Air pollution impacts of inland shipping: two case studies

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Abstract

Over the last years, a myriad of road transportation problems have been subjected to an analysis of emissions and environmental external costs. Other modes of transportation have been studied with much less diligence despite overt interest of policy makers. In this paper we present the results of two case-studies from Belgium where inland shipping and road transport were compared. The first case looked at the short distance transport of municipal solid waste from an intermodal transshipment area south of the city of Antwerp to plants north of the city. Two transportation scenarios were evaluated: by inland shipping over the river Scheldt and through the basins of the port, or by truck on the cities major roads and highways. The second case looked at long distance transport of large single items (>60 tonnes) from the cities of Tournai and Liège to Antwerp. Inland shipping trajectories were compared to road transportation. It was found that emissions and impacts from the inland shipping scenarios are not always lower when compared to all-road haulage with modern trucks. This is explained by the fact that European legislation has succeeded in lowering emission standards of trucks systematically over the last decade. The poor performance of inland ships is mainly due to high emissions of PM but is also deteriorated by the need for extra transhipment and terminal road haulage. Emissions from inland ships are rather poorly known and there is an urgent need for real-life measurements and the further drafting of emission standards for inland ships and fuels. Nevertheless, inland ships clearly have lower fuel consumption and carbon dioxide (CO₂) emissions per tonne kilometre than trucks.
1 Introduction

The ExternE-methodology has recently provided tools for the calculation of marginal air pollution impacts from transport [1]. As a result, numerous road transportation problems have been subjected to an analysis of environmental external costs over the last years. Other modes of transportation have been studied with much less diligence despite fast growing interest of policy makers. Faced with negative environmental aspects of fast road haulage growth and increasing congestion, inland shipping is now generally considered to be an important clean alternative. This clean image is based on outdated studies that do not take into account the different rates in technological evolution of heavy duty trucks and inland ships. In addition very few new ships have been built during the last decade and the average age of inland ships in the EU is very high. In this paper we present the results of two case-studies from Belgium where inland shipping and road transport were compared in real-world situations.

The first case looked at the short distance transport of municipal solid waste from an intermodal transshipment area south of the city of Antwerp. Two waste fractions are separately transported to an incineration plant in the left bank harbour area (West) and to a plant for biological separation and digestion near the Hoge Maey landfill in the right bank harbour area (East), both close to the Dutch border. Two transportation scenarios were evaluated: by inland shipping over the river Scheldt and through locks and basins of the port, or by truck on the cities major roads and highways. In this study we have compared external costs of air pollution for the current situation, taking into account the need for post haulage. The second case looked at long distance special transports of large single items (>60 tonnes) from the cities of Tournai and Liège to Antwerp. Inland shipping trajectories following the river Scheldt and the Albert canal were compared to road transport. In this case we have focussed on the changing environmental benefits of road haulage and inland shipping in the near future.

2 Methodology

2.1 Emissions for inland ships

Current emissions for inland ships were calculated with an updated version of the Ecosense-Transport model [1] based on Dings et al, 1997 [2] and the revision of Dorland [3] [4].

For the first case standard emissions for the year 2000, 100% loaded ships and an engine MCR of 95% were chosen. This choice guarantees strict comparability with other recent studies focussing on modal shift towards inland shipping. On the other hand, some recent literature [5] suggests that technological evolution of inland ship engines is slower than expected. The second case has compared both modes of transportation for the technologies mandatory in the years 1990, 2003 and 2007. Based on available statistics, both 70% loaded ships (MCR 75%) and 50% loaded ships (MCR 65%) were studied.
Unlike road transport, no European emission standards exist for inland ships. Recently, the Central Commission for Rhine Shipping (CCR) took an initiative to impose standards for new ships. They are a mix of IMO's (International Maritime Organisation) limits for $SO_2$ and $NO_x$, complemented with data from the European R47/68 standard for mobile tools (for CO, HC and PM). These new standards are mandatory in all states on the Rhine river and Belgium but not in the rest of Europe. CCR planned to impose the first phase in 2002 but this was later postponed to 2003. Phase 2 is tentatively planned somewhere between 2005 and 2007. These standards were integrated in our emissions calculations for the near future.

An overview of the technology scenarios being studied in the second case is given in Table 1. 1990 has to be seen as a reference scenario. 2003 is the year in which phase 1 of the CCR emission standards for inland ships is introduced. Phase 2 should be enforced in 2007. For each scenario, Table 1 gives the mandatory engine technologies for new road freight vehicles and inland ships. As phase 2 of the CCR is not yet official, an alternative scenario for 2007, assuming phase 2 would not come into force, was also evaluated.

