The external costs of air pollution by motorcycles

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Abstract

The main goal of this paper is to evaluate the consequences for air quality of modal shifts between passenger cars (incl. car-pooling), motorcycles and city buses. This evaluation is based on the calculation of environmental external costs. The analysis will be complemented with a literature review of congestion and accident related externalities of different modes to allow a meaningful comparison. The assessment of environmental impacts through air pollution is based on the ExternE methodology, which was developed within a European wide project, co-funded by the European Commission. It is based on a detailed ‘impact-pathway analysis’, which aims to quantify impacts on human health, crops, materials and ecosystems in 4 consecutive steps: specification of emissions, dispersion simulation, impact assessment with dose-response functions and monetary valuation.

Motorcycles are the third category of road vehicles for passenger transport for which we have calculated externalities with this methodology. This paper is the first in which our results for motorcycles are presented and discussed. Motorcycles with different cylinder capacities between 50 and 750cc are compared. Based on the results of previous studies on passenger cars and buses, we can now compare three major vehicles for passenger transport while taking differences in capacity into account. Calculations with a simplified world model provide us with a means to distinguish the different impacts that are dominant in cities, rural areas and on highways. We assess which pollutants are dominant in the assessment of external costs and which measures could be taken for the abatement of motorcycle emissions. This could result in recommendations for the drafting of Euro2 emissions standards for motorcycles by the European Commission.
1 Introduction

1.1 Scope of the research projects

The results presented in this paper were obtained from an ongoing series of research projects at Vito. These projects, funded by national and European authorities, aim to estimate the external costs of all major transport modes. Results for passenger cars and buses have been published before [1, 3] and results for Heavy Duty Vehicles (HDV, lorries) will be published shortly [4]. This paper is the first to discuss the results for motorcycles.

In contrast to some other, mainly southern European countries, Belgium’s fleet of powered two-wheelers is rather small. Most motorcycles in Belgium (98% of the fleet) are equipped with a four-stroke petrol-fuelled engine. Despite the spectacular increase of the fleet in recent years (+60% between 1990 and 1997), the fleet’s mileage remains almost constant. The average mileage per vehicle is less than half that of passenger cars. This reflects the fact that motorcycles are mainly used for recreational purposes and not for commuting. It is estimated that only about 1% of all passenger-kilometres in road transport can be attributed to powered two-wheelers.

1.2 Objectives of this paper

The first objective of this paper is to present our first estimates of external costs of different types of motorcycles. In this paper we will only address vehicles with 4-stroke engines larger than 50cc. Two-stroke motorcycles with an engine capacity over 50 cc are negligible and are not included in our analysis. Two-stroke engines and mopeds (<50cc) generate emissions with a very different composition and will therefore be dealt with in a forthcoming publication.

Our second and most important objective is to compare the environmental performance of motorcycles with cars and buses. We assess which emissions are dominant in the external costs and which measures could be taken for the abatement of air pollution by motorcycles. This could result in recommendations for the drafting of Euro2 emissions standards for motorcycles by the European Commission. Finally we address the question whether motorcycles are an alternative to cars and buses from an environmental perspective.

2 Methodology

2.1 The Impact Pathway Methodology

Our estimates of environmental externalities are based the ExternE-methodology. This methodology was developed over the course of a number of projects in the European Joule research program and is implemented in a common accounting framework. It uses an impact-pathway approach to trace a pollutant from its emission through its dispersion until it causes an impact. The magnitude of an impact is calculated from the concentration increase of a
pollutant with exposure-response functions. The impact is then converted to a monetary value (damage) so that different impacts can be compared and summarised into a single figure. Generally there are 4 types of impacts that are considered: human health, crop loss, damage to materials and ecosystems. This 'impact pathway' methodology is illustrated in Figure 1.

**Steps in the analysis**

1. **EMISSIONS**
   - e.g. g CO/vehicle km

2. **DISPERSION**

3. **EXPOSURE**

4. **IMPACTS**
   - e.g. respiratory effects of PM2.5 on asthmatics

5. **DAMAGE**
   - of health care costs, crop loss, etc.

**Models and data**

- Site and vehicle specific inventory
  - speed dependent classification by cylinder capacity

- Atmospheric modelling
  - OPS, EUROS, HTM, Roadpol

- GIS calculation of Exposure
  - Receptor data, maps

- Exposure-effect functions
  - human health
  - crops
  - materials

- Critical Loads
  - ecosystems

- Monetary valuation
  - "Willingness to Pay" studies

Figure 1. The impact pathway methodology.

A more detailed description of the general methodology was given by De Nocker et al. [1]. For a detailed description of the methodology, including exposure-response functions and monetary valuation of different health endpoints, the reader is referred to the new ExternE report that is due to be published later this year [2].

Although a discussion of methodological details is clearly beyond the scope of this paper, it should be stressed here that the accounting framework has undergone profound improvements. New findings in the epidemiological literature have prompted the ExternE team to make alterations to the exposure-response functions for human health. In addition a new approaches to the marginal impacts of ozone and global warming impacts were adopted. These improvements have reduced some of the uncertainty and enhanced the credibility
of the results. Comparability with earlier results is not an issue because we are not aware of any other externality estimates for motorcycles.

