The relevance of non-road transport and mobile machinery in urban air quality management

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Abstract

Combustion engines of non-road transport and mobile machinery are often underestimated in urban air quality management. Contrary to road transport, there is little data for non-road activity at the urban level and tools for source appointments are less common. Through the necessity of nation emission ceiling (NEC) reports and the development of differentiated emission calculation models, more insight in the non-road sector was gained in recent years. These emission inventories highlight the importance of non-road transport and mobile machinery compared to road transport at the national level. The results for Germany show that the non-road sector is responsible for more than a quarter of NO_X and half of PM emissions today. Especially non-road diesel engines have high specific emission rates compared to road vehicles due to less strict regulations and long engine life.

A comparison of non-road sources at the urban level shows that ship engines can significantly contribute to NO_2 pollution at important waterways and ports. Train and aircraft emissions are not considerately high at urban hotspots. Mobile machinery usually contributes a minor but still relevant share to the urban background concentration. However, at local hotspots, such as large construction sites, the contribution can be significantly higher. For a medium sized construction site it was estimated that the PM_{10} contribution from engine exhaust can exceed that of a busy road, if average German machinery age is considered. Additionally, non-exhaust particles can have a high influence on local PM_{10} concentration. Mitigation actions can therefore focus on the local level to support compliance with PM_{10} air quality limits. A further overall reduction in concentrations should, however, also be considered due to the health risks through carcinogenic diesel exhausts. This, for instance, can be achieved by large retrofit programs or the introduction of new emission limits.

Introduction

Urban air quality measures today often focus on road transport, mostly neglecting the non-road sector. Various Studies have shown that combustion engines from non-road vehicles and machines are important emission sources. While many European countries have developed non-road-models for their national emission ceilings (NEC) reports, detailed source appointments for urban areas and local hot spots are rarely available. Local authorities therefore have no reliable basis for developing suitable measures.

Clean air plans in Germany show that already in source appointment analyses non-road transport and especially mobile machinery is rarely addressed. This may be partly due to the typical characterization of pollution hot-spots, since clean air plans often aim at medium and long term actions. While hotspots for road and non-road transport are usually easy to identify, e.g. main roads, ports, railway stations or airports, mobile machinery, such as construction equipment, tends to be operated more dynamic in place and time. Therefore, few attempts for air quality assessments in this sector have been made so far.

Commissioned by the German Federal Environment Agency (Umweltbundesamt), IFEU has developed the emission models TREMOD (transport emission model) for road and non-road transport and TREMOD-MM for mobile machinery. The non-road sector in TREMOD covers rail and air transport as well as inland waterway navigation while TREMOD-MM includes mobile machinery e.g. in the agricultural and construction sector. These models use highly differentiated data to calculate national fuel consumption and emissions. Therefore, much information has been gathered about the characterization of non-road fleets, their activity and

emission behaviour. Currently, IFEU works on a project to evaluate the impact which mobile machinery, especially in the construction industry, has on urban air quality.

In this paper, important non-road applications are analysed regarding their total and specific emission levels and their impact on urban pollution hotspots in Germany. Finally, an approach for an assessment of the impact of construction machinery on urban air quality and the effect of possible mitigation actions is presented.

National emission situation

Results from TREMOD and TREMOD-MM (IFEU 2009, 2010) show the relevance of the non-road sector in air quality management. In 2010 the non-road sector was responsible for about half of PM and about ¼ of NO_X emissions in transport (Figure 1). The fact that only 15 % of the fuel consumption is due to non-road engines indicates that their average emission rates are much higher than those of road vehicles. The main reason for this is the later introduction of an emission legislation in the non-road sector compared to road transport. For example, Euro 1 standards for cars have been introduced in 1992, while non-road engines have been regulated just since 1999. Also, some non-road engines still have comparable low emission limits, e.g. Inland waterway vessels which are currently regulated by EU stage 3A (year of manufacture 2009 or later). Without additional regulations for non-road engines, this trend is likely to increase in the future.