Table 1: Technology scenarios within the second case study

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Engine technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy duty trucks</td>
<td>Inland ships</td>
</tr>
<tr>
<td>1990 reference</td>
<td>Pre-Euro 1 Technology 1990</td>
</tr>
<tr>
<td>2003 CCR-1</td>
<td>Euro 3 CCR-1</td>
</tr>
<tr>
<td>2007 CCR-2</td>
<td>Euro 4 CCR-2</td>
</tr>
<tr>
<td>2007 CCR-1</td>
<td>Euro 4 CCR-1</td>
</tr>
</tbody>
</table>

$SO_2$ emissions are directly proportional to fuel consumption and the amount of sulphur in the fuel. The sulphur content of medium fuel for inland shipping is limited to 0.2% by weight. Recent analyses and data from Belgium and Holland have demonstrated that actual levels may be up to 50% lower than the standard. Nevertheless this is more than 20 times higher than in diesel for road transport.

**2.2 Emissions for truck transport**

Emissions for trucks were estimated with MEET-functions based on estimated average speeds on the selected trajectories and given load factors [6]. MEET reports emissions for transports up to 60 tonnes. Emissions for heavier road vehicles were extrapolated from MEET's three highest categories (32-40t, 40-50t & 50-60 tonnes). It is assumed that weight is a more important determining factor than size, given the low speed (30-45 km/h) of special transports in Belgium. In this way we obtained first estimates for road transports of 90, 150, 220 and 300 tons (weight of trailer, semi trailer, pusher and load, used in case 2).

Specific emissions for road transport have gradually decreased by the introduction of a series of European standards, generally specified as Euro
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\[\text{(technology of 1990 = Pre-Euro 1; 1993 = Euro 1, 1996 = Euro 2, 2001 = Euro 3; 2006 = Euro 4). In addition fuel quality has also improved. Limits for the sulphur content of diesel have decreased from 0.2% in 1990 to 0.005%}.

2.3 Dispersion exposure and impact assessment

The European ExternE project provides a widely used accounting framework for air pollution impacts. It basically follows a pollutant from its emission until it causes an impact or damage. It allows monetization of environmental damage costs from air pollution (external costs or externalities) for a specific technology and trajectory. This methodology was implemented in the Ecosense-transport software. The studied trajectories were digitized in its GIS-environment, for the detailed analysis of emissions, their atmospheric dispersion, exposure of man and environment to the pollutants and the resulting impacts on public health, agriculture and buildings. Calculating external costs is a clear method to weigh and sum the different types of impacts caused by each pollutant. Most costs of PM, NO\(_x\) and SO\(_x\) are derived from public health impacts including both “mild” conditions such as coughing and asthma as well as more serious respiratory and cardiovascular illness. Exposure to CO and carcinogenic VOC’s can cause cardiovascular diseases and fatal cancers such as leukaemia, but they are emitted in such low concentrations that the number of affected people is very low. Damages to crops and buildings are always much lower than the damages to public health and don’t have a significant effect on the conclusions presented in this paper. More detailed descriptions of this methodology can be found in [1].

Emissions of greenhouse gasses are only attributed with global effects so that no dispersion or exposure analysis is necessary. It has been argued that the latest central global warming estimates from ExternE are far too low (e.g. 2.4 Euro/tCO\(_2\)) (Krewit, in press). But Tol and Downing did propose uncertainty distributions that include issues such as discounting and equity in their original texts [7]. The highest ExternE-values (based on EU-values throughout the world and no discounting of future impacts) are around 18 Euro/tCO\(_2\). This is very close to costs for Kyoto-compliance in many European countries (e.g. [8]). A rounded value of 20 Euro/ton was used for this study.

3 Results

3.1 Case 1, short range transport of domestic waste

In the first case study we have calculated external costs per ton of waste transported. This allows us to compare two very different modes in terms of capacity. For each mode two alternative options were studied. Two very different types of ships, a typical class B ship called “Kempenaar” (451-650t) and a large class I convoy (4x2700 Push tug) were compared. For road haulage we selected large uncontrolled (pre-Euro1) lorries and compared them with results for modern trucks complying with Euro 2 standards (built after 1996). It was
assumed that only Euro2 trucks were used for post haulage (i.e. the final road transport trajectories between the ship and the final destination).