2.2 The implementation of the Impact Pathway Methodology

2.2.1 Calculation of emission factors

In the ExternE methodology emission factors are calculated with the speed dependent functions from MEET [5]. MEET distinguishes controlled and uncontrolled motorcycles, but only differentiates the uncontrolled vehicles in three classes according to cylinder capacity (<250cc, 250-750cc, >750cc). The speeds that were used for the calculations in this paper are given in Table 1.

Table 1: Average speeds (km/h) for different vehicle types and road types under normal traffic conditions

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>urban dense / normal</th>
<th>rural dense / normal</th>
<th>highway dense / normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>15 / 22</td>
<td>25 / 51</td>
<td>25 / 110</td>
</tr>
<tr>
<td>Public bus</td>
<td>11 / 15</td>
<td>25 / 45</td>
<td>25 / 80</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>15 / 25</td>
<td>25 / 51</td>
<td>25 / 110</td>
</tr>
<tr>
<td>Moped</td>
<td>15 / 25</td>
<td>25 / 31</td>
<td>25 / -</td>
</tr>
</tbody>
</table>

It is assumed that speeds are similar for passenger cars and motorcycles in rural driving conditions and on highways, but it cannot be ignored that motorcycles have a slightly higher average speed in urban traffic.

2.2.2 Assessing spatial variation

Earlier results have shown that environmental externalities from transport are very site specific. To calculate public health impacts we must accurately take the population density into account, especially when applying the methodology to urban environments. To achieve this goal, the ExternE has developed embedded GIS-tools for the accounting framework Ecosense which allows to precisely calculate exposure for any given trajectory.

To answer policy related questions; generalised results are more useful than fully detailed modelling results. Therefore we have included data from multiple Ecosense runs to derive a simplified world model ExTC (External Transportation Costs) (Vito). This model allows the fast calculation of total and marginal external costs for typical trajectories. It is designed to combine high speed with reasonable accuracy by elimination of the need for repeated atmospherical modelling. ExTC was used to calculate externalities for three typical situations: rural (or country average), urban (Brussels) and highway.
3 Results

3.1 Environmental damage costs of uncontrolled motorcycles and cars

Traditionally motorcycles are considered to be cleaner vehicles than cars. Very often the lower fuel consumption is cited as one of their major environmental advantages. In Figure 2 we have illustrated the environmental damage costs of uncontrolled motorcycles in different driving conditions. It is clear that motorcycles do perform better from an environmental perspective when compared with uncontrolled passenger cars. The main impacts however are not caused by CO₂ or global warming (which is directly linked to fuel consumption). The adverse health effects of nitrates, particles (PM2.5) and ozone are much more important.

Nitrates are formed from NOₓ emissions by chemical reactions in the atmosphere. Their effect is mainly regional (Europe-wide), and therefore little difference is found between the three locations shown in Figure 2. Particles on the other hand have a local effect and are found to dominate in urban locations, where population densities are highest.

Uncontrolled motorcycles have lower emissions of NOₓ and PM2.5 than uncontrolled (pre-catalyst) cars. This explains why the impacts are generally 20-50% lower. There is an interesting parallel between the emissions and the size of the engine. Heavy motorcycles (that were designed for higher speeds) have lower emissions in highway driving. Smaller engines (<250cc) which are often used to power scooters have lower emissions at low speeds (e.g. in urban traffic).

Figure 2: Environmental external costs of uncontrolled motorcycles compared to small petrol cars in different locations

Emissions of VOC's from motorcycles are relatively high. This leads to the formation of ozone that can causes significant impacts. But for some vehicles
negative values (benefits) are found because of the (local) depressing effect of high NOx emissions on O₃ formation in some countries.

3.2 Controlled motorcycles

Figure 3 shows the results for “controlled” motorcycles, compared to common passenger cars. It is clear at first glance that motorcycles have lost their environmental advantage over cars. Only in large cities they have slightly lower externalities than cars.

Although tighter emission standards for motorcycles have been set in 1999, they have not achieved a similar effect on external costs as in passenger cars [1]. Most significant reductions where those of VOC’s and particles. However compliance with the emission standards did not necessitate the introduction of three-way catalytic converters as in passenger cars. As a result emissions of NOx from motorcycles have not decreased.

Taking into account the January 1st 2000 introduction of Euro 3 emission standards for cars, the low penetration of controlled motorcycles and the number of passengers per vehicle (see 3.3); we conclude that motorcycles are now environmentally outperformed by cars.

The reduction of NOx from tail-pipe emissions has proven to be the single most important technological achievement in lowering external costs in passenger cars. Despite the success of catalysts in cars, motorcycles with catalysts are rare and implementing them involves technological problems unlike those in passenger cars 10 years ago. It is therefore unlikely that EC directives will impose emissions standards that force the introduction of catalysts in the near future.

