

## Methodologies of Evaluation of the Greenhouse Gases Emission from Diesel Transport

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**Abstract** – Research some basis for national annual greenhouse gases (GHG) emissions evaluation for transport is national statistic data and expert evaluations. Quality and confidence of GHG inventory for transport through evaluation methodologies, preparation procedures and processing of data is confirm. Request at national GHG inventories which contain evaluation and analyses national data and expert evaluations for transport with main elements of IPCC and EEA methodologies are determined. The use approaches IPCC and EEA methodologies for evaluation for GHG inventory for transport are proposed. This paper covers in the development of some national evaluation methodologies for the direct GHG and precursor gases from different types of diesel transport (railways, inland waterways vessels, boats and watercrafts, etc). The GHG emission evaluation algorithms for transport according to IPCC 2006 and for developed national guides are proposed.

### I. Introduction

Transport is a major contributor to GHG emissions. The most important of these are emissions of carbon dioxide (CO<sub>2</sub>), and to a lesser extent nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>). The most significant conventional emissions from transport are of nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), Non-methane Volatile Organic Compounds (NMVOCs), lead and particulate matter. NO<sub>x</sub> contribute indirectly to the greenhouse effect and directly to acid rain and the build-up of tropospheric ozone. Emissions of NO<sub>x</sub> result from the fuels combustion (FC) under high pressure and temperatures in transport engines. The greatest volumes in absolute terms of GHG emissions from transport are of CO created through incomplete FC from engines.

The energy consumption by transport varies not only in absolute terms between different countries, but also by mode of diesel transport. While most transport GHG emissions originate from passenger and freight transport, emissions from off-road vehicles can also be significant. There are few data on emissions arising from transport. The alternative to using electricity is normally diesel fuel.

Parties of the UN Framework Convention on Climate Change (UNFCCC) can estimate GHG emissions and to develop annual national GHG inventories. Intergovernmental Panel on Climate Change (IPCC) developed guide IPCC 2006 [1] for assists in compiling complete national GHG inventories. These guides are intended for calculation and the reporting on GHG emissions, in particular from transport, but they demand improvement and the further development at a national level. Guides are based on the assumption that all carbon burned as fuels is emitted mostly as CO<sub>2</sub>, CO, CH<sub>4</sub>, and NMVOCs except for the unoxidized fraction which remains as ash or soot. CO and NMVOCs are eventually oxidized to CO<sub>2</sub> in the atmosphere.

### II. Emission estimation for diesel transport for national GHG inventories

All types of diesel transport emit CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O, as well as other pollutants such as CO, NMVOCs, and NO<sub>x</sub>. The inherently energy-efficient diesel engine has comparatively high NO<sub>x</sub> emissions. For diesel transport, one may apply either one of two main methodologies to calculate GHG and precursor gases emissions: fuel-based methodology or distance-based methodology.

In the fuel-based methodology, FC is multiplied by the GHG and precursor gases emission factor (EF) for each fuel type. This EF is developed based on the fuel's heat content, the fraction of carbon in the fuel that is oxidized, and the carbon content coefficient. Fuel-based methodology can be used also when vehicle activity data (AD) and fuel economy factors are available that enables calculation of FC. Fuel use data can be obtained from several different sources including fuel receipts, financial records on fuel expenditures, or direct measurements of fuel use [2].

When the amount of fuel is not known, it can be calculated based on distance travelled and an efficiency factor of fuel-per-distance. Fuel economy factors depend on the type, age, and operating practice of the vehicle. In the distance-based methodology, emissions can be calculated by using distance-based EF to calculate GHG and precursor gases emissions. Distance travelled data can basically come in three forms, distance (e.g., kilometres), passenger-distance (e.g., passenger-kilometres), or freight distance (e.g., ton-kilometres). Because the data on fuel are generally more reliable, the fuel-based methodology is the preferred approach for this tool. The distance-based methodology should only be used as a last resort as it can introduce considerably higher levels of uncertainty in the GHG and precursor gases emissions estimates [2].

The fuel-based methodology is the preferred mode for all modes. There are different methods available to convert fuel use data into GHG emissions. The recommended methodology is to convert fuel use data into an energy value using the heating value of the fuel and to multiply by the EF of the fuel. Deciding which methodology to take depends on data availability. The distance-based methodology can be used when vehicle AD is in the form of distance travelled but fuel economy data is not available.