The highest contribution to non-road PM emissions is caused by mobile machinery, mainly diesel engines in the agricultural and construction sector. For NO_x, mobile machinery accounts for about 2/3 of non-road emissions. Inland waterway navigation is the second most important non-road sector, while rail transport in Germany is mostly electrified and thus accounts for a minor share of direct PM or NO_x emissions. Aircraft emissions are also rather low if only Landing and Take-off (LTO) emissions are considered, which, however, represent only about 10 % of total emissions. The major part of aircraft emissions is released in the upper troposphere and thus less important for air quality at ground level.

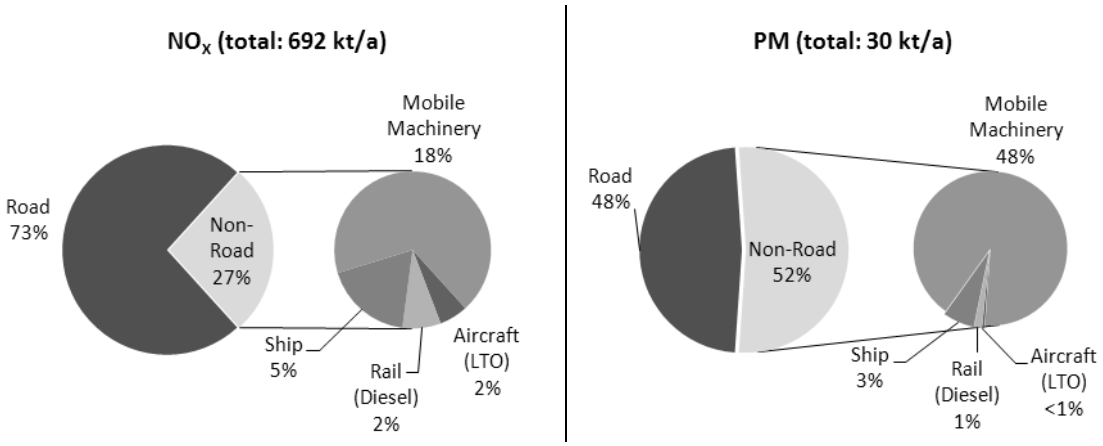


Figure 1 NO_X (left) and PM (right) emissions from road and non-road engines in Germany in 2010[1] (IFEU 2009, 2010)

Comparing national emissions and energy consumption of a certain machinery type, the specific emission rates of each sector can be roughly illustrated. This top down approach is a simple way to derive weighted emission factors that represent an average fleet/engine composition and activity, but depends very much on the quality of the national emission model.

Figure *2* shows that mobile machinery, ships and diesel trains have the highest energy consumption specific emission level. This is mainly due to less strict or later introduced engine emission standards. Also, emission standards before stage 3B represent engine testing in steady state test cycles, which can greatly differ from real world behaviour. Especially mobile

[1] Note: data for mobile machinery bases on an TREMOD-MM update in 2012 (not yet published)

machinery engines are often used at very dynamic conditions, resulting in high PM emissions, while e.g. ship engines often run at constant load.

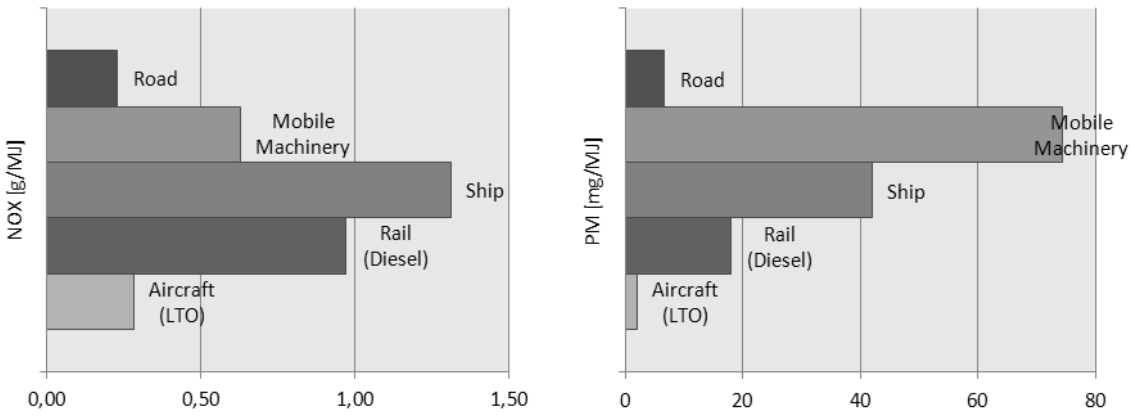


Figure 2 Average fuel consumption based emission factors for NOx (left) and PM (right)

