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External costs due to electric vehicles: a comparative analysis between new and conventional cars

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Abstract

The present paper examines the economic prospects of a technology that is relevant in this context, namely the electric vehicle. Despite the excellent environmental performance, this technology carries a cost burden which impedes a massive entry into the marketplace. An environmental costing procedure, including environmental externalities (i.e. air pollution, noise) in the framework of a social cost calculation could shift the balance unambiguously in favor of the electric vehicle, in spite of the superior environmental performance offered by this technology in comparison with traditional vehicles fueled by gasoline or diesel. The time horizon for the simulation of introducing electric vehicles in the actual and projected car fleet cover 20 years (1990 - 2010). After calculations on external costs due to gasoline, diesel and electric vehicles we can compare different scenarios in which the electric vehicle share of car fleet could range. The backbone of the ExternE procedure is the Impact Pathways Analysis (IPA) method, which is a bottom-up approach to impact estimation. The IPA method traces the fate of a pollutant from its emission into the air, followed by atmospheric dispersion across distances extending up to several thousand kilometers from the source, and , finally, evaluation of the impacts to the receptors at risk, via exposure-response functions. Once the numbers of impacts cases are calculated, the damage costs are obtained by multiplication with appropriate Monetary Unit Values (MUV).

1 Introduction

In addition to the financial costs associated with infrastructure development, capital equipment purchases and operating costs, there are many environmental damages that result from transport activity. These environmental damages are termed external costs, or "externalities". Such a cost arises when the social or economic activities of one group of people have an impact on another for which the first group is not held responsible and, therefore, does not fully compensate the other. Clearly, a well informed decision making process can no longer afford to ignore the environmental consequences imposed on the general public and its surroundings (nature) by the different policy measures, processes or products being evaluated (e.g., the choice between supporting conventional gasoline-powered cars, electric vehicles and mass transit in urban areas or the choice between rail and truck freight transport for long hauling distances). Such an oversight may lead to substantial welfare losses and, worse of all, an improper allocation of resources, which in most cases are limited. Externalities include accidents, noise, land use and pollution of air, water and land. Many human activities contribute to air pollution, but traffic emissions are far the most responsible for the weak air quality in urban areas. This is particularly evident in many urban centers where impacts to public health, ecosystems, historical monuments and agricultural crops is often front page news. In recent European studies it was shown that considering costs of air pollution by far, impacts were dominated by public health costs, followed by damages to building surfaces (*man-made* environment) and crops. It stands to reason that air pollution effects on health from transport emissions could very well be significant given that the emission levels for many pollutants are high, they occur at ground level and, above all, the number of people at risk is quite large. In fact, about one half of the world's population lives near or within the metropolitan area of major cities; and this fraction is expected to grow in the immediate future as technological development is expected to use a greater share of our natural resources. As vehicle use continues to escalate over the foreseeable future, we are therefore faced with the potentially unacceptable and unavoidable *reality* of economic, health-related and political choices and costs of air pollution. New technological advances could make electric vehicles an efficient and inexpensive mode of transport, certainly on the par with gasoline or diesel vehicles for urban transport tasks (*limited-range urban vehicles*). Furthermore, and most importantly, since the pollutant emissions to the air occur at the power plant site supplying the electricity needed to charge the car batteries, urban pollution from transport will be significantly reduced. The incremental pollution from the electricity generating station could be kept at a minimum if one takes advantage of low-polluting energy sources, such as solar, wind, hydroelectric, nuclear, natural gas, biomass and geothermal.

