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Summary

This report presents the methodological and software revisions of COPERT 4 version 9.0, compared to version 8.1.

Keywords

COPERT, heavy metals, SCR, lube-oil, emissions

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Contents

1 Methodology....6

1.1 Increase in fuel consumption due to A/C use....6
1.2 CO_2 due to lubricant oil....10
1.3 CO_2 due to SCR....10
1.4 NO2/NOx mass ratio....12
1.5 Inclusion of ethanol as a fuel....12
1.6 Apparent fuel heavy metals content....13
1.7 Biodiesel O:C and H:C ratios....16

2 Software....21

2.1 Air-condition forms....21
2.2 Lube-oil form....23
2.3 Updated SCR usage form....24
2.4 Updated Total Emissions form....25
2.5 Updated Run Details form and table....26
2.6 Updated Reports....27
2.7 Updated Export Excel files....28
2.8 Updated CRF export....29
2.9 Bioethanol....29

3 Bugs fixed....31

3.1 Software Registration....31

4 Acknowledgments....32

5 References....33

1 Methodology

1.1 Increase in fuel consumption due to A/C use

Air conditioning (A/C) systems are now installed in almost 95% of all new passenger cars (Weilenman et al., 2010). Measurements have shown that a significant increase of the fuel consumption up to 40% (Weilenman et al. (2005), Weilenman et al. (2010)) can be attributed to the systematic use of A/C. Fuel consumption and CO_2 emissions of a mobile air conditioning for a given ambient temperature and a relative humidity can be now calculated in COPERT. The methodology implemented can be found in detail in Weilenman et al. (2010). The methodology is based on measurements conducted in both gasoline and diesel passenger cars and calculates extra CO_2 emissions in g/km. The equations used follow the model structure shown in Figure 1-1 for a given temperature and relative humidity.

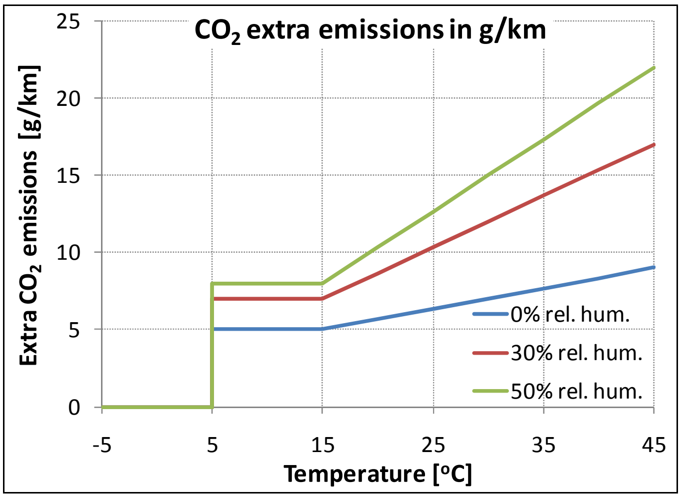


Figure 1-1: Proposed model structure

The original methodology by Weilenman et al. (2010) calculates CO_2 emissions and not additional fuel consumption. Hence, we also first calculate CO_2 emissions and then convert to fuel consumption which is added to the fuel consumption without the use of A/C. The following algorithm describes in detail the calculation method of the extra fuel consumption of mobile A/C for a given ambient temperature T (°C) and relative humidity H (%).

For a diesel vehicle we use the parameter “d”; for a gasoline vehicle we use the parameter “g”. “ee” stands for extra emissions. Default values for a, b and c parameters for gasoline and diesel vehicles can be found in Table 1-1 to Table 1-6.

Each time a high and a low value are calculated for the additional CO_2 emissions. At the end of the calculations the highest emission factor is selected, limited by a maximum set value (Table 1-7 and Table 1-8).

If T < 5° C then ee = 0.

If T > 5° C then

Calculation of efc_{low} as an interpolation between measured values at 20, 50 and 80% humidity:

If (H < 20%) then

ee_{low} = c20;

If (H >= 20%) and (H < 50%) then

ee_{low} = c20 + (c50 – c20)/30*(H – 20); (linear interpolation)

If (H >= 50%) then

ee_{low} = c50 + (c80 – c50)/30*(H – 50); (linear inter- or extrapolation)

Calculation of efc_{high} as follows:

ee_{high}20, ee_{high}50 and ee_{high}80 are first calculated for the given temperature:

ee_{high}20 = a20*T+ b20

ee_{high}50 = a50*T+ b50

ee_{high}80 = a80*T+ b80

Then, an interpolation is made for the humidity correction:

If H < 20% then

ee_{high} = ee_{high}20;

If (H >= 20%) and (H < 50%) then

ee_{high} = ee_{high} 20 + (ee_{high}50 – ee_{high}20)/30*(H – 20); (linear interpolation)

If H >= 50% then

ee_{high} = ee_{high}50 + (ee_{high}80 – ee_{high}50)/30*(H – 50); (linear inter- or extrapolation)

The higher of the ee_{low} or ee_{high} values is applied in the final calculation, limited by a maximum value (Table 1-7 and Table 1-8).

After estimating ee (extra CO2 emissions), the calculation of total fuel consumption increase for a particular vehicle type consisting of N vehicles in total, each running on average M km per year is done according to:

$$FC_{A/C} = 1/FUEL \times c_{A/C} \times N \times M \times t_{A/C} \times ee \qquad 1\text{-}1$$

where

$c_{A/C}$ is the fraction of vehicles of the particular type equipped with an A/C and $t_{A/C}$ the fraction of annual mileage that the A/C is in operation. The correction of 1/FUEL is done to correct CO_2 emissions to fuel consumption, using the conversion from fuel consumption to CO_2 emissions calculated in the model, depending on the fuel specifications. The $FC_{A/C}$ value is then added to the fuel consumption calculated using the fuel consumption factors of COPERT 4.

Table 1-1: Gasoline vehicle parameter a for CO2: aCO2g [g/km/°C]

Humidity	20%	50%	80%
Urban	1.230	2.690	4.300
Rural	0.482	0.989	1.562
Motorway	0.399	0.777	1.216

Table 1-2: Gasoline vehicle parameter b for CO2: bCO2g [g/km]

Humidity	20%	50%	80%
Urban	0.415	-17.207	-32.642
Rural	-3.700	-11.264	-18.926
Motorway	-5.435	-12.094	-19.423

Table 1-3: Gasoline vehicle parameter c for CO2: cCO2g [g/km]

Humidity	20%	50%	80%
Urban	27.694	30.492	46.675
Rural	3.721	4.097	6.271
Motorway	2.095	2.306	3.530

Table 1-4: Diesel vehicle parameter a for CO2: aCO2d [g/km/oC]

Humidity	20%	50%	80%
Urban	2.541	4.844	7.548
Rural	0.991	1.837	2.847
Motorway	0.609	1.122	1.736

Table 1-5: Diesel vehicle parameter b for CO2: bCO2d [g/km]

Humidity	20%	50%	80%
Urban	-40.818	-84.286	-133.550
Rural	-18.891	-36.342	-56.789
Motorway	-12.092	-22.905	-35.678

Table 1-6: Diesel vehicle parameter c for CO2: cCO2d [g/km]

Humidity	20%	50%	80%
Urban	8.285	9.123	13.964
Rural	2.764	3.043	4.659
Motorway	1.832	2.017	3.088

Table 1-7: Gasoline vehicle max value for CO2 [g/km]

Urban	Rural	Motorway
85.932	29.060	20.424

Table 1-8: Diesel vehicle max value for CO2 [g/km]

Urban	Rural	Motorway
96.353	35.626	21.956

Important Note

This methodology has been derived by conducting tests on cars with air-conditioning systems installed in the 2000's. New air-conditioning systems are expected to have higher efficiency thus reducing total fuel consumption and CO_2 emissions. Hence, the methodology presented in this report and included in COPERT to estimate additional fuel consumption and CO_2 emissions should correspond to the maximum impact of A/C use. It may be expected that the contribution on a per vehicle basis will gradually drop in time, as A/C systems become more fuel efficient. Therefore the methodology introduced here can only be used for historic and not future years.

For this reason, inclusion of the A/C impact on emissions is not automatically added in total fuel consumption but the user may select it or not.

It should be clarified that enabling A/C use does not affect CO_2 emissions reported to IPCC because these depend on the total statistical fuel consumption. However, enabling A/C means higher fuel consumption per kilometre driven which, by turn, means less total vkm to match the statistical fuel consumption. Hence, this will have an impact on the emission of other pollutants and not CO_2 officially reported.

1.2 CO_2 due to lubricant oil

A new emission factor has been included to calculate the additional CO_2 emissions from the consumption of lubricant oil in g/km.

New vehicles and properly maintained vehicles do not normally consume significant amounts of lubricant oil. However the use of a vehicle can usually increase this mainly due to worn parts around the cylinder, pistons and valves. Exception to this are 2 stroke engines where the lubricant is mixed with the fuel before consumed in the cylinder so lubricant oil consumption is to be expected.