Relevance of the non-road sector for urban air quality

Similar as for the national level, the emission relevance at urban hotspots is a product of specific emissions and source activity. Basically, some non-road sectors are more closely related to urban activity than others:

- Especially road transport and construction equipment play a role in most urban areas.
- Inland waterway navigation is concentrated to high frequented ports and waterways, aircraft to airports.
- Activity of sources fluctuates: passenger transport by road and rail dominates at rush hours; construction machinery in central Europe has a higher activity in warmer seasons than in winter.

Clean air plans for Duisburg and Düsseldorf found that ship emissions from the nearby Rhine River have a relevant share on PM_{10} (4 %) and NO_2 (11 %) urban background concentration (DGD 2004, 2008). NO_2 and PM_{10} measurements at Frankfurt airport, with almost half a million flights per year the biggest airport in Germany, show concentrations only slightly above urban background level and below the pollution level at road hotspots in Frankfurt city (FRAPORT 2011).

Some clean air plans show the influence of non-road mobile machinery on the urban background pollution. The NO_2 share is estimated in the range up to 6 %, PM_{10} up to 3 % (DGD 2008, John & Kuhlbusch 2004). The figures are based on emission data which is either locally deduced or allocated from national emissions. However, data is often not up to date and not further differentiated into the type of machinery, thus limiting the use of these analyses for action planning. Analysis for the impact of construction machinery on local hotspot air quality is rarely available from literature. Immission measurements near construction sites indicate that these can significantly contribute to local PM_{10} concentration, however more through non-exhaust resuspension processes than engine exhaust (Sen. Berlin 2011a, FRAPORT 2011).

Basing on the detailed and topical database from TREMOD-MM, IFEU elaborated an approach to estimate urban background and local hot spot pollution due to construction machinery as discussed in the following chapter.

Impact and mitigation potential assessment for construction machinery

Case study for this impact assessment is the city of Berlin, in the reference year 2009, for which various recent data in the context of the clean air plan 2011 have been available. Emissions of construction machinery were derived from the overall emissions in Germany as calculated by TREMOD-MM (IFEU 2009). The allocation for Berlin bases on the working hours in civil engineering and road construction, which were considered as especially machinery-intensive activities. Non-exhaust induced dust emissions were estimated on the construction site area from building completion. Activity data in terms of construction hours and building completion have been obtained by the GENISIS database of the German Federal Statistical Office (DESTATIS 2012).

The contribution to urban air pollution is based on literature data on emissions and immission contribution of road traffic. For this purpose, similar dispersion conditions have been assumed. Beside exhaust and non- exhaust, the PM_{10} and $PM_{2.5}$ concentration has been differentiated into direct particle emissions and secondary particles. The corresponding share on the PM concentration has been estimated based on source appointment analyses ([Pesch et al. 2008], [John & Kuhlbusch 2004], [IVU 2011]).

The presented values are preliminary results from an ongoing project. The final results may be different and will be documented in the final report for the German Federal Environment Agency (published in 2013).

The major emission sources for NO_X in Berlin are road exhaust (40 %) and industry (35 %), while for PM_{10} and $PM_{2,5}$ not specified 'other sources' are dominant (51 % and 42 %, respectively). Construction machinery contributes about 5 % to the urban NO_x, and around 6% to the particle emissions. While for PM_{10} from construction about half of the emissions are due to non-exhaust activities, $PM_{2,5}$ emissions are about 80% due to diesel engine exhaust.

