Air pollutant emissions of combustion engines in Off-road equipment and machinery (The forgotten sector)

Methodology, data and results

Expert meeting on the Improvement of Transport Emission Inventories
19th October 2007, JRC Ispra, Italy

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IFEU - Institut für Energie- und Umweltforschung GmbH Heidelberg
IFEU Company Profile

**IFEU** = Institute for Energy and Environmental Research Heidelberg, since 1978
- Independent science
- organised as a private non profit company
- with about 40 scientists

**IFEU Topics**
- Transport and Environment
  - Life Cycle Assessment
  - Agriculture
  - Air pollution control
- Waste management
- Radioecology
- Energy

**IFEU Clients**: National and international associations, organisations and companies (e.g. World Bank, International Aluminium Association, Shell, Chevron-Sasol, European Commission, NGOs etc.)

**Software**:
- TREMOD
- Umberto
Overview

- Background
- Methodology
- Emission Factors
- Data on stock and activity
- Results
- Summary
Background: Situation in the Year 2000

- High contribution of the non-road-mobile machinery to emissions ($\text{NO}_x$, Particulates, NMVOC) and health impacts (e.g. studies from USA, Europe, Switzerland, Austria).

- Starting position:
  - No detailed analysis for Germany;
  - No (harmonised) data about stock, activity, emission-factors
  - No scenario calculation; influence of measures?

- Commonly used data (CORINAIR, "Handbuch" Switzerland):
  - not state-of-the-art (Guidebook February ´96)
  - methodology and data not compatible with new EU emission limits
What we did

- Calculation of
  - fuel consumption and exhaust emissions of several pollutants
  - of combustion engines in off-road equipment and machinery
  - in Germany 1980 – 2020

- Harmonised and transparent input-data => improve quality of data
  - Stock / Population of Engines/Machinery
  - Activity
  - Emission-Factors

- Developing a Microsoft Access based tool “TREMOD MM” (Mobile Machinery).
  - Considering the structure of actual emission regulation
  - Input-data are transparent, very detailed results
  - Future emissions can be calculated by using different scenarios.

- Workshops with Experts from Industry, Science, Administration
Considered mobile sources and machinery

### Internal Combustion Engines in:

<table>
<thead>
<tr>
<th>CORINAIR Nummer</th>
<th>CORINAIR Bezeichnung</th>
<th>IFEU Kategorie</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNAP 080100</td>
<td>Military</td>
<td>Militär</td>
</tr>
<tr>
<td>SNAP 0802xx</td>
<td>Railways</td>
<td>Eisenbahn: Private Hafen- und Werkbahnen</td>
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<tr>
<td>SNAP 0803xx</td>
<td>Inland Waterways</td>
<td>Binnenschifffahrt (ohne gewerblichen Güterverkehr)</td>
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<tr>
<td>SNAP 0806xx</td>
<td>Agriculture</td>
<td>Landwirtschaft</td>
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<td>SNAP 0807xx</td>
<td>Forestry</td>
<td>Forstwirtschaft</td>
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<tr>
<td>SNAP 0808xx</td>
<td>Industry</td>
<td>Bauwirtschaft und Industrie</td>
</tr>
<tr>
<td>SNAP 0809xx</td>
<td>Household and Gardening</td>
<td>Haushalt und Garten, Grünpflege</td>
</tr>
</tbody>
</table>

**Quelle:** [EMEP/CORINAIR 1996] IFEU 2003
Considered Emissions - Calculation of total emissions

\[ E = E_A + E_V + E_B \]

with:

- \( E \): Exhaust emissions
- \( E_A \): Direct exhaust pipe emissions
- \( E_V \): Evaporation emissions (only hydrocarbon)
- \( E_B \): Refueling emissions (only hydrocarbon)
Calculation of direct exhaust pipe emissions

Calculation via stock and activity:

\[ EO(t) = EFO(t) \times LF(t) \times P(t) \times Act(t) \times Stock(t) \]

- **EO(t)**: Emissions [t/a] of a pollutant for the basic year t
- **EFO(t)**: Emission-Factor [g/kWh] for the pollutant and fuel type for the basic year t (including deterioration and transient adjustment)
- **LF(t)**: Typical load factor \( \leq 1 \) for a category or subcategory for the basic year t
- **P(t)**: Average rated power [kW] of the considered engines for the basic year t
- **Act(t)**: Activity [hours/engine/year] for the basic year t
- **Stock(t)**: Stock of equipment and machinery
Example for Agricultural Tractor, Diesel < 37 kW