Table 1-9 contains lubricant oil consumption factors for different vehicle types, fuel used and vehicle age. All values are in kg consumed per 10.000 km. The data was collected from various sources; Internet references but also interviews with vehicle maintenance experts from the following sectors:

- Technical service at municipal bus operator of Thessaloniki (604 Busses Euro III to Euro V)
- Five dealers with service centres for passenger cars
- Two independent service centres
- Interviews with taxi driver owners

In order to calculate how much CO_2 is emitted due to the lubricant oil consumption the same approach for the calculation of fuel-dependent CO_2 was used [1-2]. Instead of the fuel consumed one must use the lube oil consumption values displayed in the above table. By applying the equation the result will be CO2 emitted in kg per 10.000 km.

Hydrogen to carbon ratio ($r_{H:C}$) in lube oil is 2.08, while oxygen to carbon ratio ($r_{O:C}$) is 0.

Based on this procedure and the values in Table 1-9, CO_2 emission factors per vehicle type and technology have been calculated and are provided by default in the software. Better emission factors may be used, if such information is available.

When exporting to CRF, lube-oil related emissions are added to the fuel consumption related emissions. A special note about exporting lube-oil related CO_2 emissions is then added to the CRF file.

1.3 CO_2 due to SCR

CO_2 is produced when urea is consumed in vehicles equipped with SCR (selective catalytic reduction) aftertreatment systems. The source of CO_2 is independent to fuel consumption and it is derived by carbon included in the urea molecule. More detailed on the mechanisms is provided in the EMEP/EEA Emission Inventory Guidebook. In order to calculate emissions, one has to provide the share of Euro V and Euro VI trucks and Euro 6 cars equipped with SCR.

When exporting to CRF, SCR related CO2 emissions are added to total diesel emissions. A special note about exporting SCR related CO2 emissions is then added to the CRF file.

Table 1-9: Lubricant oil consumption for different vehicle types, fuel and age in kg/10.000 km

Category	Fuel/engine category	Age*	kg/10.000 km		
			Mean	Min	Max
PC	Gasoline	Old	1.45	0.85	2.13
		New	1.28	0.85	1.70
	Diesel	Old	1.49	0.85	2.13
		New	1.28	0.43	2.13
LDV	Gasoline	Old	1.45	0.85	2.13
		New	1.28	0.85	1.70
	Diesel	Old	1.49	0.85	2.13
		New	1.28	0.43	2.13
Urban Buses	Diesel	Old	8.50		
		New	0.85		
Coaches	Diesel	Old	1.91	1.70	2.13
		New	1.70	1.28	2.13
HDV	Diesel	Any	1.56		
Mopeds	2-stroke	Old	10.20	6.80	13.60
		New	6.80	5.10	8.50
Motorcycles	4-stroke	Any	0.43		0.85

* At or beyond useful life

$$E_{CO_2,k,m}^{CALC} = 44.011 \times \frac{FC_{k,m}^{CALC}}{12.011 + 1.008 r_{H:C,m} + 16.000 r_{O:C,m}} \quad 1\text{-}2$$

1.4 NO2/NOx mass ratio

The NO_2/NOx ratios have been completed for some vehicle technologies for which no values were available in the older COPERT 4 versions. These are shown in Table 1-10. The diesel Euro 5 values are slightly lower than Euro 4 ones, by using the assumption that DPFs produce less NO_2 than oxidation catalysts in Euro 4s. It is also assumed that some NO_2 is consumed while oxidizing particles thus leading to overall lower emissions. More measurements are necessary to validate the exact NO_2/NOx ratio. For Euro 6 diesel cars it has been assumed that some of them will be equipped with SCR systems which further reduce NO_2 emissions. Hence, an additional reduction is assumed on average. For all LPG, CNG and motorcycle vehicles, a constant value of 4% has been assumed as no significant differentiation over gasoline vehicles is expected.

1.5 Inclusion of ethanol as a fuel

(Bio)ethanol is used in blends with petrol in spark-ignition vehicles. Blends up to 10% E10 are readily available and can be used by normal spark-ignition vehicles. Higher blends (up to E85) can be only used in specially designed vehicles. Version 9 of COPERT introduced bioethanol as an available fuel in order to be taken into account in the total energy balance, together with normal petrol. Bioethanol is considered to be consumed by all spark-ignition vehicles when refuelled. No particular bioethanol vehicle technology has been introduced. However, when CO_2 emissions to IPCC are reported through the CRF file, then the following distinctions are made:

1. CO_2 emissions reported for petrol vehicles only correspond to the statistical fuel consumption of fossil petrol.

2. CO2 emissions of bioethanol are separately reported – as a sum to biodiesel emissions – as biomass related emissions. These are only used as memo items and are not included in the total

3. Total emissions of CH_4 and N_2O from petrol vehicles are calculated using the Tier 3 method in COPERT 4. Then, when exporting to CRF, total CH_4 and N_2O emissions allocated to petrol fuel and bioethanol respectively, are calculated according to:

    a. $CH_{4,\ petrol} = CH_{4,\ COPERT4} \times PETROL_{STATISTICAL} / (PETROL_{STATISTICAL} + BIOET_{STATISTICAL})$

    b. $CH_{4,\ BIOET} = CH_{4,\ COPERT4} \times BIOET_{STATISTICAL} / (PETROL_{STATISTICAL} + BIOET_{STATISTICAL})$

    c. $N_2O_{,\ petrol} = N_2O_{,\ COPERT4} \times PETROL_{STATISTICAL} / (PETROL_{STATISTICAL} + BIOET_{STATISTICAL})$

    d. $N_2O_{,\ BIOET} = N_2O_{,\ COPERT4} \times BIOET_{STATISTICAL} / (PETROL_{STATISTICAL} + BIOET_{STATISTICAL})$

4. The bioethanol emissions of CH_4 and N_2O are added in the biomass related emissions together with the biodiesel ones. These are taken into account in the total balance, i.e. they are NOT just a memo item.

Table 1-10: NO2/NOx ratios for vehicle technologies that no ratio was available in Copert 8.1

Sector	Subsector	Technology	NO2/NOx primary mass ratio (%)
Passenger Cars	Diesel <2,0 l	PC Euro 5 - EC 715/2007	40
Passenger Cars	Diesel <2,0 l	PC Euro 6 - EC 715/2007	30
Passenger Cars	Diesel >2,0 l	PC Euro 5 - EC 715/2007	40
Passenger Cars	Diesel >2,0 l	PC Euro 6 - EC 715/2007	30
Light Duty Vehicles	Diesel <3,5 t	LD Euro 5 - 2008 Standards	40
Light Duty Vehicles	Diesel <3,5 t	LD Euro 6	30
Buses	Urban CNG Buses	HD Euro I - 91/542/EEC Stage I	4
Buses	Urban CNG Buses	HD Euro II - 91/542/EEC Stage II	4
Buses	Urban CNG Buses	HD Euro III - 2000 Standards	4
Buses	Urban CNG Buses	EEV	4
Mopeds	<50 cm³	Conventional	4
Mopeds	<50 cm³	Mop - Euro I	4
Mopeds	<50 cm³	Mop - Euro II	4
Mopeds	<50 cm³	Mop - Euro III	4
Motorcycles	2-stroke >50 cm³	Conventional	4
Motorcycles	2-stroke >50 cm³	Mot - Euro I	4
Motorcycles	2-stroke >50 cm³	Mot - Euro II	4
Motorcycles	2-stroke >50 cm³	Mot - Euro III	4
Motorcycles	4-stroke <250 cm³	Conventional	4
Motorcycles	4-stroke <250 cm³	Mot - Euro I	4
Motorcycles	4-stroke <250 cm³	Mot - Euro II	4
Motorcycles	4-stroke <250 cm³	Mot - Euro III	4
Motorcycles	4-stroke 250 - 750 cm³	Conventional	4
Motorcycles	4-stroke 250 - 750 cm³	Mot - Euro I	4
Motorcycles	4-stroke 250 - 750 cm³	Mot - Euro II	4
Motorcycles	4-stroke 250 - 750 cm³	Mot - Euro III	4
Motorcycles	4-stroke >750 cm³	Conventional	4
Motorcycles	4-stroke >750 cm³	Mot - Euro I	4
Motorcycles	4-stroke >750 cm³	Mot - Euro II	4
Motorcycles	4-stroke >750 cm³	Mot - Euro III	4

1.6 Apparent fuel heavy metals content

Introduction

Combustion in road vehicles is not a major source of metals, as automotive fuels are refined compared to bunker fuels. However, lube oil derived metals and metals from engine wear may be additional sources of the total metal content in vehicles' exhaust. These are not due to fuel combustion. The best method to assess vehicle exhaust metal emissions is to collect particulate matter (PM) samples and analyze the metal content of these samples. In this way, all three exhaust metal sources (fuel, lube oil, engine wear) are taken into account. However, there are several disadvantages of this method. First, the low metal quantity in PM makes it difficult to determine their exact content. Second, the method is too much specific on the particular vehicle, fuel and lube oil combination. A reliable picture may only be obtained if a large number of combinations are sampled. However, this is cumbersome and expensive and there are no dedicated studies that have determined metal emissions from a large number of cars. The third issue is that the sampling system that is used to collect PM (pipes, lines, holders, etc.) may be contaminated from previous measurements. As only traces of metal PM are necessary to change their measurement level, sampling system contamination may compromise the reliability of the measurement.

