Research Article

Electric Vehicles: Potential for Pollution Reduction

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Summary: *The energy consumption of an electric vehicle (EV) is compared with that of the same model with a gasoline internal combustion engine (ICE) under local road and traffic conditions. It is found that as far as on-board energy is concerned the EV consumes about one tenth of the energy of its ICE counterpart. When overall (EV + power station) efficiency is concerned the EV still has an energy advantage of 2.5. As a result, the EV and power station combination allows strong reductions in almost all the major pollutants produced by road traffic, the one exception being SO2. As far as CO2 is concerned the EV emits under half that from ICE cars, because of its residual energy advantage. All these reductions can be significantly enhanced by photo-voltaic battery charging.*

Keywords: Electric vehicles, pollution, gas emission

Introduction

In the European Union (EU) transport currently accounts for around 25% of the total energy-related emissions of CO_2, as well as for smaller proportions of other greenhouse gases like N_2O and CH_4. Road traffic produces 80% of total transport emissions of CO_2 and passenger cars are responsible for 45% of that. So with a 1992 total of 8070 million tonnes(Mt) of CO_2 emissions, passenger cars are responsible for some 800 Mt. From another angle, passenger cars emit the largest amount of CO_2 of any land people mover: some 133 - 200 g/ pass.km as against, for instance, 35 - 62 g/pass.km for a bus (Stanners & Bourdeau, 1995).

There are other major pollutants connected with road traffic. Vehicle diesel engines account for close to 3% of total SO_2 emissions, admittedly a rather small quantity compared to SO2 from electricity generation. However, the situation for CO, NO_x, volatile organic compounds (VOC) and particulates is very different. Road vehicles account for well over 50% of total CO, especially in urban settings; in the US 50% of urban CO comes from traffic (Mackenzie,1994). As for NOx and VOC, EU motor vehicles produce 45% of the first and 31% of the second.

Diesel produces almost the whole of transport SO_2 and close to 70% of particulates, especially of the sub-10 micron variety. NOx comes from both types of fuel but CO, lead and VOC come predominantly from petrol engines. The VOC, together with NO_x and strong sunlight are the ingredients of photo-chemical smog and tropospheric ozone.

The local situation

The local balance between pollution from electricity generation and from road traffic, which is of interest here, is not too easy to establish, mainly because of a serious lack of reliable information. We have attempted to arrive at total quantities of pollutants by a careful determination of fuel consumption (Mallia & Fsadni, 1999) with use of widely accepted emission factors. For CO we assumed different emission factors for power stations (where excess oxygen is present in the flue gases) and for car engines. For quantities of VOC we have simply kept proportionality to petrol consumed thus tacitly using the emission factor used by Buttigieg (1998) for the 1990 CORINAIR inventory.

Table 1. Emissions from Electricity Generation and from Road Traffic

Year		SO_2	NO_x	VOC	CO	CO_2
1990	V	2230	2652	4530	24661	309467
	E	18977	7590	---	2491	500100
1994	V	2667	3214	5362	28870	362267
	E	23987	7796	---	281	1695867
1997	V	3127	3325	5339	30994	388285
	E	29000	5036	---	251	1514333

Table 1 gives the quantities in metric tonnes (t) of five pollutants produced in electricity generation (E) and by road vehicles (V). It shows quite clearly that electric vehicles can be expected to make little impact on SO_2 emissions, where local road transport contributes only some 10% of the SO_2 from electricity generation. Some impact on CO_2, and a very marked impact on NO_x and especially on VOC and CO, can be expected. These last three pollutants have known negative health effects, while VOC and NO_x contribute to the formation of low-level ozone.

At present, there is no basis for comparing power station and vehicle particle emissions. The EU limit value of 50 mg Nm^{-3} is not observed at Marsa, where the electrostatic precipitators are inoperative. Recent efforts by Enemalta to curtail particle emissions at Marsa by use of fuel additives (Pace, 1999, pers comm) have provided information of particle densities in flue gas: minimum values of around 150mg Nm-3 have been reported, but these cannot be translated into reliable estimates of concentrations at ground level. As no flow rates have been published, even an estimate of total mass of emitted particles is difficult to arrive at. Deposition rate at any one place is in any case highly variable, depending on weather conditions and the timing of soot-blowing episodes, when particle density in the flue gas may increase by several orders of magnitude for periods up to 15 minutes. In the presence of an atmospheric temperature inversion ground level particle densities could be very high indeed.