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Stock</th>
</tr>
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<tbody>
<tr>
<td>0-1</td>
<td></td>
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<tr>
<td>2-3</td>
<td></td>
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<tr>
<td>4-5</td>
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<td>6-7</td>
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<td>8-9</td>
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<tr>
<td>10-11</td>
<td></td>
</tr>
<tr>
<td>&gt;11</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity (hours/engine/year)</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>10-20</td>
</tr>
<tr>
<td>10-20</td>
<td>20-30</td>
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<td>20-30</td>
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<td>40-50</td>
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<tr>
<td>40-50</td>
<td>50-60</td>
</tr>
<tr>
<td>&gt;50</td>
<td>60-70</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Emission-Factor (g/kWh)</th>
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<tbody>
<tr>
<td>Stage 2</td>
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<tr>
<td>Stage 1</td>
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<tr>
<td>Before Stage 1</td>
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</tbody>
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Differentiation of Stock and Emission-Factors (1980 – 2020)
Derivation of *Emission-Factors* - Background

- **Basic data:**
  - Research Institute tests (FAT, Adlershof)
  - Studies (Switzerland, US-EPA, CARB….)
  - Certification data (KBA, CARB)
  - Industry tests (Euromot, Stihl)
  - Computer-Models (Switzerland, COPERT, NONROAD….)
  - Current measurements (Boat engines RWTÜV, Trains)

- **Derivation steps:**
  - Selection of data
  - Classification of engines/measurements (engine type, measurement date…)
  - Incorporation in electronic data base
  - Analysis following different criteria (technology, year, power…)
  - Derivation of average Emission-Factors
Differentiation of *Emission Factors*

- Power Categories (Based on EU legislation)
- Several emission standards (before 1980..... Stage 3)
- Emission-Factors are based on values in steady-state cycles

- Transient-Adjustment-Factors (TAFs)
- Deterioration Factors (DF)
Emission-Factors: Summary

- Collection and analysis of several hundred data sets
- Derivation of emission factors for
  - Diesel, Gasoline 2-stroke, Gasoline 4-stroke, LPG
  - Classes (kW-classes, SN, SH)
  - Fuel Consumption, NO\textsubscript{x}, PM, CO, HC, ....
  - Before 1990 ...... Stage III
- Review (Science, Industrie)
Equipment Population, Activity: Data sources

- **Equipment Population:**
  - Statistics (e.g. Agriculture, Construction)
  - Estimation based on “annual sales” and “equipment life time”
  - Other parameters (households, engines per household....)

- **Annual hours of use**
  - Database of sales; industry, estimations

- **Verification/Validation if possible**
  - Using different methods
  - Check with the fuel consumption of sector if possible.

- **In Germany:**
  - good Data for the Agriculture Sector, highly differentiated
  - Other sectors not as good data as Agriculture Sector.
Development of the tractor population in Agriculture

- Decrease of Tractor population with shift to higher power categories
Examples of construction machinery populations
Calculated Fuel Consumption – Agriculture Diesel Statistics

Abb. 1: Kraftstoffverbrauch in der Landwirtschaft und nach Gasölabrechnung (kt)
NO$_x$ and Particle Emissions in Agriculture
Off-Road: NO\textsubscript{x} and VOC Emissions in Germany 1980 - 2020
Particulates - Off-road and Road Transport – A comparison

Abb. 1: Gegenüberstellung Resultate TREMOD MM und Straßenverkehr - Partikel

IFEU 2003
Summary

- A database (emission factors, load factors, activity) for the off-road-sector has been developed.
- The Computer-Tool considers the structure of actual emission regulation and allows to calculate different scenarios.
- The level of calculated PM-Emissions from Mobile Machinery is comparable to Road Transport.
- Uncertainties in emission factors, load factor, stock, working hours....
- There is a need for harmonizing the data of Off Road Sector (NEC, PM10-Directive...) in Europe.
- Further efforts are necessary for defining default values for
  - Share of technologies
  - Age distribution
  - Load factors
  - Annual hours of use
Questions / To discuss

- How to improve the Off-Road-Inventories?
- What database (engine population, lifetime, load factors…) are available in different countries (or could be created)?
- Practical methodologies

=> “Rule of thumb method”s in questionable quality
- Which default values should be defined?
- Need of bulk emission factors (g/kg fuel)
- Harmonization of different approaches/emission factors

- Improvement of emission factors (transient cycles, deterioration factor, aftertreatment)
Thank you for your attention

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