2 Impact Pathways Analysis (IPA) Procedure

Transport events include upstream processes (e.g., fuel and material extraction and processing, vehicle production, building of new infrastructure), downstream circumstances (e.g., vehicle disposal, dismantling of existing infrastructure) and vehicle utilization (conversion of fuel into motive force). Each of these steps has an associated external cost, which can be quantified according to the ExternE methodology of the European Commission. In this approach, the methodology adopted for evaluating the social costs of transport (*external costs*) consists of four main steps. The procedure beginning with airborne emissions, followed by an estimation of marginal ambient concentrations (through the use of short and long range atmospheric dispersion models) and ending with an evaluation of physical impacts (i.e., number of asthma attacks or hospital admissions, tons of potatoes lost per year or m^2 of building surface soiled) and monetary costs or estimates (Euro per kilometer driven). An economic valuation is quite useful for comparing the implications of different policy measures and decisions. Since policy makers have to confront the reality of the market, an economic valuation is the only logical choice for making a well informed decision which is sensitive to both economic and environmental issues. The IPA procedure begins by quantifying the airborne emissions. To do this, we multiply the emission factors for each pollutant considered by the transport distance. Since the emission factors are highly dependent on the prevailing traffic conditions and driving cycle, we may have to subdivide the total distance into smaller segments, each with his own unit emission ratios. The total emissions are, therefore, the algebraic sum of the emissions for each road segment. Next, estimates of the marginal increase in pollutant concentration level (that is, above the existing background value)are performed. Atmospheric dispersion is subdivided into *local* range dispersion, extending up to 35 kilometers on each side of the road, and *regional* scale dispersion, extending across the European continent. Depending on the scale, different air transport algorithms (models) are employed in estimating the concentration fields. For the local range, the degree of pollutant dispersion is dependent primarily on meteorological parameters. Of these, certainly, the most important are wind speed and wind direction. For the regional domain, on the other hand, atmospheric chemistry and pollutant removal via dry (gravitational settling, for example) and wet deposition (rain) mechanisms are equally important as meteorological data in determining pollutant concentration levels. Physical impacts are calculated next. These include, for example, the number of asthma attacks, hospital visits or admissions and mortality impacts such as the number of Years Of Life Lost (YOLL). Impacts to health (morbidity and mortality), crops and materials (damages to building surfaces) are estimated by applying the *concentration-response* (CR) relationships. These functions relate an increase in pollutant concentration level (exposure) to an anticipated damage or negative effect

(response) on a particular receptor. A receptor is anything which is affected adversely or positively by an increase in air pollution. Of course, a potential *benefit* of air pollution is also possible as in the case of crops exposed to a marginal increase in atmospheric concentrations of SO_2 and/or NO_X (fertilizer effect). These benefits, however, depend strongly on existing ambient concentration levels and are quite often small by comparison to public health impacts. Finally, the last step in the analysis is the economic valuation or estimation of the external costs of air pollution. This involves multiplying the number of cases (responses) by the monetary unit cost per incidence (unit cost factors). Unit costs are determined via contingency valuation studies, such as an individual's *Willingness To Pay* (WTP) to achieve an environmental benefit or an individual's *Willingness To Accept* (WTA) payment in lieu of an incurred environmental harm. Other valuation techniques include the use of *hedonic* pricing schemes, which are "indirect" methods used to quantify the value (worth) of one good through variation in the price of another.

3 The implementation of the Impact Pathway Methodology

The main source for data and calculations concerning the characteristics of vehicles according to the European standards, the traffic conditions and the zoning has been the reference study DE NOCKER [6] from which the results have been selected.

3.1 Reference Technologies and category split

For passenger cars the most representative motor/fuel technologies were identified. According to international and European emission standard legislation, we distinguish between EURO 0, EURO 1, EURO 2 and EURO 3 types of vehicles.

3.1.1 Calculation of emission factors

Accurate quantitative data about actual exhaust emissions for the different pollutants is made a complex issue due to the multitude of parameters involved. For this paper, emissions calculated by means of the HBFA model have been applied because it allows to calculate the impact of congestion. Three drive types for passenger cars have been adopted -urban drive, highway and rural drive- and for each it can be distinguished between peak and non-peak traffic conditions. For the urban and highway drive the peak traffic condition should be regarded as congestion (average speed of 5 and 10 km/h respectively), while the peak rural drive is merely increased traffic density. In total, we can distinguish between 7 traffic conditions, 3 different cylinder capacity ranges and 4 different mileage. Results cover only part of these possible combinations.

3.2 Impact of regulatory emission standards on external costs

As the life expectancy of a car is around 10 years (in Italy it reach 14 years), we also have to consider older cars. As emission standard regulation allowed higher emissions we may expect higher external costs. Table 1 shows the external costs of the past and future regulation of emission standards, at lest for the regulated pollutants. The figures refer to the reference case "rural non peak". We need to consider 4 categories (EURO0, EURO1, EURO2, EURO3) . In addition the figures also reflect technological changes over time that were not subject to regulation as well as the impacts of changes in fuels. This is important for the reduction of sulfur content of diesel, which affects SO_2 emissions.