As a result, fuel and lube oil chemical analysis is sometimes conducted to specify their content in metals. This may then be converted to exhaust concentration by assuming a fuel consumption rate. This method has the advantage of being conducted under well-defined conditions, it allows for a selection of fuel and lube oil, and is generally less prone to detection limit issues. On the other hand, uncertainties arise when trying to convert results in actual vehicle exhaust emissions. The lube oil consumption is largely an unknown. Therefore, it is difficult to estimate how much lube oil contributes to total exhaust emissions. Moreover some lube oil metals are not emitted but are bound on the engine walls and deposited on the engine. Finally, this method fails to characterize how much metal is emitted due to engine component wear.

Therefore, the determination of metal emission rates in vehicle exhausts is a procedure associated with large uncertainties. Measurements from alternative literature sources have been collected in this report, based on both exhaust PM analysis and fuel and lube analysis. The objective is to compare these values with any alternative or additional measurement sources available, in order to provide guidance for the calculation of metal emissions from road vehicles.

Metal emissions

The UNECE HM protocol lists the following metals as being interesting from and AQ point of view: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn. Emission rates for these metals have been summarized in Table 1-12 for diesel vehicles and Table 1-13 for gasoline vehicles. It has not been possible to further distinguish diesel into heavy duty or light duty, although this is indeed expected to have an impact on emission rates. These two tables quote the literature source, the range of the emission measurement and the units by which results have been expressed (column 'Original'). In order to develop a consistent dataset, all values have been expressed to equivalent concentration in fuel (ppb). The conversion factors are given below each literature source. Expressing metal emissions as equivalent fuel content is convenient: these can then be directly multiplied with fuel consumption factors and calculate emissions at various scales (vehicle, urban inventory, national inventory, etc.). It is repeated that this is not the fuel content in the particular metals but the equivalent fuel content or 'apparent' fuel content, i.e. taking into account lube oil and engine wear emissions as part of the fuel consumption.

The average of all measurements, together with the min and max values are also given in both tables per metal species. The range is typically very wide. Therefore, for diesel vehicles, an additional row calculates the average if the min and the max values are excluded (w/o outliers).

This is not exclusion of outliers in a statistical sense, but rather simplified procedure to eliminate extremes. This was not possible to perform for gasoline vehicles due to the small number of measurements.

Table 1-14 provides values of fuel and lube oil content in metals. Finally, Table 1-15 provides the main sources of these metals in engine exhaust. Cd, Hg, As, and Se are not metals for which a definitive source may be found. They are rather contaminants of the fuel and lube oil. Ni, Cr, and Pb are metals which mainly originate from attrition of engine components. Cu originates from engine component wear and is also used as a lube oil additive. Finally, Zn is the most widespread anti-wear additive used in lube oil. With this information and comparison of Table 1-14 results with Table 1-12 and Table 1-13, one is in the position to assess the main contributing mechanism for all of these metals.

Observations

- The range of values reported in the literature per species extends over several orders of magnitude. This makes conclusions to be highly uncertain.

- The role of lube oil is important regarding the total metal emissions in the exhaust. It appears that additives may or may not be used. This leads to a very wide range of lube oil contribution in total metal emissions.

- The composite fuel and lube oil content in heavy metals is much lower than the apparent fuel content resulting from exhaust PM measurements for various metals (Ni, Cr, Pb, Cu, Cd). Engine wear must be a significant source of emissions for the particular vehicles.

Synthesis

Several rounds of discussions have taken please and the emission factors of heavy metals have been presented in the ERMES consortium and the TFEIP Transport Expert Panel. The lack of reliable information has been identified in all studies as a major limiting factor in updating the COPERT emission factors. However, some of the so far used COPERT emission factors were also found quite unrealistic, so it has been decided that a revision is necessary, despite the uncertainty. Table 1-16 demonstrates a synthesis of four different estimation methods. These values refer to the apparent fuel metal content (in pbb) assuming that all HM emissions can be attributed to fuel consumption. This is the current approach in COPERT as well.

- Method 1: “Diesel/Gasoline plus 0,1% lube oil” refers to fuel content which should be equivalent to fuel (Table 1-12 for diesel and Table 1-13 for gasoline) and lube oil, assuming lube oil consumption equal to 0.1% of fuel consumption. This should be at the low end because no emissions due to engine component attrition are considered in this case.

- Method 2: “Diesel/Gasoline exhaust analysis” shows the mean emission of studies collecting PM in the vehicle exhaust and analyzing this. This should include all HM sources however detailed fuel or lube oil analysis is not available most of the times.

- Method 3: “COPERT” refers to apparent fuel metal content factors that have been used in COPERT so far (i.e. up to COPERT 4 v8.1).

- Method 4: “Danish Inventory” refers to the apparent fuel metal content values which can be derived by the work conducted by Winther and Slentø (2010), related to the calculation of metals in the Danish territory.

Based on this comparison, and due to the consistent character of the Danish inventory values, it was decided to use Method 4 to estimate HM emissions in COPERT 4. They are generally found within the ranges of values determined by Method 1 and 2. The only prominent exception is Zn, for which the Danish inventory comes with higher values than what found in the literature. However, they are still within the same order of magnitude of values of Method 1. The final values selected are shown in Table 1-11. In the same table we have estimated HM emission factors for CNG and LPG cars, assuming they are only derived from lube oil and engine attrition. These are derived from the gasoline apparent fuel metal content factors subtracting the actual HM content in gasoline found in Table 1-14.

Table 1-11: Final HM apparent fuel content factors

Metal	Gasoline (ppb)	Diesel (ppb)	CNG and LPG (ppb)
Cd	10.8	8.7	10.6
Hg	8.7	5.3	0.0
Pb*	33.2	52.1	31.6
As	0.3	0.1	0.0
Cr	15.9	30	9.3
Cu	41.8	21.2	37.3
Ni	13	8.8	10.7
Se	0.2	0.1	0.0
Zn	2164	1738	2130

By using the new method over the old one, one should expect the following changes in the inventory:

- Addition of Hg and As, that were not estimated before†
- Significant reductions in Cr, Cu, Ni, Se that can reach up to 99%
- An increase in the emissions of Zinc

An additional, minor change has been also introduced compared to older COPERT 4 versions. Specifically, up to COPERT 4 v8.1, the apparent fuel lead content factor was multiplied with 0.75 to produce total emissions, as it was assumed that part of the lead was accumulated on the engine subsystems. Since the new apparent fuel metal factors have been derived on the basis of exhaust analysis, this correction is not anymore necessary for unleaded fuelled vehicles. However, we have still kept this correction for leaded fuel vehicles.

1.7 Biodiesel O:C and H:C ratios

The default O:C, H:C ratios for biodiesel have changed to 0.11 and 1.94, respectively, assuming a typical biodiesel ester molecule containing 18 C atoms, 2 O atoms, and one double bond.

* Density correction has been taken into account to convert ppb to mg/l in COPERT 4.

† Due to technical reasons, As and Hg have not yet implemented in v9.0 of COPERT 4. Experts may use directly the values proposed in this report when reporting emissions. These values will be implemented in a subsequent version of the software.