There are three methodological options for estimating GHG emission from diesel transport. Those evaluation tiers methodologies are variations of the same general equation:

$$E_{T1} = \sum_j FC_j \cdot EF_j \text{ [Gg or kg]}, \quad (1)$$

where:  $j$  is fuel type;  $FC_j$  is FC for fuel type  $j$  [Mt or TJ];  $EF_j$  is EF for fuel type  $j$  [g/t or kg/TJ].

Emissions for Tier 1 are evaluation using fuel-specific default EF [kg/TJ] for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, assuming that for each fuel type the total fuel is consumed by a single transport type [1, 3].

Tier 2 for CO<sub>2</sub> again uses equation (1) with country specific data on the carbon content of the fuel. There is little or no advantage in going beyond Tier 2 for estimating CO<sub>2</sub> emissions.

Emissions for Tier 2 and CH<sub>4</sub>, and N<sub>2</sub>O are estimated using country-specific and fuel-specific EF which, if available, are specific to broad transport technology type:

$$E_{T2} = \left( \sum_i FC_i \cdot EF_{CH_4i} \right) + \left( \sum_i FC_i \cdot EF_{N_2O_i} \right) \text{ [kg]}, \quad (2)$$

where:  $i$  is diesel transport type;  $FC_i$  is FC by diesel transport type  $i$  [TJ];  $EF_{CH_4i}$ ,  $EF_{N_2O_i}$  are EF for CH<sub>4</sub> and N<sub>2</sub>O for diesel transport type  $i$  [kg/TJ] respectively.

National level FC data are needed for CO<sub>2</sub> emission estimating for Tier 1 and Tier 2 methodologies. For CH<sub>4</sub> and N<sub>2</sub>O emission estimating using Tier 2, diesel transport type level data is needed.

For Tier 3 methodologies require AD for operations (for example gross ton-kilometres and duty cycles) at specific diesel transport level. These methodologies also requires other transport-specific information, such as source population (with age and power ranges), mileage per train tonnage, annual hours of use and age dependent usage patterns, average rated horse power (with individual power distribution within given power ranges), load factor (LF), section information (such as terrain topography and train speeds).

To evaluation CH<sub>4</sub> and N<sub>2</sub>O emissions are encouraged to use country-specific EF for diesel transport, if available. If data are available for this method use more detailed modeling for each diesel transport type. Data needed includes the FC which can be further stratified according to typical journey and kilometers travelled by transport type. This data type may be collected for other purposes.

In next equation is a Tier 3 example for CH<sub>4</sub> and N<sub>2</sub>O, which is mainly based on the method for evaluation off-road emissions [4]:

$$E_{T3} = \left( \sum_i N \cdot H_i \cdot P_i \cdot LF_i \cdot EF_i \right) \text{ [Gg]} \quad (3)$$

where:  $i$  is diesel transport type;  $N$  is amount of each diesel transport type;  $H_i$  is annual hours of use of diesel transport type  $i$  [h];  $P_i$  is average rated power of diesel transport type  $i$  [kW];  $LF_i$  is typical LF of diesel transport type  $i$  (dimensionless between 0 and 1);  $EF_i$  is average EF for GHG and diesel transport type  $i$  [g/kWh].

The parameters  $H_i$ ,  $LF_i$  and  $EF_i$  may be further split by classification systems, such as  $H_i$  into age dependent usage pattern [3]. With regard to the typical  $LF_i$ , if possible, need apply the weighting factors provided in ISO 8178-4 [5]: 0.25 for 100 % torque at rated speed; 0.15 for 50 % torque at intermediate speed, and 0.6 for low idle conditions.

The default EF may for GHG be modified depending on the engine design parameters in accordance with next equation, using pollutant weighing EF for specific technologies [1]:

$$EF_{di} = PWF_i \cdot EF_{dd} \quad (4)$$

where:  $EF_{di}$  is engine specific EF for GHG and diesel transport type  $i$  [g/GJ];  $PWF_i$  is pollutant weighing factor (PWF) for diesel transport type  $i$  (dimensionless);  $EF_{dd}$  is default EF for diesel and GHG [g/GJ].

The PWF for diesel transport types are applies to CH<sub>4</sub> from 0.8 to 1.0 and to N<sub>2</sub>O – 1.0. To take into account the increase in CH<sub>4</sub> and N<sub>2</sub>O with the age, the default EF for CH<sub>4</sub> may be increased by 1.5 % per year while deterioration for N<sub>2</sub>O is negligible [1, 3].