Results of case 1 are summarized in Table 2. Results for both trajectories are not very different because general location, speeds and distances are similar. It is clear that both small and large ships had an environmental advantage (lower externalities) over trucks 10 years ago when only uncontrolled trucks were used. External costs of road haulage with newer trucks are 50% lower because of tighter emission standards and better fuel quality. Emissions of ships have not decreased at a similar rate. This evolution has eliminated most of the environmental advantages of inland ships in this specific case. Moreover, even more sophisticated trucks have already been introduced to the market (Euro3) or will become available in the near future (Euro4 and Euro5).

Table 2: Case 1. External environmental cost per tonne of waste transported

<table>
<thead>
<tr>
<th>Trajectories</th>
<th>EuroCent/ton waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>East</td>
</tr>
<tr>
<td>Small ship &quot;Kempenaar&quot;</td>
<td>9.8</td>
</tr>
<tr>
<td>Large ship &quot;Push Tug&quot;</td>
<td>5.2</td>
</tr>
<tr>
<td>Truck Pre-Euro1</td>
<td>20.8</td>
</tr>
<tr>
<td>Truck Euro2</td>
<td>8.7</td>
</tr>
<tr>
<td>Truck Euro2, Stop &amp; go traffic</td>
<td>- 19.96</td>
</tr>
</tbody>
</table>

Figure 1: External environmental costs in Eurocents/ton of different transport modes (case 1, western trajectory, allocation to modes, 2000-technology)
Paradoxically, one of the reasons for the weak performance of inland ships is the need for post haulage with trucks. In some cases (western trajectory) this final phase in the intermodal transport solution contributed significantly to the total environmental impact (figure 1) whereas on the other trajectory, where almost no additional transport is needed, the contribution of road transport in the intermodal scenario was insignificant.

![Graph showing environmental impact of Kempenaar and Rhine ship](attachment:image.png)

Figure 2: Gain in external environmental costs for “Kempenaar” and Large Rhine vessel (loading factor 50%) under the 4 defined technology scenarios, in euro/ktonne.km (euro 2000)
3.2 Case 2: long range transport of large single items

In the second case study emissions and external costs were estimated per kilo tonne transported over one kilometre (kt tonne km). This makes it possible to compare different modes and to take into account loading factors. Road transport was compared to two types of ships: “Kempenaar” (50 m, 600 tonne) and Large Rhine vessel (110 m, 3,000 tonne).

Compared to road transportation, long range transportation of large single items by inland shipping has a distinct advantage for fuel consumption, CO$_2$ and CO emissions. This advantage is less pronounced for HC emissions. For NO$_x$, PM and SO$_2$, emissions and impacts are generally lower for road transport.

The results for each of the four technology scenarios are plotted in Figure 2, distinguishing between the different pollutants. Only results for a 50% loaded Kempenaar (10 km/h) and Large Rhine vessel (14 km/h) compared to road transport (30 km/h) are shown here. Results are expressed as a gain in external environmental costs (in Euro per kt tonne km modal shift). Positive figures indicate an environmental advantage for inland ships, negative values indicate that emissions are lower for trucks.

Analysis of the gain in external environmental costs shows that the gain for inland shipping is most pronounced under the reference scenario (1990). The environmental advantage for inland shipping decreases when comparing future engine technologies for both modes of transportation. Comparing the CCR 1 technology for ships with euro 4 trucks (scenario 2007 CCR-1) clearly shows an overall environmental advantage for trucks. Much better results were found for ships loaded for about 70% (graphs not shown here). Gains could be up to 5 euro/kt tonne km under the reference scenario and 1 euro/kt tonne km under the 2007 CCR-2 scenario. For 50% loaded ships these gains were respectively 3.5 and 0.4 euro/kt tonne km.

4 Discussion

4.1 Exposure analysis

For 10 different sections on the studied waterways we calculated the impacts for the emission of 1 kg of each pollutant. PM has by far the highest external costs per tonne. Values between 50 and 100 Euro/kg were found for rivers and canals in rural areas of Flanders. A similar PM emission from a truck would have an impact between 100 and 200 Euro/kg [1] because rural road trajectories are often closer to (or even situated inside) population centres. Impacts from emissions on waterways that are close to a major city (Ghent, Antwerp or Liège) varied between 120-180 Euro/kg for most sections. Extreme values of 300 and 400 Euro/kg were found for two short sections very near to the city centres. Impacts from PM emitted in cities by trucks are estimated between 200 and 420 Euro/kg.
This illustrates that the local exposure of people along rivers and canals is somewhat lower than along roads. The resulting health impacts and external costs of ship emissions are therefore also lower than those of equivalent truck emissions. Due the small size of Belgium, a separate detailed analysis of each trajectory is needed to ascertain this conclusion.