Table 1-12: Studies on heavy metal content in diesel vehicle exhaust

DIESEL Exhaust Source	Cd		Hg		Pb		As		Cr		Cu		Ni		Se		Zn	
	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb
Cheung et al. 2010	5.23, 5.53	0.1			18 ng/km	0.36			240 ng/km	4.8	BDL		160 ng/km	5.2			7000 ng/km	140
(0,05 kg fuel/km)	ng/km				240 ng/km	4.8			340 ng/km	6.8			200 ng/km	4			22000 ng/km	440
Al-Swaidan 1994	0,01 ug/g	10																
Wang et al. 2003		214			41 ug/m3	820			88,6 ug/m3	1772	55,4 ug/m3	1108	51 ug/m3	1020			111 ug/m3	2220
20 m3 exh./kg	10,7 ug/m3																	
Sternbeck et al.2002		6			37 ug/km	740					150 ug/km	3000					200 ug/km	4000
(0,05 kg fuel/km)	0,3 ug/km										170 ug/km	3400						
Hu et al. 2009	40 ng/km	0.8							300 ng/km	6	700 ng/km	14	200 ng/km	4			100 ug/km	2000
(0,05 kg fuel/km)	300 ng/km	6							3000 ng/km	60	2000 ng/km	40	800 ng/km	16			300 ug/km	6000
Vouitsis et al. 2007	18 ug/km	360			2,2 ug/km	44			3,4 ug/km	68	2,5 ug/km	50	2,3 ug/km	46	1,1 ug/km	22	4,2 ug/km	84
(0,05 kg fuel/km)	69 ug/km	1380			10,2 ug/km	204			38 ug/km	760	17,9 ug/km	358	17,3 ug/km	346	12,1 ug/km	242	69 ug/km	1380
Geller et al. 2006									90 ng/km	1.8	600 ng/km	12	650 ng/km	13			5,6 ug/km	112
(0,05 kg fuel/km)									600 ng/km	12	2000 ng/km	40	2300 ng/km	46			21 ug/km	420
Lim et al. 2007							0,004 ppm	4	0,005 ppm	5	0,09 ppm	90	0,04 ppm	40			0,14 ppm	140
							0,010 ppm	10	0,02 ppm	20								
Grieshop et al. 2006					19 ug/kg	19	5 ug/kg	5			100 ug/kg	100					70 ug/kg	70
					45 ug/kg	45					209 ug/kg	209					2100 ug/kg	2100
Schauer et al. 1999	0,06 % PM	370			0,01 % PM	62			0,01 % PM	62	0,01 % PM	62			BDL		0,07 % PM	432
(185 mg PM/km, 0,3 kg fuel/km)																		
Weber et al. 2000	43 ng/m3	0.86	0,3 ng/m3	0.006	1 ng/m3	0.02	0,1 ng/m3	0.002	7 ng/m3	0.14	5 ng/m3	0.1	6 ng/m3	0.12	0,1 ng/m3	0.002	8 ng/m3	0.16
20 m3/kg f, 0,05kg f/km																		
Won et al. 2007			3 ng/km	0.06														
(0,05 kg f/km)			8 ng/km	0.16														
Mean with outliers		235		0.075		194		5		214		606		140		88		1303
Min		0.1		0.006		0.02		0.002		0.14		0.1		0.12		0.002		0.16
Max		1380		0.16		820		10		1772		3400		1020		242		6000
Mean w/o min-max values		121				140		4.5		91.5		424		58				1041

Table 1-13: Studies on heavy metal content in gasoline vehicle exhaust

GASOLINE Exhaust Source	Cd		Hg		Pb		As		Cr		Cu		Ni		Se		Zn	
	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb	Original	ppb
Cheung et al. 2010	2,7 ng/km	0.054			28 ng/km	0.56			46 ng/km	0.92	700 ng/km	14	160 ng/km	3.2			2 ug/km	40
(0,05 kg fuel/km)																		
Al-Swaidan 1994	0.085 ug/g fuel	85																
Geller et al. 2006									9 ng/km	0.18	16 ng/km	0.32	20 ng/km	0.4			200 ng/km	4
(0,05 kg fuel/km)									140 ng/km	2.8	1700 ng/km	34	100 ng/km	2			4600 ng/km	92
Sternbeck et al.2002											150 ug/km	3000						
(0,05 kg fuel/km)											170 ug/km	3400						
Weber et al. 2000	0,4 ng/m3	0.005	0,3 ng/m3	0.00375	3 ng/m3	0.0375	2 ng/m3	0.025	35 ng/m3	0.4375	22 ng/m3	0.275	40 ng/m3	0.5	2 ng/m3	0.025	39 ng/m3	0.49
12,5 m3/kg f																		
Won et al. 2007			4 ng/m3	0.08														
(0,05 kg f/km)			17 ng/m3	0.34														
Mean with outliers		28.4		0.1		0.3		0.0		1.1		1074.8		1.5		0.0		34.1
Min		0.005		0.00375		0.0375		0.025		0.18		0.275		0.4		0.025		0.4875
Max		85		0.34		0.56		0.025		2.8		3400		3.2		0.025		92

Table 1-14: Heavy metals content in fuels and lube oil

FUEL Source	Cd Original	Cd ppb	Hg Original	Hg ppb	Pb Original	Pb ppb	As Original	As ppb	Cr Original	Cr ppb	Cu Original	Cu ppb	Ni Original	Ni ppb	Se Original	Se ppb	Zn Original	Zn ppb
Denier Van Der gon & Kuenen 2009 (mg / kg fuel) DIESEL	0,05 µg/kg	0.05	5,3 µg/kg	5.3	0,5 µg/kg	0.5	0,1 µg/kg	0.1	8,5 µg/kg	8.5	5,7 µg/kg	5.7	0,2 µg/kg	0.2	0,1 µg/kg	0.1	18 µg/kg	18
Denier Van Der gon & Kuenen 2009 (mg / kg fuel) GASOLINE	0,2 µg/kg	0.2	8,7 µg/kg	8.7	1,6 µg/kg	1.6	0,3 µg/kg	0.3	6,3 µg/kg	6.3	4,5 µg/kg	4.5	2,3 µg/kg	2.3	0,2 µg/kg	0.2	33 µg/kg	33

LUBE OIL Source	Cd Original	Cd ppb	Hg Original	Hg ppb	Pb Original	Pb ppb	As Original	As ppb	Cr Original	Cr ppb	Cu Original	Cu ppb	Ni Original	Ni ppb	Se Original	Se ppb	Zn Original	Zn ppb
Vouitsis et al. 2007											41 ppm	41000					900 ppm	900000
Lim et al. 2007	0,034 ppm	34			1 ppm	1000	0,014 ppm	14	0,051 ppm	51	0,04 ppm	40	0,09 ppm	90			950 ppm	950000
Hu et al. 2009					<1 ppm				<1 ppm		<1 ppm		<1 ppm				1440 ppm	1440000
Oil Analysers 2006 (gasoline)					15 mg/kg oil	15000			4,5 mg/kg oil	4500	17,5 mg/kg oil	17500	5 mg/kg oil	5000				
Oil Analysers 2006 (diesel)					30 mg/kg oil	30000			12,5 mg/kg oil	12500	9 mg/kg oil	9000	5 mg/kg oil	5000				
Neptune 2006 (gasoline)																	1000 mg/kg oil	1000000
Neptune 2006 (diesel)																	1000 mg/kg oil	1000000
Castrol 2006 (gasoline)																	1000 mg/kg oil	1000000
Castrol 2006 (diesel)																	1000 mg/kg oil	1000000
Shell 2006 (gasoline)	5 mg/kg oil	5000																
Shell 2006 (diesel)	5 mg/kg oil	5000																
Mean Lube Oil		3344.67				15333.3		14		5683.6667		16885		3363.33				1041429

Table 1-15: Main vehicle exhaust sources of heavy metals

Source	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Merkel et al. (2001), http://www.kittiwake.com/ 5_2_additives.htm, http://www.polarislabs1.com/ metals.php			Main and Rod Bearings, Bushings, Lead Solder		Engine wear, Manifold wear, Rings, Liners, Exhaust Valves, Shaft Plating, Stainless Steel Alloy	Engine wear, additive for catalytic activity, Lube Coolers, Main and Rod Bearings, Bushings, Turbo Bearings, Lube Additive	Manifold wear, Valve Plating, Steel Alloy from Crankshaft, Camshaft		Anti-wear lube oil additivelube oil additive (ZDTP, ZDDP)

Table 1-16: Synthesis table

Estimation Method (All in ppb)	Cd	Hg	Pb	As	Cr	Cu	Ni	Se	Zn
Diesel plus 0,1% Lube Oil	3.39		15.8	0.11	14.2	22.6	3.6		1059
Diesel Exhaust Analysis	235	0	194	5	214	606	140	88	1303
COPERT 4 Diesel	10.0				50	1700	70.0	10.0	1000
Danish Inventory	8.7	5.3	52.1	0.1	30.0	21.2	8.8	0.1	1738
Gasoline plus 0,1% Lube Oil	3.54		16.9	0.31	12.0	21.4	5.7		1074
Gasoline Exhaust Analysis	28.4	0.1	0.3	0.0	1.1	1075	1.5	0.0	34.1
COPERT 4 Gasoline	10.0				50	1700	70	10.0	1000
Danish Inventory	10.8	8.7	33.2	0.3	16	42	13	0.2	2163

2 Software

2.1 Air-condition forms

New forms were added for the emission calculations due to the use of air-condition.

In 'A/C Usage' form (Figure 2-1) under the 'Advanced' menu, the parameters on A/C usage have to be added. First one needs to estimate the number of vehicles equipped with an air-conditioning system (Vehicles equipped with A/C(%)). Some 'default' values are proposed which are rough estimates only. More detailed data on a per country level have to be sought for by national experts. In general, the number of passenger cars equipped with an A/C increases for late models. One also needs to estimate the A/C usage (Usage(%)), as a percentage fraction of the annual vehicle mileage. For simplicity, one single usage factor is proposed regardless of urban, rural, or highway driving. This usage factor is uniformly applied to all driving conditions. Moreover, this usage factor is an average value over the year, i.e. there is no seasonal differentiation.