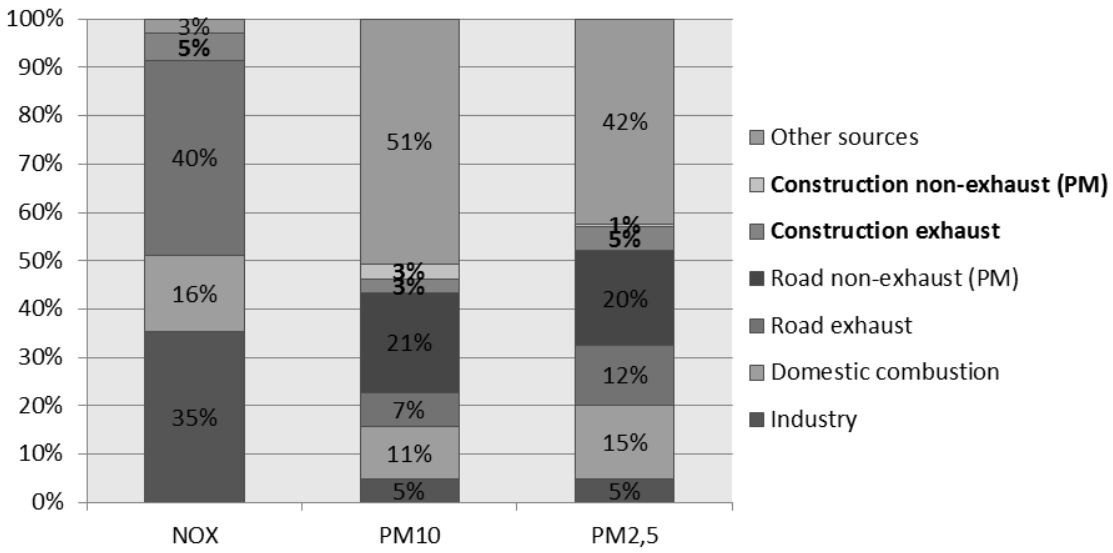


Figure 3: Annual Emissions in Berlin for 2009 based on (IVU 2011) and own assumptions

As for the emission shares, also the contribution of construction machinery to the urban background concentration is limited. About 60 % of the NO_2-background concentration is due to road traffic, while construction machinery makes a much smaller but still relevant contribution of about 8 %. On the other hand, about 80 % of the PM_{10} concentration in Berlin comes from emissions sources out of the city limits (long range transport). Construction machinery therefore contributes only about 2 % to the overall background concentration, which however, refers to 8 % of the PM_{10} concentration from urban sources (see Figure *4*). The contribution to the total $PM_{2,5}$-concentration is with approximately 4 % clearly higher and mainly caused by exhaust emissions. Construction activity, however, is higher in summer, while daily mean air quality limits are mostly exceed in winter (see Figure *4* right). Mitigation measures targeting construction machinery can thus only partly contribute to the extensive compliance with PM_{10} daily mean values.

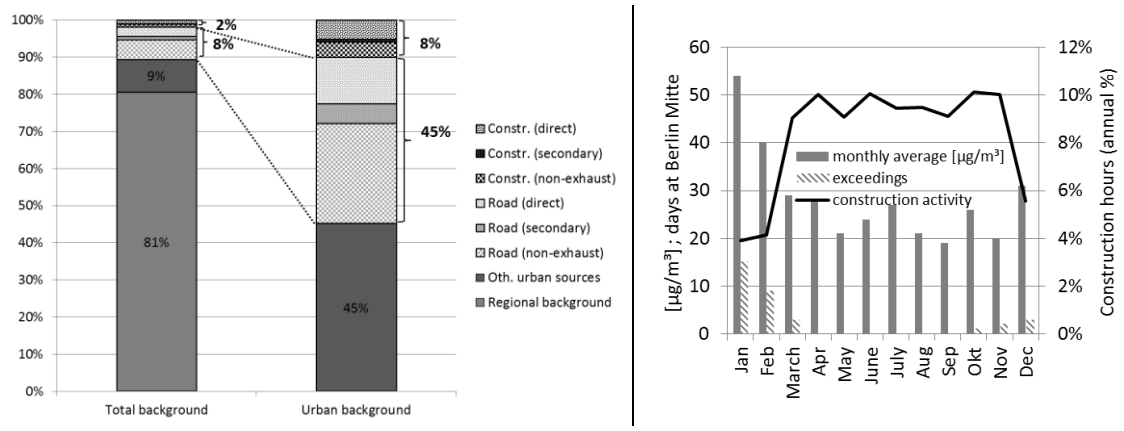
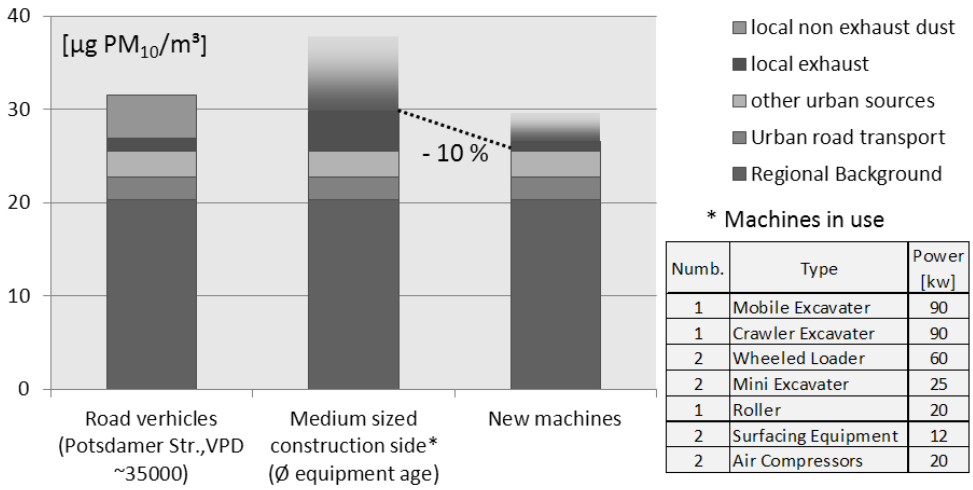