The work of Pulis (1996) on airborne particle density at roadsides, with collection times of 15m, established a strong correlation with traffic volume. Maximum densities of 95μg m^{-3} were recorded at Msida, with average values for low (500 vehicles an hour) and high (900 vehicles an hour) traffic volumes being 20μg m^{-3} and 63μg m^{-3} respectively.

Lead emissions from petrol amounted to 24t in 1997 (Mallia & Fsadni, 1999), in which year 75% of petrol sold was leaded. In urban areas at peak traffic times the density of lead particles has been estimated at 1.6μg m^{-3} (Savona Ventura, 1998).

Road concentrations of benzene and toluene from petrol have recently been reported by Vella and Gaerty (1998).

Electric Vehicle (EV) Energy Consumption

The vehicle used was a small four-seat passenger car with its 704cm^3 internal combustion engine (ICE) replaced by a 6kW DC series motor operating at 60V. The two rear seats had to be sacrificed to create space for the five 12V, 110Ah lead-acid batteries, with a nominal energy content of 6.6kWh and a total weight of 240kg. The overall weight gain of the car was 150kg from its standard 640kg. The original gear train and stick shift were retained.

Motor voltage and current, together with motor temperature and battery voltage, were sampled once a second and 10s-averages stored in an on-board computer. At the end of each run, energy consumption and other parameters of interest were displayed. Distance covered was read off to the nearest tenth of a mile from the car odometer.

The EV energy consumption was compared with that of an ICE version of the same car with an established fuel consumption of 7.0l/100km (40 mile/gallon) under local conditions. Petrol was rated at 33.4MJ/l or 9.28kWh/l (Goodgere, 1982), giving the ICE car an average energy consumption of 0.65 kWh km^{-1}.

About twenty unmonitored runs were made to determine parameters like range with full battery charge, top speed on the flat, acceleration at various speeds and hill climbing ability. Energy consumption was determined from two 50km runs separated by a few days (runs 1 & 2); a series of short commuter journeys over a total distance of 106km (run 3); and a shorter series of longer journeys over 125km (run 4). Table 2 carries the results for all four runs. The energy ratio is obtained by dividing the petrol equivalent for the ICE by that of the EV.

The average energy consumption for each of the four runs was 0.061 kWh km-1, 0.057 kWh km-1, 0.058 kWh km-1, and 0.060 kWh hr-1 respectively.

The energy ratios refer to electrical energy taken from the batteries. As such, they need to be adjusted for overall efficiency of the charging, distribution and generating system. For generation and distribution,

Table 2. Energy Consumption

Run no.	Distance (km)	Energy (kWh)	Petrol Equivalent (l)		Energy Ratio
			EV	ICE	
1	52	3.18	0.34	3.64	10.70
2	48.6	2.75	0.30	3.40	11.34
3	106	6.08	0.66	7.42	11.24
4	125	7.35	0.79	8.72	10.99

present efficiency can be taken as 25%; from a comparison of the energy meter attached to the mains and the energy actually going into the batteries, the charger efficiency was determined to be 90%. Incorporating these efficiencies, one obtains net energy advantages ranging 2.41 to 2.55 in favour of the EV.

So from the point of view of curtailment of CO_2 from road transport, use of electric vehicles as passenger cars can make a significant decrease (by a factor of 2.5). For the 1990 local vehicle fleet, passenger cars were reckoned to produce 79% of total road transport CO_2 emissions (Buttigieg, 1998, pers comm). For all other pollutants except SO_2, Table 1 shows that electric vehicles will produce marked reductions, the most significant of which would be for CO and VOC and consequently in photochemical smog and low-level ozone.