For Tier 3 use of improved diesel with lower sulphur content contributes to reduced SO<sub>2</sub> emissions. IPCC manages IPCC Emission Factors Database (EFDB).

In [1–4] used SI and non-SI unites (for example lb, HP) which not recommended for using in international documents and guides. The International Committee of Weights and Measures (CIPM), recognizing that users would wish to employ the SI with units which are not part of it but are important and widely used, listed three categories of non-SI units: units to be maintained; to be tolerated temporarily; and to be avoided. Environmental guides (for example [1, 2]) used on international level, therefore must be prepared with employ preferably SI units [6].

The proposed general algorithm of GHG emission evaluation for diesel transport according to IPCC methodology [1] show on Figures 1 and give the Tiers 1–3 methodologies for choosing between them.

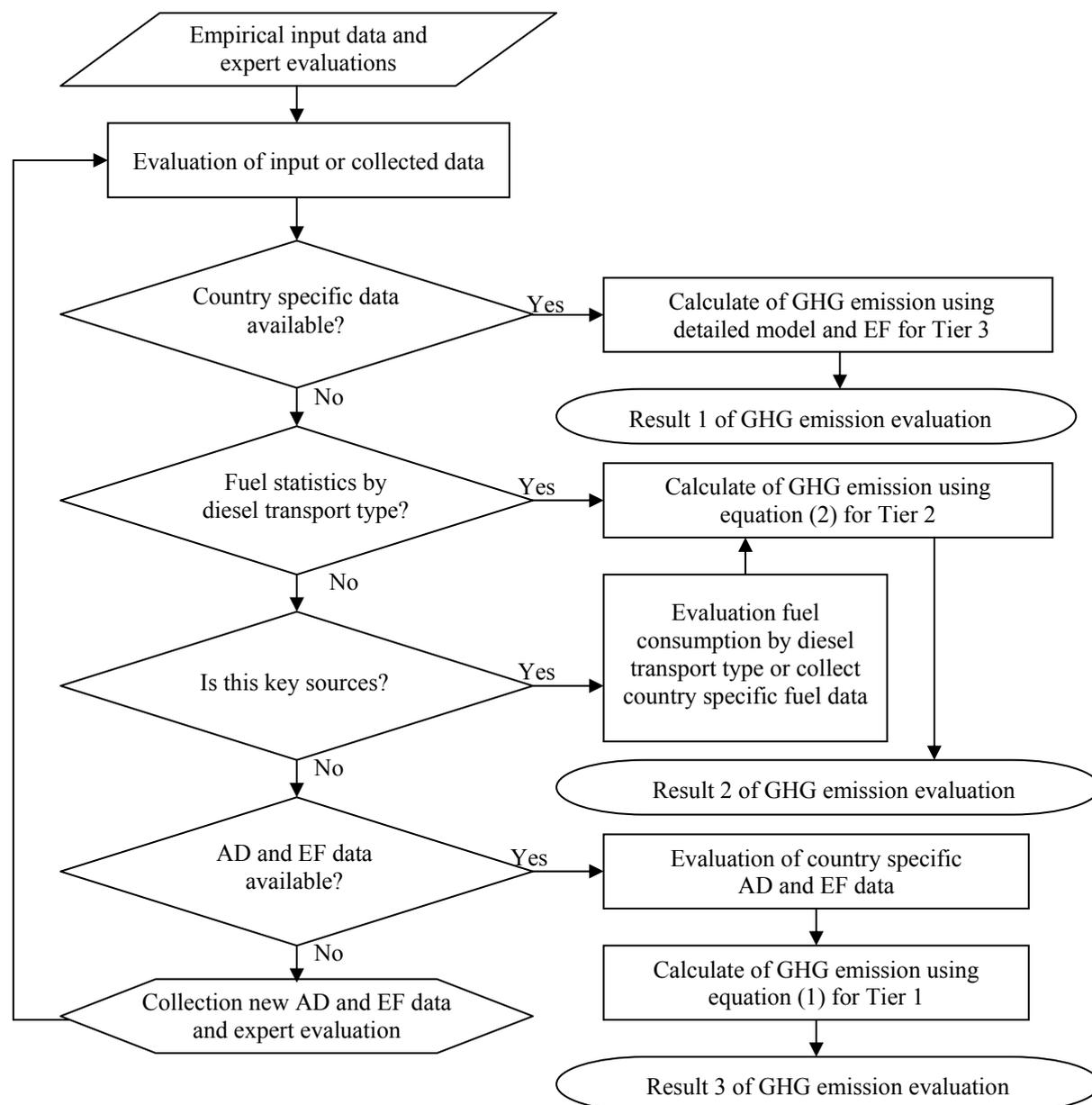


Figure 1 Algorithm GHG emission evaluation from diesel transport according to IPCC methodology