Figure 4: PM_{10}-background concentration in Berlin (left), Construction activity and PM_{10} daily mean limit exceeding at station ‚Berlin Mitte'. Sources: IFEU based on [IVU 2011], [DESTATIS 2012], [Sen. Berlin 2012b]

Locally and temporally, construction sites can make a considerable additional contribution of PM_{10} and thus also contribute to the exceeding of daily mean limit values (see Figure *5*). A medium sized construction site as exemplified can cause more than double the local share of the exhaust PM10-concentration compared to a busy street. These exhaust emissions should also be given special consideration since diesel exhaust has been classified as carcinogenic by the WHO ([WHO 2012]). A "clean" fleet of machinery (e.g. engines complying at least Stage 3B) could reduce this local pollution considerably (see Figure *5*). Non-exhaust generated PM_{10} from resuspension processes may have the major impact on the local concentration. This can however, also be reduced by measures e.g. speed limits on unpaved roads, earth moistening.



* Machines in use

Numb.	Type	Power [kw]
1	Mobile Excavater	90
1	Crawler Excavater	90
2	Wheeled Loader	60
2	Mini Excavater	25
1	Roller	20
2	Surfacing Equipment	12
2	Air Compressors	20

Figure 5: Exemplification of the influence of construction sites and potential mitigation measures on local PM_{10}-daily mean concentration. Source: IFEU based on [IVU 2011]

Mitigation potentials

The potential effect of selected mitigation measures has been calculated with TREMOD-MM. Emission scenarios show that PM emissions from construction machinery decrease considerably after 2014 due to the introduction of stage 3B. Small machinery, which is not at all (under 18 kW) or only weakly regulated (18-36 kW), will be responsible for the larger share of emissions in the future. The considered measurement scenarios for Germany should therefore address a regulation of such small machinery on the one hand but also a retrofitting of bigger, older machinery on the other hand. The scenarios are based on regulations, which are already implemented in the USA and Switzerland (see Table 1). The so 'called' OEM (original equipment manufacturer) option would mean higher for emission standards of new machines, while the retrofit option additionally demands higher standards for existing machinery, e.g. by

the use of diesel particulate filters (DPF). Latter was assumed to cause a 90 % reduction of particle mass emissions in the scenarios.