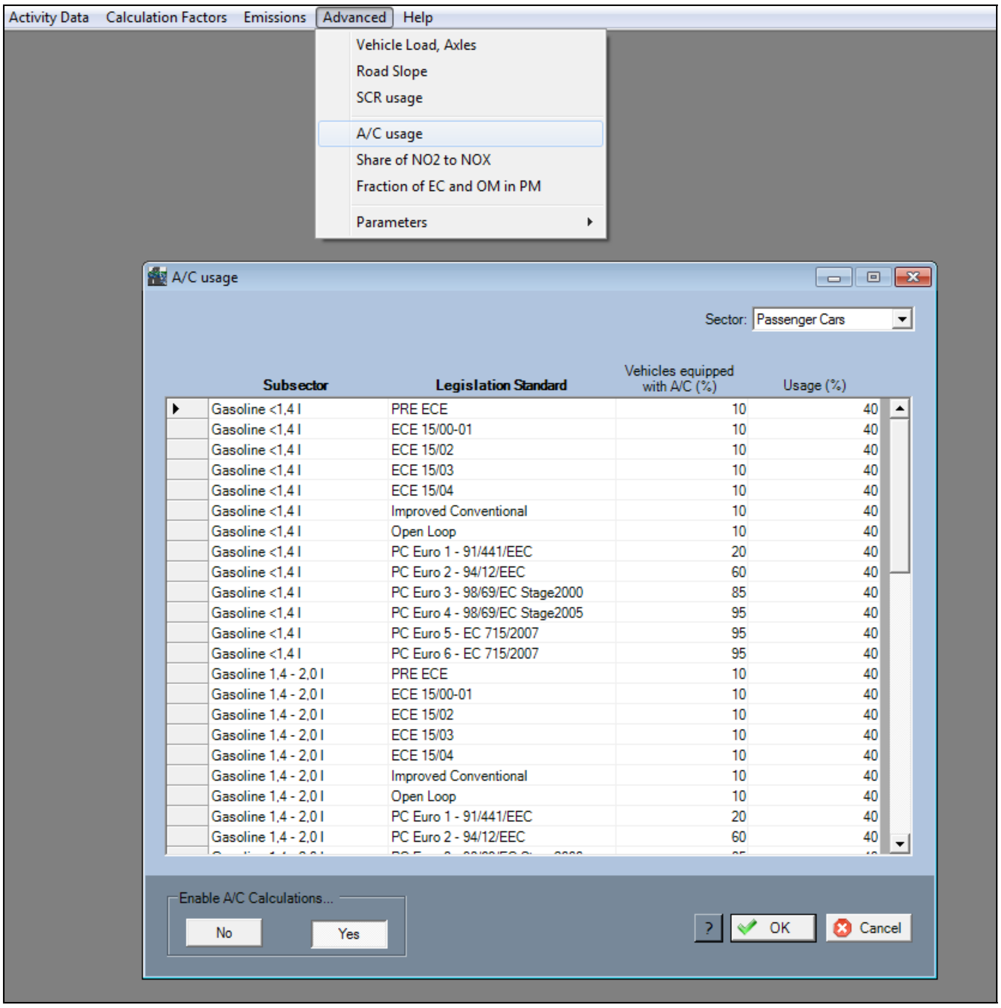


Figure 2-1: 'A/C usage' form

The A/C fuel consumption factors appear in the 'Fuel consumption increase factors due to A/C operation' form (Figure 2-2) under the 'Calculation Factors' menu (this form is enabled only when the user presses "Yes" on the 'A/C' usage form). These are multiplied with the annual mileage per mode (urban, rural, highway), the usage factor and the number of vehicles equipped with A/C per technology, to calculate total the fuel consumption increase. Own emission factors may be preserved by selecting the Keep check box for any vehicle technology and month. The "Recalculate A/C Factors" button executes the modules to calculate the A/C factors in case the user has made changes during the session. One can view the factors for each sector through the Sector drop-down list.

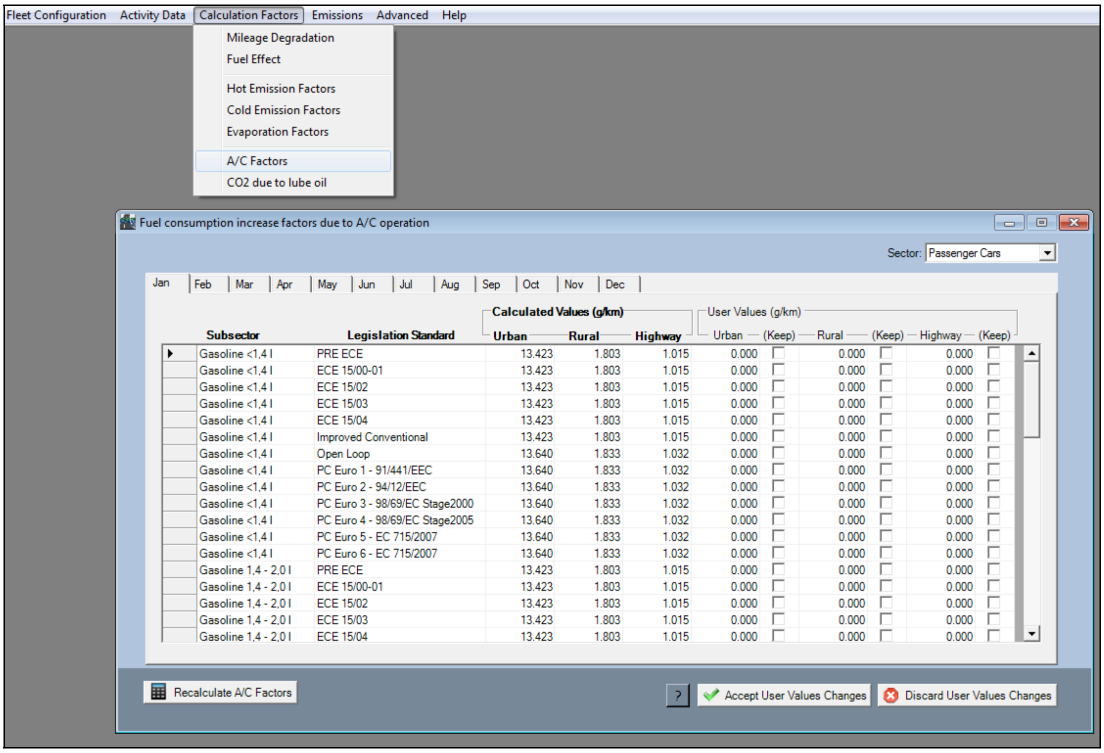


Figure 2-2: 'Fuel consumption increase factors due to A/C operation' form

Also relative humidity per month is required to calculate the load of an air-conditioning (A/C) unit. A high value denotes high humidity and a higher load for the A/C that increases consumption. RH in % can be added in the 'Country info' form (Figure 2-3) under the 'Country' menu.

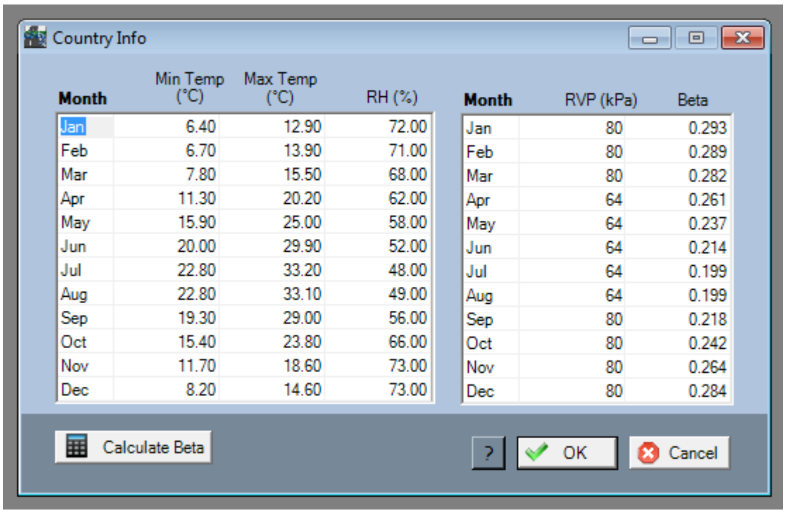


Figure 2-3: RH (%) in 'Country Info' form

2.2 Lube-oil form

A new form was added for the emission calculations due to lube-oil.