Uncertainties in calculating GHG emissions from diesel transport may result from several factors: incomplete or do not clearly indicate purchases of specific fuel types; conversion of fuel expenditure data to fuel quantity based on fuel price data; evaluation of distance traveled and/or fuel economy are roughly evaluation; EF are not customized to reflect actual conditions, etc. In general, use of the fuel-based methodology for produces less uncertainty than use of the distance-based methodology [1–3].

The general principle of uncertainty estimating and some practical numerical examples of estimations of uncertainties components for used environmental guides are provided in [1, 2] and papers [7, 8]. The practical numerical calculations of uncertainties components and total uncertainties for used national guides are provided in papers [8, 9]. To reduce uncertainty, a comprehensive approach is needed for both EF and AD. The use representative locally evaluated data is likely to improve accuracy although uncertainties may remain large.

### III. Emission evaluation for diesel transport for national guides

The special national guides of GHG emissions evaluation from the diesel transport which based on IPCC and EEA methodologies are developed in Ukraine [9]. Their methodologies include various methods of emissions evaluation from the main diesel transport type which exploitation in NIS countries.

The first methodology (M1) of national guides of GHG emissions evaluation is the fuel-based methodology and uses the general FC data and generalized EF. In this methodology calculation of emissions in atmosphere NO<sub>x</sub>, CO, CH<sub>4</sub>, CO<sub>2</sub>, NMVOCs and particulate matter is stipulated. At the account of SO<sub>2</sub> emissions data about FC and the contents in it sulfurs is apply. The M1 methodology is average for all types of engines and types of fuel and provides approximate enough calculations. Thus it is necessary to apply final data for AD and EF:

$$E_{M1i} = \sum_i (AD \cdot EF_i \cdot A_i) \text{ [g]}, \quad (5)$$

where:  $i$  is pollutant component (NO<sub>x</sub>, NMVOCs, CH, CO, SO<sub>2</sub>);  $AD$  is FC for fuel [kg];  $EF_i$  is average EF of pollutant component for diesel engine [g/kg];  $A_i$  is operating ratio of fuel (0,89);

The second methodology (M2) of national guides of GHG emissions evaluation is the fuel-based methodology and uses the elements of IPCC and EEA methodologies for AD and EF for diesel transport type:

$$E_{M2i} = \sum_{ij} (AD_j \cdot EF_{ij}) \text{ [g]}, \quad (6)$$

where:  $i$  is pollutant component (NO<sub>x</sub>, CH<sub>4</sub>, CO, CO<sub>2</sub>, NMVOCs);  $j$  is locomotive type;  $AD_j$  is FC for diesel transport type [t];  $EF_{ij}$  is EF for pollutant component  $i$  and diesel transport type  $j$  on unit of fuel [g/t].

The third methodology (M3) of national guides of GHG emissions evaluation is the distance-based methodology and uses distance travelled statistic data for freight and passenger transport, and average EF for pollutant components:

$$E_{M3i} = \sum_i (AD_f \cdot EF_f + AD_p \cdot EF_p) / 10^6 \text{ [t]}, \quad (7)$$

where:  $i$  is pollutant component (NO<sub>x</sub>, CO, C<sub>x</sub>H<sub>y</sub>);  $AD_f$ ,  $AD_p$  are distance travelled statistic data for freight transport (ton-kilometres) and passenger transport (passenger-kilometres) respectively;  $EF_f$ ,  $EF_p$  are EF for freight transport (g/ton-kilometres) and passenger transport (g/passenger-kilometres) respectively.