Figure 3: Environmental external costs of controlled motorcycles compared a small petrol car in different locations
Last year, only two major manufacturers could offer a motorcycle with a catalyst and one of them withdrew its model because of disappointing sales. Given the relative importance of nitrate impacts in rural and highway driving, it is expected that motorcycles could regain their favourable environmental image with the mandatory introduction of three-way catalytic converters. At that point, the lower fuel consumption of motorcycles may again make a difference.

3.3 Environmental performance in urban peak traffic

There seems to be only one exception to the comparison of present-day vehicles made above. In urban peak traffic, when speeds are low, NOx emissions are also much lower. Combined with the large population at risk, we find that local health effects of primary particles dominate externalities (see Figure 2 & Figure 3). The reduction of particulate emissions in controlled motorcycles has been adequate to ensure that impacts per vehicle-kilometre are lower than for passenger cars (Figure 5).

![Figure 4: Air pollution impacts from urban peak traffic](image)

This apparent advantage of motorcycles quickly evaporates when occupancy rates are taken into account. Obviously passenger cars and public buses can carry many more passengers than a motorcycle. Although the average occupancy of cars and buses is low (1.3 and 15 passengers respectively), these could be increased significantly (e.g. in peak traffic). Policy makers may therefore consider that promoting car-pooling and public transport with buses are just as effective for reducing externalities as a modal shift to motorcycles.
3.4 Other external costs

It would be misleading to compare motorcycles with other transport modes in terms of impacts by tail-pipe emissions only. In urban peak traffic, air pollution is but one of several causes of external costs. Other possible externalities include Life Cycle Impacts (LCI) as well as impacts from noise, accidents and congestion. Despite the severe lack of useable data from literature, we have attempted to create a graph with preliminary estimates for some of these impacts. Life Cycle impacts and external costs of noise were included in Figure 5 to provide a comparison with externalities through air pollution. It shows that air pollution impacts from tailpipe emissions are usually the most important environmental costs.

![Diagram of external costs for different transport modes]

Figure 5: Summation of different types of externalities for different means of urban passenger transport (peak traffic, Eurocent/passenger.km)

External costs resulting from the production of motorcycles and their fuel are lower than for cars because of their low weight and low fuel consumption (based on ExternE data from IER, Bickel pers. comm.). An increase of the average occupancy rate of cars (car-pooling) however can achieve a similar reduction in the costs per passenger.km. For buses, air pollution costs are much larger than other externalities.

We have found no applicable literature on the external costs of noise from motorcycles. European emission standards are now at the same level as for heavy lorries (80 dB). Therefore it can be expected that noise externalities will be at least 10 times higher than for cars. This means that noise may be the major impact from motorcycles in urban traffic (based on data from Mayeres & Van Dender, pers. com.).
Two other types of (non-environmental) external costs are derived from the interaction of motorcycles with other vehicles in real life traffic situations: external accident costs and external congestion costs. The external accident cost (the risk that someone else gets injured) for motorcycles appears to be much higher than for other vehicles. Recent studies shown that this cost may amounts to 0.17 Euro/km, dwarfing the externalities shown in Figure 5 (based on data from Mayeres, pers. com.). The main uncertainty however lies with external cost of congestion. None of the recent studies of externalities have addressed the specific impacts of motorcycles. For cars, these costs are by far the most important category (up to 30 times as high as all other costs combined in urban peak traffic). Unfortunately, there is no obvious relationship between the external congestion costs of cars and motorcycles.

3.5 Opportunities for motorcycles in Belgium

In contrast to data for passenger cars (see [3] for a summary), no official figures are available on yearly activity of motorcycles and mopeds in Belgium. Mileages from motorcycles as reported in MEET for Belgium (3000 km) are very different from those for Austria (7800 km) and France (6500 or 9000 km). According to European statistics, the average mileage of Belgian motorcycles has decreased by 30% since 1990. Their estimate (6200 km/y) is very close to Vito’s assessments of motorcycle mileage (6390 km/y; De Vlieger, pers. com.) which are therefore believed to yield the best estimates of motorcycle mileage.

The number of new motorcycles sold in Belgium has risen sharply over the last few years. Although this growth mainly occurred in the heavier segment of the fleet, it can be expected that small scooters (some of them with 2-stroke engines) will appear in urban traffic as congestion problems worsen. On the other hand, the introduction of a separate driver’s license for motorcycles and passenger cars may inhibit some drivers to make this modal shift.

4 Conclusions

- Since the introduction of the three way catalyst for petrol cars, motorcycles have higher air pollution impacts than (small) petrol cars, because the strengthening of emission standards for motorcycles went less far. Only in cities, the higher NOx impacts from motorcycles are compensated by higher particle impacts from petrol cars.
- However, based on emission standards, noise impacts from motorcycles could be the dominant impact in urban areas and result in higher total environmental externalities from motorcycles.
- Motorcycles need to improve their environmental performance (air pollution and noise) to be seen as a clean alternative for petrol cars.
- Other external costs of motorcycles such as accidents and congestion have hardly been studied and are poorly understood.
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References