In 'CO2 Emission Factors due to lube-oil' form (Figure 2-4) under the 'Calculation Factors' menu, the CO2 factors due to lube-oil appear. Lubricant oil is used in engines to reduce friction and to cool down specific components. Lube oil enters the combustion chamber and is oxidized during combustion, before it is exhausted to the atmosphere. The hydrocarbon composition of lube oil means that it unintentionally contributes to the CO2 emissions without taking part to the energy consumption of road transport. The only exception is two-stroke engines where the lube-oil is intentionally delivered to the cylinder and part of the lube oil could be used to deliver some energy to the engine (especially in older two-stroke engines). Emission factors of CO2 due to lube oil consumption per vehicle technology are provided in this form, which are based on typical lube-oil consumption factors for different vehicle types. These emission factors can be used "as is" unless there are better estimates. The user may also select whether lube oil consumption will be estimated in the total CO2 emissions or not (Add CO2 Emissions due to lube-oil (Yes/No)). Own emission factors may be preserved by selecting the ‘Keep’ check box for any vehicle technology. One can view the factors for each sector through the Sector drop-down list.

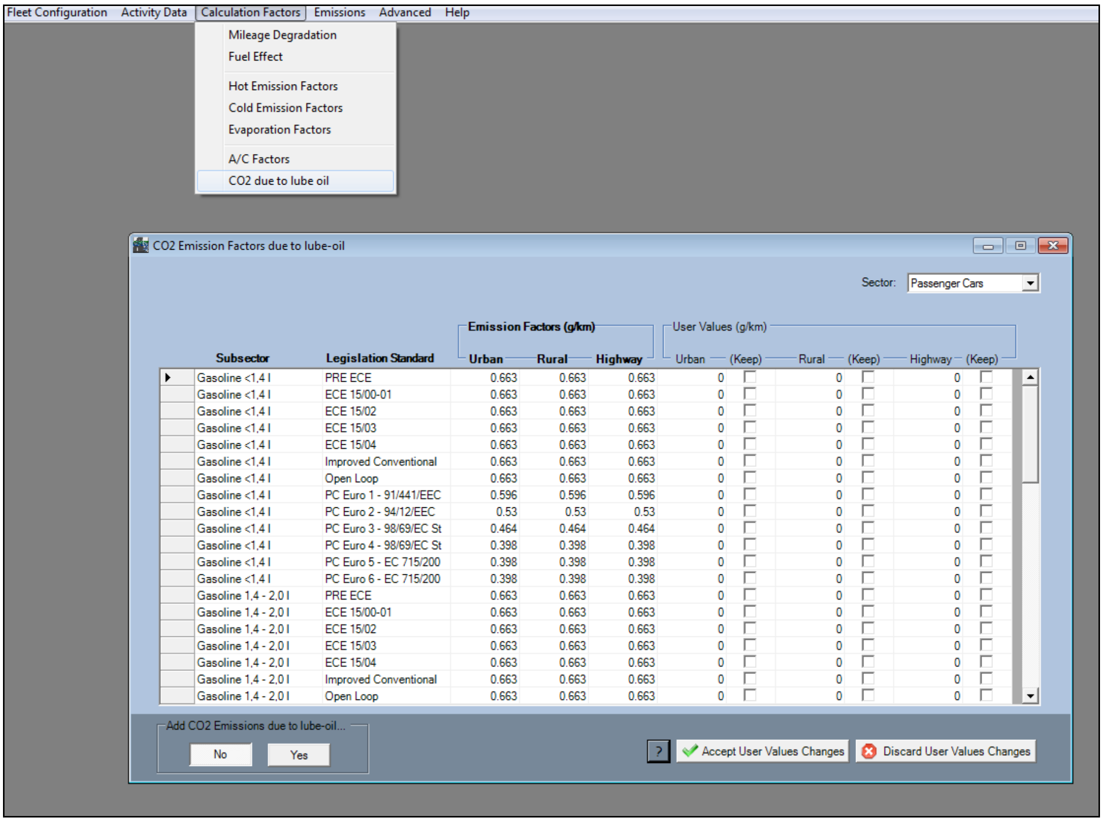


Figure 2-4: 'CO2 Emission Factors due to lube-oil' form

2.3 Updated SCR usage form

The 'EGR, SCR for Euro V' form (v8.1) is now changed to 'SCR usage' (Figure 2-5) and is also used to calculate CO2 emissions due to the SCR methodology.

An additional column is now provided in the new form"UC as a % of FC (%)"where the user has to introduce the urea consumption rate, as a percentage of the fuel consumption rate. This is only used to estimate the CO2 emissions produced by the consumption of urea. While urea is consumed, it liberates some CO2, which is independent of the CO2 produced due to the combustion of the fuel. This adds to the total greenhouse gas emissions of the vehicle. Some default values for urea consumption, as a percentage of fuel consumption, have been already filled in to guide the user. These are based on market figures and consultation with the automotive industry. They can be changed if better information is available.

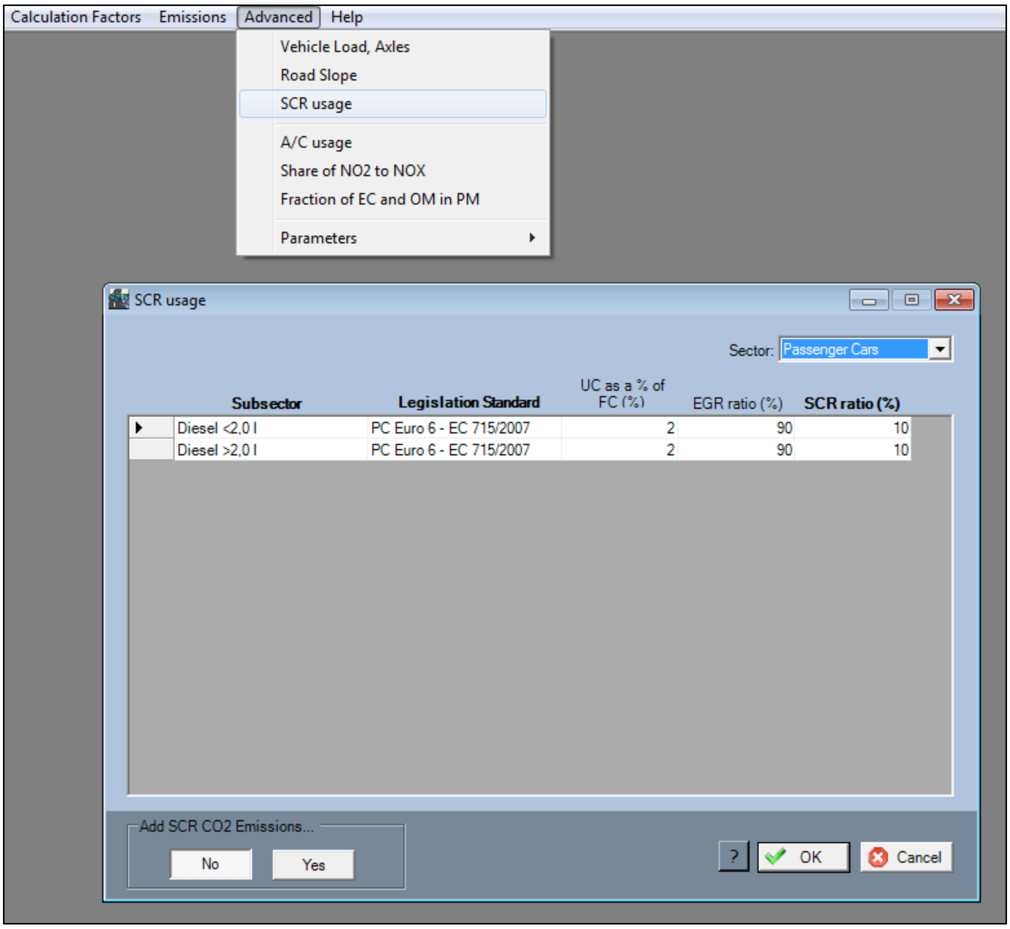
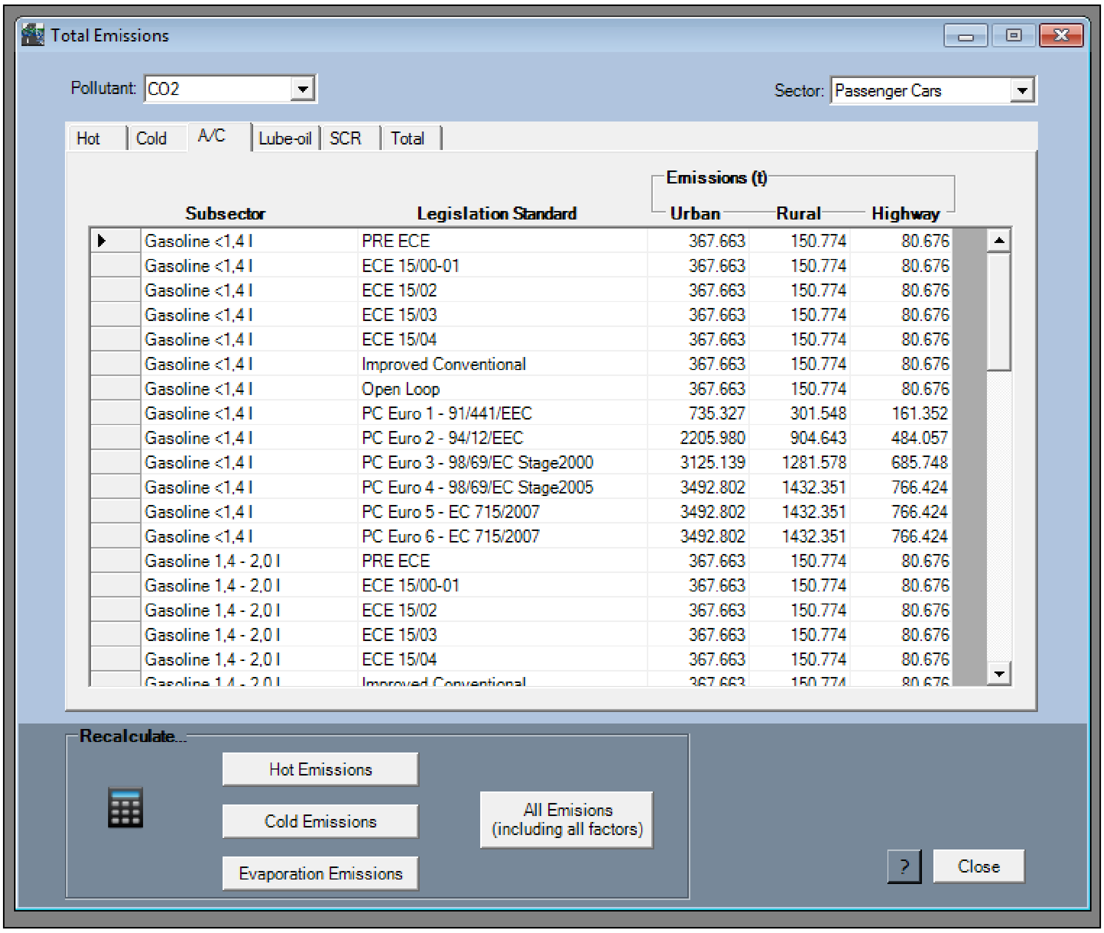