The fourth methodology (M4) of national guides of GHG emissions evaluation is the detail fuel-based methodology and uses a Tier 3 of IPCC methodology [1, 4] for NO<sub>x</sub>, CO, CH<sub>4</sub>, CO<sub>2</sub>, SO<sub>2</sub>, NMVOCs:

$$E_{M4i} = \sum_{ij} N_i \cdot H_i \cdot P_i \cdot LF_i \cdot EF_{ij} \text{ [g]} \quad (8)$$

where:  $i$  is diesel transport type;  $N_i$  is amount of diesel transport type  $i$ ;  $H_i$  is annual hours of use of diesel transport type  $i$  [h];  $P_i$  is average rated power of diesel transport type  $i$  [kW];  $LF_i$  is typical LF of diesel transport type  $i$  (dimensionless between 0 and 1);  $EF_{ij}$  is average EF for NO<sub>x</sub>, CO, CH<sub>4</sub>, CO<sub>2</sub>, SO<sub>2</sub>, NMVOCs respectively ( $j$ ) and diesel transport type  $i$  [g/kWh].

Amount of diesel transport type  $N_i$  classify on term of operation and power. Amount of annual working hours  $H_i$  define for each of diesel transport type depending on an individual operating mode and term of operation. The recommended typical  $LF_i$  makes 0.25 for nominal, 0.15 – for intermediate, 0.60 – for a mode of idling turns of diesel engine.

### IV. Particularity of main types of the diesel transport

In this paper particularity only of main types of the diesel transport are considered.

Railway locomotives generally are one of three main types: diesel, steam, and electric. The diesel locomotives (shunting locomotives, railcars, and line haul) generally use a diesel engine and an alternator or generator to produce the electricity required to power its traction motors. Steam locomotives are used for much localized operations, and correspondingly their contribution to GHG emissions is insignificant. Electric locomotives are used only electrical motors therefore their contribution to GHG emissions also is insignificant [1, 3].

Shunting diesel locomotives are equipped with diesel engines having a power output of about 200 to 2000 kW. Railcars are mainly used for short distance rail traction and equipped with a diesel engine having a power output of about 150 to 1000 kW. Line haul locomotives are used for long distance rail traction for freight and passenger,

and equipped with a diesel engine having a power output of about 400 to 4000 kW [3].

The railway companies may be able to provide FC data for the shunting locomotives. The contribution from shunting locomotives is likely to be very small for almost all countries. If the annual FC is not provided separately for shunting locomotives, it may be possible to estimate fuel use if typical data on their use and daily fuel use is available according to the following equation:

$$FC_{hl} = N_{hl} \cdot FC_{aid} \cdot DO_{aid} [t] \quad (9)$$

where:  $N_{hl}$  is number of shunting locomotives;  $FC_{aid}$  is average FC per locomotive and day [t] – default value of 863 litres per day can be used [4];  $DO_{aid}$  is average number of days of operation per locomotive in the year (usually 365).

The inland waterways vessels, boats and watercrafts (inland goods carrying vessels; sailing boats with auxiliary engines; motor boats/workboats, and personal watercrafts) generally use a diesel engine and 2- or 4-stroke petrol engine. Since not all vehicles/machinery listed above make use of all types of engines, the methodology can be concentrated on those engines mainly used. In [1, 3] provides an overview on the engine types taken into account. The diesel (D) is use for inland goods carrying vessels, sailing boats, and motor boats/workboats. The 2-stroke gasoline (2SG) is use for sailing boats, motor boats/workboats, and personal watercrafts; the 4-stroke gasoline (4SG) is use only for motor boats/workboats.

The inland goods carrying vessels are all equipped with slow diesel engines having a power output between 200 and 800 kW with an average of about 500 kW. For larger sailing boats mainly diesel engines are used having a power output between 5 and about 500 kW. The small engines used for small sailing boats have a power output between about 2 and 8 kW and are all 2-stroke petrol engines. Four stroke petrol engines with a power output between about 100 and 200 kW are also on offer but rarely used. The recreational motor boats/workboats with 2-stroke petrol engines have a power output between 1 and 200 kW. There are also 4-stroke engines on offer having a power output between 5 to 400 kW. The boats for inland passenger transport have a power output of about 20 to 400 kW and are all diesel engine equipped. The personal watercrafts are “moped” type crafts, all equipped with two stroke engines [3].

#### IV. Conclusions

Significant attentions are paid to questions concerning to developing detail methodologies for national level on base of two main methodologies of the GHG emission evaluation for diesel transport: fuel-based methodology or distance-based methodology. Basic positions concerning to GHG emission evaluation for diesel transport (railways, inland waterways vessels, boats and watercrafts, etc) on national level, shown in well-known international environmental guides for national GHG inventory, are considered. General algorithm of GHG emission evaluation for diesel transport according to IPCC methodology is proposed.

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