Table 1 External Costs generated by diesel and gasoline vehicles: The reference case

Vehicle technology	**Euro0**	**Euro1**	**Euro2**	**Euro3**
	Euro/100vkm			
gasoline	3.75	1.05	0.98	0.75
diesel	2.75	2.60	2.15	1.25

3.3 Impact of location on external costs

A further step in the analysis concerns the combined influence of higher population densities and increased emissions of less favorable cases with respect to the reference ("rural non-peak"). The "rural" location corresponds to the country average for Belgium, with a 350 hab./km^2 population density; The "small city" location corresponds to a city of 80 000 habitants; The "big city" location corresponds to a 1000 000 habitants .Table 2 depicts external costs estimates for a present-day EURO2 gasoline and diesel passenger car in the earlier described non-peak cases.

Table 2 External Costs of different *non peak* cases for EURO2 cars (gasoline and diesel)

Area	rural (ref. Case)	small city	big city	big city ring
Vehicle	Euro/100vkm			
Gasoline	0.97	1.32	1.90	1.62
diesel	2.05	4.20	10	5.70

External costs estimates show a sharp increase from approx. 1Euro/100vkm for the reference case to 1.9 Euro/100vkm for the big city in the case of gasoline car and from 2 to 10 Euro/100vkm for diesel cars respectively. These changes are the results from changes in the emissions because of differences in traffic conditions between rural and urban traffic and from higher local impacts per kg pollutant of $PM_{2.5}$, SO_2 and carcinogens for emissions in the city. The differences in emissions are particularly important for gasoline cars. Different traffic conditions lead to higher CO_2 emissions for urban traffic compared to rural traffic. The impact of higher population densities is especially important for particulate and for the increase between small and big city. For the big city, $PM_{2.5}$ reveals itself as the dominant pollutant, even for gasoline cars. For diesel cars, the externalities in the big city are 5 times higher compared to the reference case. A more detailed subdivision of the local impacts show that in particular the immediate vicinity of the road (first 2 km) is responsible for external cost increases. This can be explained by the very nature of urban traffic emissions, namely at ground level in highly populated areas.

3.4 Impact of peak traffic on external costs

In this section, the influence of peak traffic (also called congested or stop and go traffic) is considered. For this reason, 3 different driving conditions are selected, i.e. a "urban peak drive" at 5km/h, a "normal urban drive" of 28 km/h and a "free flow drive" similar to the "rural drive" case of 60 km/h. In the following table, external costs estimates are produced as a function of average speed. In addition, different combinations of locations and technologies were chosen as parameters.

Table 3.1 External costs according to location, technology and traffic conditions.

Area	**Small City**					
Traffic	peak		normal		free	
Technology	G*	D**	G	D	G	D
EURO 0	**9.5**	**20**	**5.0**	**5.5**	**4.0**	**4.5**
EURO 2	**3.0**	**11**	**1.3**	**4.15**	**1.0**	**3.0**
EURO 3		**4**		**2.0**		**2.0**

* G = gasoline car; ** D = diesel car

cont.

Area	Big City					
Traffic	peak		normal		free	
Technology	G	D	G	D	G	D
EURO 0	**19**	**53**	**8.0**	**19.0**	**6.0**	**14.5**
EURO 2	**5.0**	**26.5**	**2.0**	**10.0**	**1.6**	**10.5**
EURO 3	**3.0**	**11.0**	**1.3**	**4.2**	**1.0**	**3.0**

A general and major perception of these figures is the relatively flat curve for higher average speeds, including both free flow and urban non peak driving conditions. On the other hand, peak traffic is characterized by very high values. For gasoline cars peak values are a factor 2 to 3 higher than "free flow" externalities for a small city and a factor 3 to 4 for a big city, with the higher ranges for the most recent vehicle types. For diesel cars these factors go from 3.5 for a EURO 0 to 2.5 for the other types (both for small and big city). Gasoline EURO 3 cars are not included as results approximately coincide with the EURO 2 standards. These results suggested that peak traffic should be regarded as a predominant factor in external costs resulting from air pollution. In combination with unfavorable geographical conditions and older motor technology, external costs estimates can mount up to extremely high values as more than 18 EURO/100vkm for gasoline cars and 50 EURO/100vkm for diesel cars.

4 A rough tentative to simulate benefits from introduction of electric vehicles

We have seen as a number of European studies (ExternE-Transport (1998), OSTC-Belgium (1998)) have estimated external costs due to the use of conventional vehicles (according to actual and future emission standards) in different situations (free flow, normal congested traffic) and location (small city, big city). Results have confirmed what we can expect: the figures vary with a so wide range that general considerations are impossible to avoid misleading conclusions. For this reason, the following simulation should be taken with care, because it represent a simple, and incomplete exercise to depict a possible scenario for policy decisions. Nevertheless, a magnitude order of the values proposed could be a starting point of discussion of possible alternatives.