Figure 2-5: Updated 'SCR usage' form

2.4 Updated Total Emissions form

When the user selects FC, CO2, SO2 and heavy metals the relevant tabs of A/C, Lube-oil and SCR emissions appear (Figure 2-6).



Subsector	Legislation Standard	Urban	Rural	Highway
Gasoline <1,4 l	PRE ECE	367.663	150.774	80.676
Gasoline <1,4 l	ECE 15/00-01	367.663	150.774	80.676
Gasoline <1,4 l	ECE 15/02	367.663	150.774	80.676
Gasoline <1,4 l	ECE 15/03	367.663	150.774	80.676
Gasoline <1,4 l	ECE 15/04	367.663	150.774	80.676
Gasoline <1,4 l	Improved Conventional	367.663	150.774	80.676
Gasoline <1,4 l	Open Loop	367.663	150.774	80.676
Gasoline <1,4 l	PC Euro 1 - 91/441/EEC	735.327	301.548	161.352
Gasoline <1,4 l	PC Euro 2 - 94/12/EEC	2205.980	904.643	484.057
Gasoline <1,4 l	PC Euro 3 - 98/69/EC Stage2000	3125.139	1281.578	685.748
Gasoline <1,4 l	PC Euro 4 - 98/69/EC Stage2005	3492.802	1432.351	766.424
Gasoline <1,4 l	PC Euro 5 - EC 715/2007	3492.802	1432.351	766.424
Gasoline <1,4 l	PC Euro 6 - EC 715/2007	3492.802	1432.351	766.424
Gasoline 1,4 - 2,0 l	PRE ECE	367.663	150.774	80.676
Gasoline 1,4 - 2,0 l	ECE 15/00-01	367.663	150.774	80.676
Gasoline 1,4 - 2,0 l	ECE 15/02	367.663	150.774	80.676
Gasoline 1,4 - 2,0 l	ECE 15/03	367.663	150.774	80.676
Gasoline 1,4 - 2,0 l	ECE 15/04	367.663	150.774	80.676
Gasoline 1,4 - 2,0 l	Improved Conventional	367.663	150.774	80.676

Figure 2-6: Updated 'Total Emissions' form

2.5 Updated Run Details form and table

The 'View All Run Details' form (Figure 2-7) and table (Figure 2-8) now include the A/C, Lube-oil and SCR labels indicating if the user has enabled the corresponding calculations for every run.

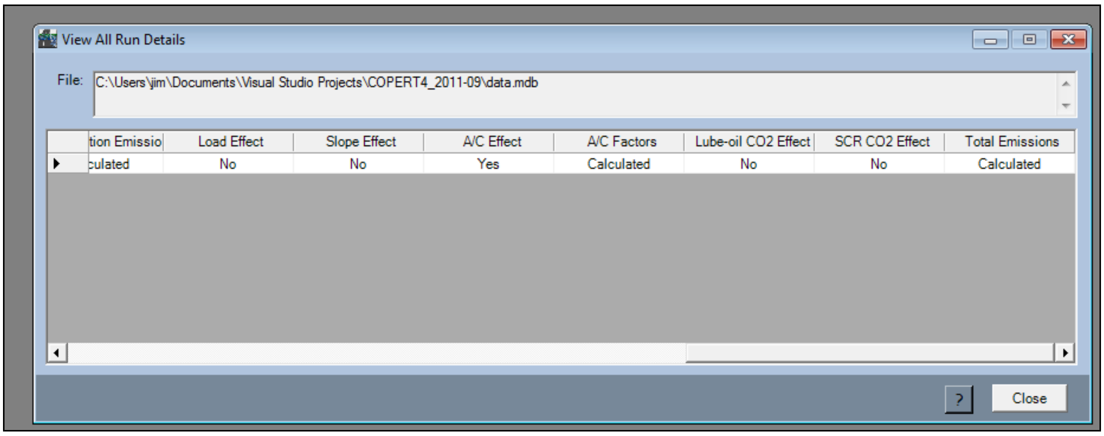


Figure 2-7: 'View All Run Details' form

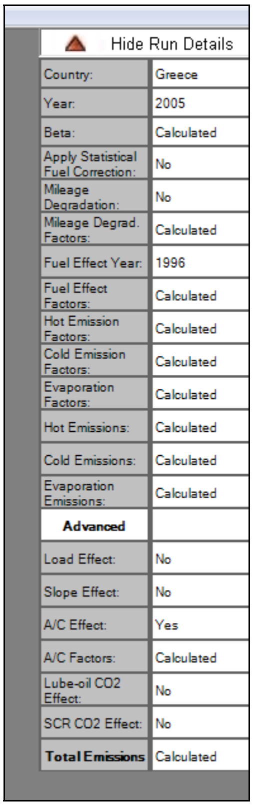


Figure 2-8: 'Run Details' table

2.6 Updated Reports

Now the Source oriented reports also include the A/C, Lube-oil and SCR emissions (Figure 2-9).

Also both Source and Driving mode oriented reports have a footnote for CO2 (Figure 2-10), indicating that the appeared CO2 is based on the Calculated or the Statistical fuel consumption.