A marked reduction of airborne carbon particles, with their adsorbed polycyclic aromatic hydrocarbons (Hemminki & Pershagen, 1994) should also come about through the substitution of diesel engined passenger cars by EVs. As for power station sources of soot, until Marsa flue gases are properly filtered, EVs will not display their full advantage in this respect.

Two comparisons of electric and ICE vehicle emissions are shown below (Lestienne & Vergels, 1998). For CO_2, with the standard European driving cycle, the EV produces an average of 2.7 times less CO_2 km^{-1} as do petrol and diesel ICE cars. This value is close to those for overall energy advantage of the EV.

Local gains are likely to be greater than those shown in Figs. 1(a) and 1(b) because of the low average speeds of local traffic. The effects of speed might be seen in the results for the 1982 Swiss car fleet, for instance. The average emission of CO at 80km h^{-1} was 6g km.$^{-1}$ (Lamure, 1990), already significantly higher than that shown in Fig. 1(a), which deals with a more modern fleet. The CO emission went up to 14g km-1 for a speed of 36km h-1, which is close to average speeds in the heavily-built up area south of Mosta.

Conclusion

In our situation of limited distances and severe traffic congestion, electric vehicles can play a part in reduction of CO_2 as well as in strong abatements of most of the worst pollutants associated with road transport. Electric drives have motors with efficiencies at least three times the thermodynamic efficiency of a petrol engine; a low inertia rotor against pistons and crankshafts; zero energy consumption going downhill and stopped at lights or in

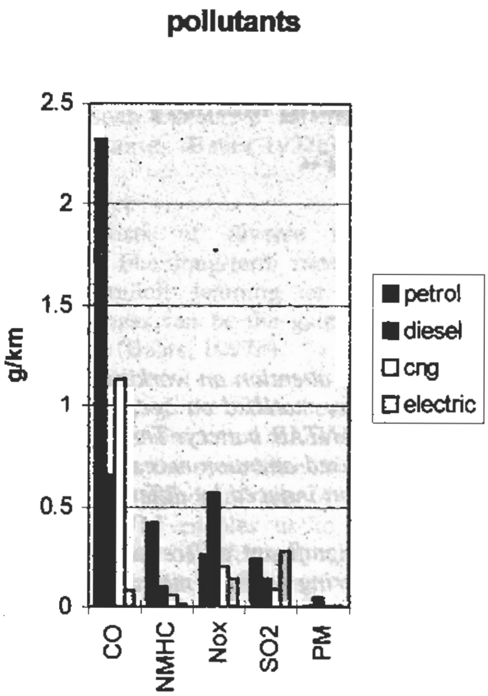

Figure 1(a).

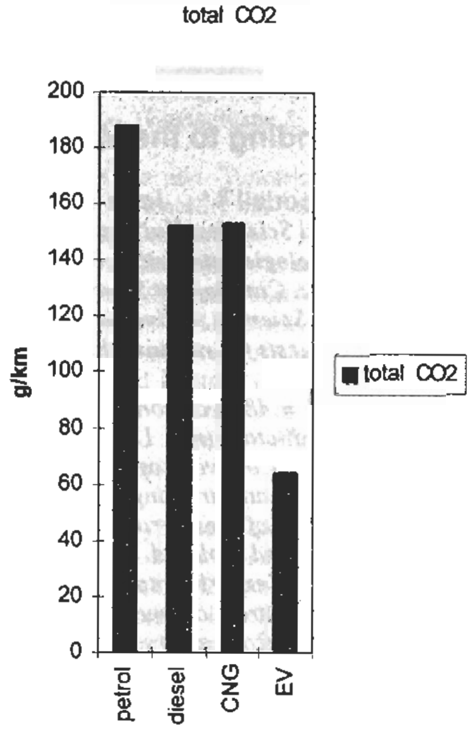

Figure 1(b).

N.B. CNG = compressed natural gas.

traffic jams; use less energy going low speeds. They are then ideally suited to local conditions (other than the state of road surfaces), while the properties of the ICE demand a different type of environment if the engine is to function at its best. Of course, even that best is far more polluting than an electric drive.

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