTT	84	68	110	139

From these data, the annual WTW consumptions were calculated for the different versions of the Golf together with the consumption reduction for the hybrid and electric models respect to the petrol car (Table 4).

Cars	Annual Mileage (km/year)	WTW EC (MWh/anno)	WTW EC reduction (%)
Petrol	15.000	8,27	-
Petrol-Electric	15.000	6,64	- 19,6%
Petrol-Electric Plug-In	15.000	5,94	- 28,2%
Electric	15.000	4,18	- 49,4%

Table 4: WTW consumption and % reduction respect to petrol Golf. Font: ENEA estimations from VW official data

The electrification of the collective transport is even more advantageous because electric vehicles, such as metro, trams and trolleybuses, are not penalized by the weight of the batteries and their losses in the charging and discharge phases. In fact, by comparing, for example, a trolleybus and an 18-car (18-inch) ATV (ATAC data) we have a consumption of 0.83 L/km of diesel per kilo of diesel and 2.2 kWh / km of trolley buses. Considering the same transformation / distribution yields of the previous case, the electric vehicle consumes 53% less, always in terms of primary energy.

Even greater reductions would be made with innovative electric buses (without catenary) with quick charging at the terminus stations, so that their battery package can be minimized, from the at one for travelling 100-150 km with only night recharging to the one required for a few tens of km [5].

3. Conclusions

The approaches to vehicle electrification followed by car manufacturers are of two kinds: the progressive hybridization of their range, preferred by most manufacturers, or the one adopted by Nissan and Renault, considering the electric vehicle sector a strategic development axis, and offering a full range of fully electric vehicles, from the micro car to the van.

Which of the two strategies is the winning one, we cannot know, but surely the path of a progressive electrification of road transport is marked and goes through the development of electrical storage systems of two types: "power storage" that have allowed the birth of the hybrid, and "energy storage", which push the spread of the "pure electric" vehicle.

From the results illustrated above, it is clear that electrification of road transport leads to significant energy savings, even in global terms, from the well to the wheel. In addition to this benefit, the electrification gains another important advantage at local level, in terms of air quality in urban areas, lowering the emissions of toxic and harmful gases. Of course, CO_2 emissions are also reduced, even in comparison to bifuel gasoline-methane vehicles.

Given that the transport sector has become over the years the most critical one in achieving the goals of reducing energy consumption and global emissions in our country, the certain advantages represented by a transition to road vehicles hybridization and electrification would well justify incentive measures similar to those taken in the past with the introduction of Green Certificates and Energy Efficiency Titles.

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