Table 1: Measurement examples and scenario definition for the EU and Germany

Year of Introduction	2008	2010	2013	2014	2015	2016	2017
OEM Option: Extension of emission standards for new engines similar to US-Standards							
Example: USA	<19 kW, MY≥2008*		19-37 kW, MY≥2013*				
Scenario: EU						<37 kW, MY≥2016	
Retrofit Option: DPF for new and existing engine similar to the Swiss Air quality directive							
Example: Switzerland		≥37 kW, MY≥2000 19-37 kW, MY≥2010			≥37 kW, MY<2000		
Scenario: Germany				>37 kW, MY≥2002 19-37 kW, MY≥2014			≥37 kW MY<2002
MY: Manufacture Year References: (BAFU 2010), (Dieselnet 2012)							IFEU 2012

Both scenarios lead to a considerable reduction in PM emissions from construction machinery. Retrofitting, however, leads to a much faster reduction in the emission level (see Figure *6*): Until 2020 about 10 kt of diesel particle emissions could be avoided with this scenario in Germany, while the introduction of new emission limits only shows marginal effects due to the slow turnover of the machinery fleet. Also until 2030, the retrofitting option avoids about twice as much particle emissions (20 kt) than the single introduction of new limit values for small machinery (about 10 kt). Nevertheless, the OEM option would address not only construction machinery, but also other sectors regulated by directive 97/68/EC. Thus also a great share of emission e.g. from agricultural and forestry machinery, which primarily operate outside urban areas, would be reduced.

If only a compliance with air quality limit values is aspired, local measures at pollution hotspots could prove more cost efficient than national regulations, since fewer machines are concerned. Furthermore, already existing ‘clean machinery’ can be mainly used in those areas.

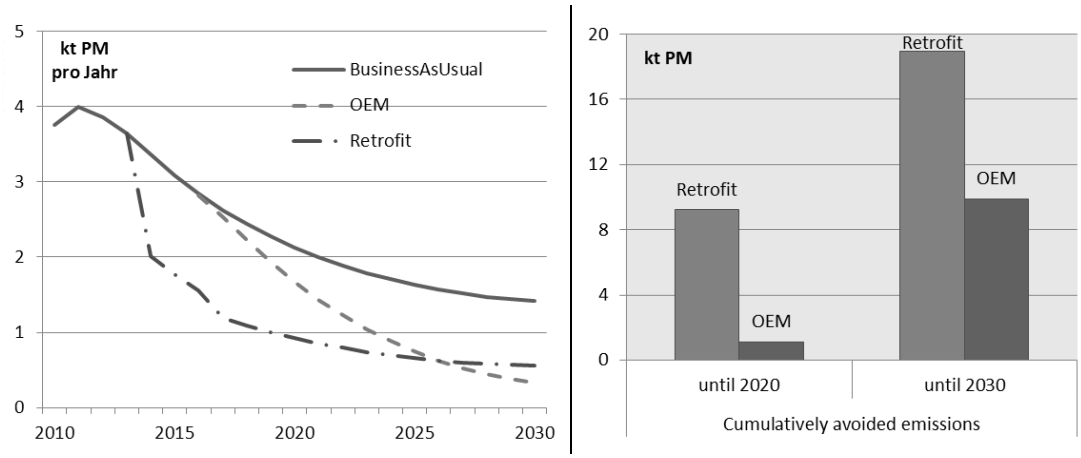


Figure 6: Development of annual diesel particle emissions from construction machinery in Germany (left), cumulated effect of the considered scenarios (right). Source: IFEU calculations based on TREMOD-MM (IFEU 2009)

Conclusions

The analysis shows that non-road transport and mobile machinery make a relevant contribution to national emissions in Germany and most probably also in other European countries. Therefore, non-road sources should be increasingly considered in clean air plans and urban air quality management. Especially construction machinery is relevant in urban hot spots, but so far often not adequately quantified.

A top down approach based on national emission models as presented here, using relevant allocation factors such as working hours in the construction sector, can be the basis for a good first assessment of urban emissions of mobile machinery. The assessment of the impact on urban air quality, however, is complex and has to deal with uncertainties. Especially the background concentration of particles is often dominated by long distance transport. Therefore the contribution of construction machinery to the background PM_{10} and $PM_{2,5}$ concentrations remains in the range of 2 and 4 % respectively. Locally, however, construction machinery can make a more relevant contribution, not only by dust resuspension, but also by diesel exhausts.

Possible actions can therefore focus on the local level if only a compliance with air quality limits is aimed for. Since diesel exhaust emissions have been classified as carcinogenic by the WHO, however, an overall reduction in concentrations appears to be necessary. This, for instance, can be achieved by large retrofit programs or the introduction of new emission limits. While retrofitting can lead to a comparably fast reduction in emission levels, new emission limits require more time to show an effect. Ideal seems to be combination of the two approaches.

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