4.1 External costs generated by electric vehicles

We simulate the renewal of the car fleet introducing 200 000 electric vehicles with actual characteristics:

energy consumption: 20 - 25 kWh/100 km

annual urban mileage: 5000 km

External costs: 2.3 - 26 mEuro/kWh (see the Table 4)

Tab. 4. External Costs due to Electricity Generation

Fuel	External costs (mEuro/kWh)
Nuclear	0.1 - 4
Coal	12 – 136*
Gas	2.3 - 11.05
Oil	12.61 - 16
Hydro	2.25

* This figure concern old technology coal fired power plant.
Source: the ExternE Project, EEC-DGXII (1997)

Considering the average energy consumption of 20-25 kWh /100 km of an electric car , and the external cost due to electricity generation according to Table 4, a rough estimation of the total external cost for a 200 000 car fleet with a 5000 Km per year traveled range between:

22.5 kWh/100vkm x 0.1 mEuro/kWh x 5000 km/year x 200 000 v = 22 500 Euro/year for a nuclear power plant (smaller value)

22.5 kWh/100vkm x 2.25 mEuro/kWh x 5000 km/year x 200 000 v = 506 000 Euro/year for an Hydro power plant

22.5 kWh/100vkm x 16 mEuro/kWh x 5000 km/year x 200 000 v = 3 600 000 Euro /year for a fuel oil fired power plant.

4.2 External costs due to conventional vehicles

To proceed in the comparison, according to Section 2. We extrapolate four values :

1.0 Euro/100vkm as the smallest value (not really representative of the real car fleet, nor of the usual traffic conditions) corresponding to a gasoline car,

responding to the EURO3 standards located in a big city and driving in a free flow conditions.

4.15 Euro/100vkm corresponding to a diesel car, responding to the EURO2 standards located in a small city and driving in normal conditions.

19.0 Euro/100vkm corresponding to an actual gasoline car EURO 0, located in the congested traffic of a big city.

53.0 Euro/100vkm corresponding to an actual diesel car EURO 0, located in the congested traffic of a big city.

The 5000 km/year and the 200 000 vehicles still apply. The results are the following:

1.0 Euro/100vkm x 5000 km/year x 200 000 v = ~ 10.0 Million Euro/year

4.15 Euro/100vkm x 5000 km/year x 200 000 v = ~ 41.5 Million Euro/year

19.0 Euro/100vkm x 5000 km/year x 200 000 v = ~ 190.0 Million Euro/year

53.0 Euro/100vkm x 5000 km/year x 200 000 v = ~ 530.0 Million Euro/year

As anticipated, the results present a variability of various factors that can easily confusing the policy makers. Nevertheless, there is evidence of the smaller external cost due to the electric vehicle if compared to the conventional vehicles as it can be seen if we compare the estimated external cost of 190 million Euro /year due to air pollution of an actual gasoline (EURO 0) vehicle with the 0,506 million Euro/year external cost due to an electric car when electricity is produced by Hydro power plant .

- A full external cost evaluation, should take into account :
- the cost supported to subside the purchasing of electric vehicles, considering the actual price is almost twice of a similar gasoline car.
- The cost of the electric car battery disposal
- The advantage to reduce oil imports for gasoline production

The advantage to eliminate the noise and its external cost These aspects have not been valued because they depend on such a various number of variables and policy decisions that should be the object of specific studies. They do need to be investigated in order to make effective and consistent the cost-benefit analysis, reducing the magnitude of incertitude that affect all the calculation. Further, it is difficult to predict the real technology development that will affect the characteristics of both conventional and electric vehicles.

A cost-benefit analysis including estimates for point b), c) and d) could allows for a balance that could constitute the reference amount of subsides to devote to the electric vehicle dissemination. Nevertheless, the variety in external cost estimates is challenging for the development of efficient transport and environmental policies. Past and present policies aim at reducing tail-pipe emissions by regulatory standards. External cost estimates indeed decrease substantially by emission standard legislation. However, a quite remarkable result of European studies was precisely the doubling or tripling of congested traffic external costs with respect to normal traffic conditions. As without policy changes, congestion is likely to increase exponentially, it will reduce or even offset the benefits we can expect from more severe emission standard legislation.

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