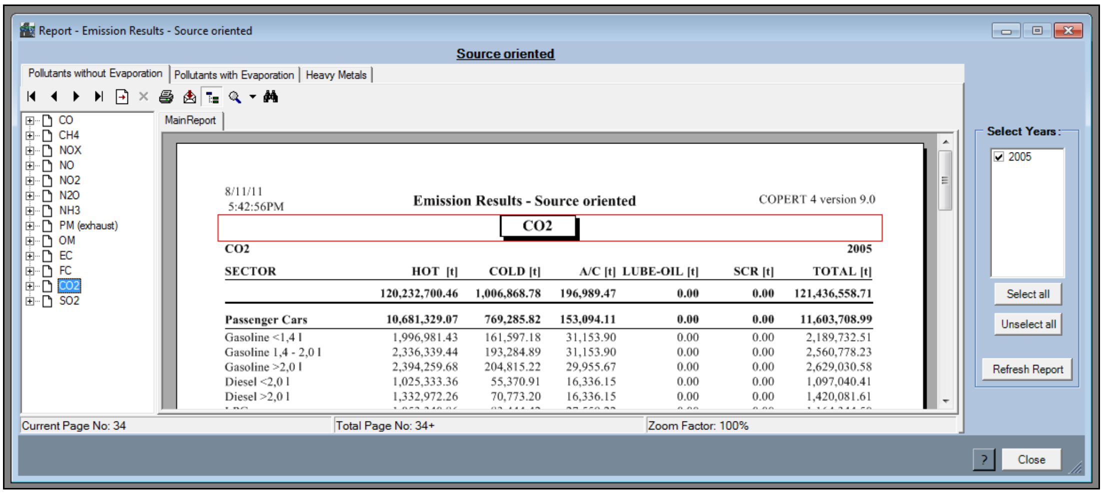


Figure 2-9: Updated Source oriented Reports

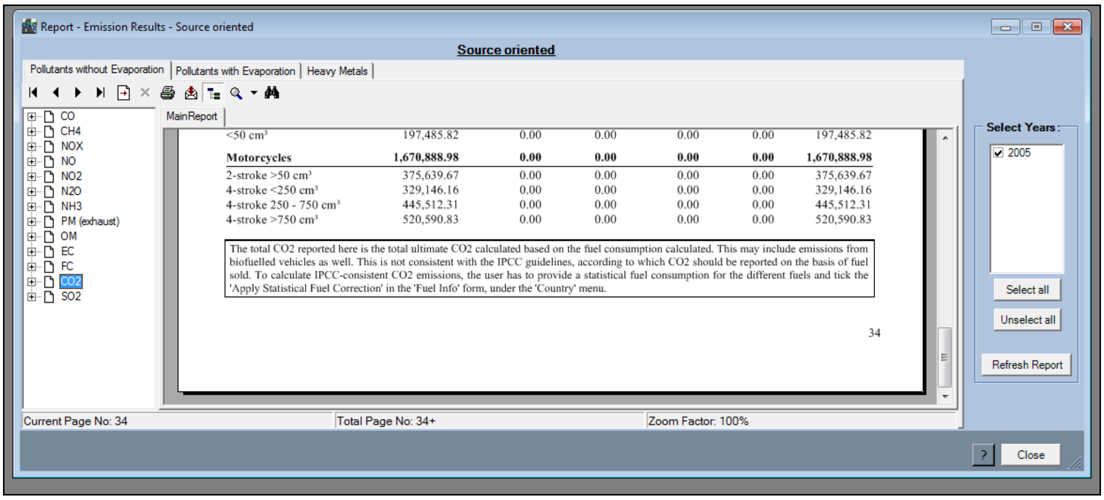


Figure 2-10: CO2 footnote

2.7 Updated Export Excel files

Now the Export Excel files also include the A/C, Lube-oil and SCR emissions for the corresponding pollutants (Figure 2-11).

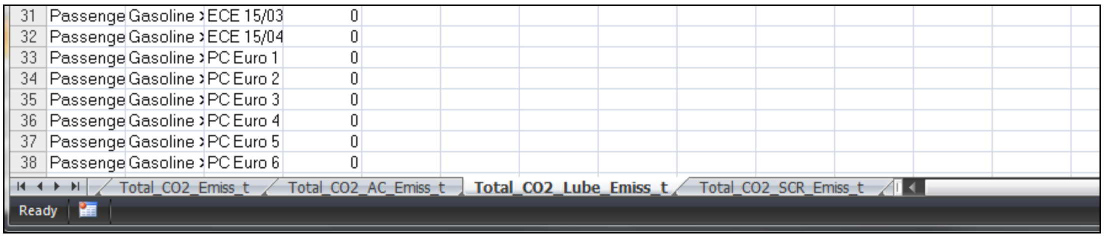


Figure 2-11: Updated Export Excel files

2.8 Updated CRF export

Now the CRF export XML files also include the CO2 emissions due to A/C, Lube-oil and SCR and are compatible with the latest version of CRF Reporter 3.5.

2.9 Bioethanol

Bioethanol fuel was added in the 'Fuel Info' form (Figure 2-12, Figure 2-13) under the 'Country' menu.

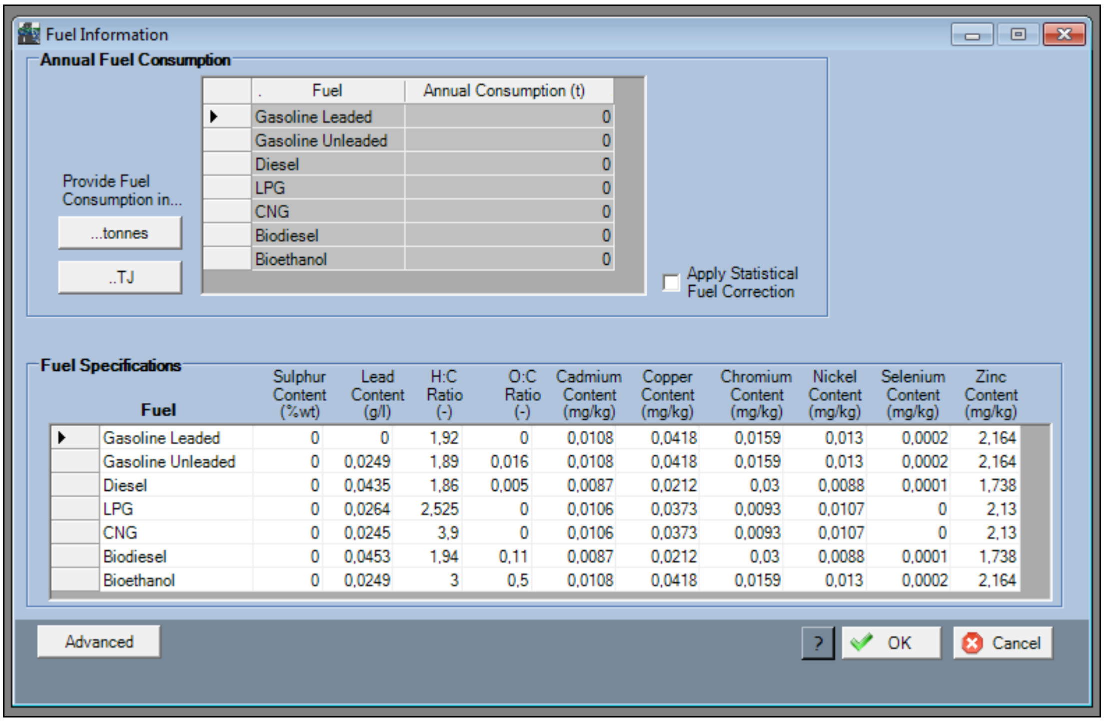


Figure 2-12: Bioethanol fuel information

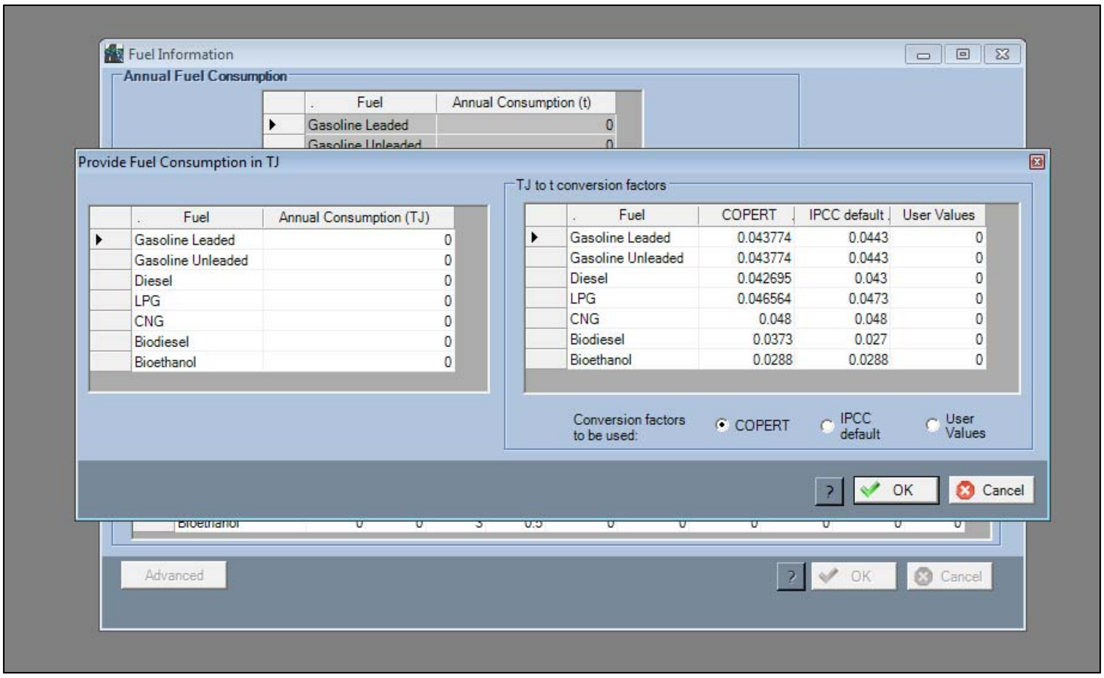


Figure 2-13: Bioethanol conversion factors

3 Bugs fixed

3.1 Software Registration

Some computer configurations didn't let COPERT to connect to the server in order to complete the registration process on the 'Register' form under the 'Help' menu. Now this bug is fixed and the registration is done internally.

4 Acknowledgments

Morten Winther is greatly acknowledged for post-processing data from the Danish National Inventory for inclusion in this report.

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