4.2 Case 1

It was found that emissions and impacts from the inland shipping scenarios are not always lower when compared to all-road haulage with modern trucks. This is explained by the fact that European legislation has succeeded in lowering emission standards of trucks systematically over the last decade. Until now, no such stringent emission regulation exists for inland ships. Recent findings indicate that emissions of inland ships have remained at much the same level over the last decade, partly because of the slower turn-over of the fleet. For most pollutants, differences between different engine technologies are larger than differences between both transportation modes. Nevertheless we can demonstrate that, from an air pollution perspective, the current fleet of inland ships is not always an environmental friendly alternative to road transport.

The relatively poor performance of inland ships is mainly due to high emissions of PM to which, despite lower exposure, important health effects can be attributed. But it is also deteriorated by the need for extra transhipment and terminal road haulage. Emissions of locking in and out, docking and other manoeuvres as well as emissions of gantry cranes were neglected in this study which may therefore have underestimated emissions of the multimodal scenarios.

On the other hand, one of the main reasons of choosing for ships is increasing road congestion. In the last column of Table 2, we have calculated the external costs of air pollution when the entire road trajectory is congested (using very plausible average speeds of 10 km/h on the R1 section). Due to the low speed and high dynamics of the driving pattern in stop-and-go traffic, both fuel consumption and emissions are much higher than in normal traffic. In this case air pollution impacts of road transport are significantly higher than for shipping, even when the effect of extra trucks on the other vehicles (the formal definition of congestion externalities) are neglected. Given the high frequency of congestion in and around Antwerp, using inland ships to bypass the city may still be an environmentally sound alternative, even for short range transports.

4.3 Case 2

The findings of case 1 are confirmed by case 2. Moreover case 2 clearly shows that the implementation of phase 2 of the CCR emission standards for inland ships is needed to preserve environmental advantages of inland shipping over road haulage. Although, one has to be aware that potential advantages in the future will be much lower than under the 1990 scenario. Lower emissions of CO2 are the main benefit of inland ships in all scenarios. Conclusions therefore
depend heavily on which monetary value is chosen to rate CO₂ emissions. In principle this analysis is about which impacts are more important: the global effects of CO₂ or the local and regional impacts of PM and NOₓ.

Unfortunately the CCR emission standards do not apply to engines installed before 1 January 2003 nor to replacement engines (revised second-hand engines) installed before 31 December 2011.

Case 2 also showed that the loading factor of ships is an important parameter when analysing environmental impacts from inland shipping. A policy towards coordination of transport of large items and ordinary goods has to be stimulated.

4.4 Other environmental aspects

In both case-studies, we have only looked at emissions and impacts of exhaust gasses. It is important to stress that comparisons of other types of environmental impacts often turn out in favour of inland ships.

- External costs of noise are negligible (esp. for the trajectories studied here) but may be very high for trucks (e.g. 0.58 €/tonne.km CER/UIC, 2000[9]).
- External costs of emissions related to infrastructure, vehicle production and fuel production (LCA-costs) are lower for inland ships (Int Panis et al., 2000 [10]).
- External costs of congestion are very high for trucks but negligible for ships (De Borger & Proost, 1997)[11].

This is also confirmed in a recent overview of external costs for road, railway and waterway traffic by the European Union [12].

5 Conclusions

- Inland ships clearly need less energy and have much lower specific CO₂ and CO emissions than trucks.
- Emissions of other pollutants from ships are poorly known. Very few studies report PM and NOₓ emissions. There is an urgent need for real-life measurements. Available data suggests that ships currently operating in Europe have much higher emissions than modern trucks.
- Potentials benefits (to air quality) of a modal shift from road haulage to inland shipping have decreased significantly since 1990.
- Introducing phase 2 of the emission standards of the Central Commission for Rhine Shipping (CCR) is absolutely necessary to keep pace with emission reductions achieved by the road transport sector. The further drafting of emission standards for inland ships and fuels should be considered.
- Given the extremely low fleet turn-over rate of inland ships, retrofitting existing ships with SCR-convertors (NOₓ) or particle filters should be considered to achieve a broader compliance with CCR-standards.
Given the room available for improvement, their low fuel consumption, their low noise externalities and increasing road congestion, inland ships may overtake trucks again in the next decade. In the meantime, recent technology and well maintained engines are the best environmental choice in any mode.

Acknowledgement
This study was co-financed by the Belgian Federal Office for Scientific, Technical and Cultural Affairs (OSTC) in the ‘PODOII’ program (CP-67-431).

References