EMISSIONS: ENERGY, ROAD TRANSPORT

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ABSTRACT

Mobile sources account for a large fraction of fossil fuel combustion in most countries. Of this the largest source is road transport. In 1996, road transport accounted for 24% of CO_2 emissions from fuel use in the USA while in Europe the figure was 22%.

Road transport emits mainly CO_2, NOx, CO and NMVOCs, however it is also a small source of N_2O, CH_4 and NH_3. Therefore the only major direct greenhouse gas emission is CO_2. Emissions of CO_2 are directly related to the amount of fuel used. Emissions of the remaining gases depend on the amount of fuel used but are also affected by the way the vehicle is driven (e.g. the speed, acceleration and load on the vehicle), the vehicle type, the fuel used and technology used to control emissions (e.g. catalysts). Thus the simplest way to estimate the emissions of the other gases is to use fuel based emission factors; this is only appropriate where there is insufficient data to use the more complete methods available.

Methodology used depends on national legislation and availability of statistical data. The IPCC guidebook is based on USA[1] and European[2] experience.

Across the entire globe, motor vehicle usage has increased tremendously. In 1950, there were about 50 million vehicles on the world's roads; this number now exceeds 700 million - almost 500 million light duty vehicles, about 150 million commercial trucks and buses and another 100 million motorcycles. Over the past forty years, each year on average, the fleet has grown by about 11 million automobiles, 3.6 million commercial vehicles and 2.9 million motorcycles.[1] While the growth rate has slowed in the highly industrialised countries, population growth and increased urbanisation and industrialisation are accelerating the use of motor vehicles elsewhere.

Over the past several decades, motor vehicle production has gradually expanded from one region of the world to another. Initially and through the 1950's, it was dominated by North America. The first wave of competition came from Europe, and by the late 1960s European production had surpassed that of the United States. Over the past two decades the car industry in Asia, led by Japan, has grown rapidly and now rivals both those in the United States and Europe. Both Latin America and Eastern Europe appear poised to grow substantially in future decades. For example, driven in large part by Brazil, motor vehicle production in South America now exceeds 2 million units per year.

One result is that areas of rapid industrialisation are now starting to experience similar air pollution problems to those of the industrialised world. Cities such as Mexico, Delhi, Seoul, Singapore, Hong Kong, Sao Paulo, Manila, Santiago, Bangkok, Taipei and Beijing, to cite just a few, already experience unacceptable air quality; in some cases, pollution levels are several times higher than acceptable health levels.

In terms of per capita motor vehicle registration for various regions, the United States, Japan, and Europe currently account for the lion's share of the ownership and use of motor vehicles. Indeed, the non OECD countries of Africa, Asia (excluding Japan) and Latin America are home to more than four fifth's of the world's population, yet account for only one fifth of world motor vehicle registrations! When one looks at the current per capita vehicle ownership rates in different parts of the world, it is clear where the future growth is likely to occur - Asia and Latin America. As a result, vehicle pollution in these regions is likely to increase.

[1] "World Motor Vehicle Data, 1998 Edition," American Automobile Manufacturers Association, 1998.

[2] CO_2 emissions can be estimated from the mileage, however it is usually best to estimate the total emission from the fuel consumption (as this is the more reliable data) and allocate this emission to the vehicle types by vehicle mileage data and relative fuel efficiencies.

1 INTRODUCTION

It is important to make the estimates of CO_2 as good as possible. Emissions of other gases only have a small contribution to the total emissions of greenhouse gases. Emissions of CO_2 depend on, and are estimated from, the amount of each fuel used. This is discussed in section 2.1. Effort spent on improving the estimates of CO_2 emissions from road transport will result in overall improvements on the greenhouse gas inventories. Effort spent on other pollutants may not result in significant improvements in the overall inventory, as they are only small contributors to the greenhouse gas inventories. Thus greenhouse gas inventory experts should give CO_2, from road transport, a higher priority when allocating resources to improving the inventories.

Road transport is a major source of CO_2 and also emits several other gases including NOx, CO and NMVOCs together with smaller quantities of N_2O, CH_4 and NH_3. The carbon emission is estimated from the carbon contained in the fuel[3]. Emissions of other gases are best estimated from the distance the vehicles are driven and emission factors, although in the absence of other information fuel based emission factors can also be used. Emissions fall into three groups.

- Exhaust (tail-pipe) emissions from the vehicle's engine as it is driven;
- Cold Start emissions are additional emissions from the vehicle when started from cold;
- Evaporative emissions are evaporation of petroleum from the vehicles' fuel system, engine, and fuel tanks. Evaporation from vehicle refuelling and the supply of fuels is calculated elsewhere.

However, for inventories of greenhouse gases, the only large contribution is likely to be CO_2. Evaporative emissions are not likely to be significant, (they only relate to NMVOCs). A simple, fuel based, approach will estimate emissions of CO_2 accurately enough provided the fuel consumption is known. A similar approach can be used for other gases where more detailed data cannot be found.

In general emissions are estimated using the following equation:

EQUATION 1

$$\text{Emission} = \sum_{abcd} (EF_{abcd} \bullet \text{Activity}_{abcd}) + \sum_{b} \text{Cold}_b + \sum_{b} \text{Evaporation}_b$$

Where:

Emission:	Total emissions from road transport
EF:	Emission factor, as mass per unit of activity rate
Activity:	activity rate (fuel consumed or distance travelled)
Cold:	Extra emissions due to cold starts
Evaporation:	extra emissions due to evaporation (NMVOCs)
a:	fuel type (petrol, diesel, LPG, etc)
b:	vehicle type (passenger car, light-duty truck, bus etc)
c:	emission control
d:	road type or vehicle speed

Estimation of emissions from road transport requires data for a range of parameters including:

- Fuel consumed, quality of each fuel type;
- Emission controls fitted to vehicle in the fleet;
- Operating characteristics (e.g. average vehicle speeds or types of roads;
- Maintenance;
- Fleet age distribution;

[3] CO_2 emissions can be estimated from the mileage, however, it is usually best to estimate the total emission from the fuel consumption (as this is the more reliable data) and then allocate this emission to the vehicle types by vehicle mileage data and relative fuel effiencies.

- Distance driven, and
- Climate.

Usually not all of these data are available. For example, total fuel consumption may be known but not how it is used by different types of vehicles (e.g. total petrol sales, but not petrol consumption by cars, light duty trucks and motorcycles separately). Thus the simplest methodology is based on fuel consumption alone.

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines)* present two sets of emission factors based on emission estimation research and emission estimation models from the United States and Europe. These are detailed models that take into account many factors that may not be available in many other countries. In the past much of the effort in estimating emissions from road transport focused on the main local and regional pollutants and so there is not much reliable data for greenhouse gases such as N_2O and CH_4 although CO_2 is better understood due to the interest in fuel consumption. It is important to remember that:

- The emission measurements and factors presented in the IPCC Guidelines are based on the vehicle fleets in Europe and the USA. They reflect the vehicle types; emission controls and legislation; driving patterns and road types; vehicle maintenance; vehicle age distributions and mileage; and fuel types and quality in Europe and the USA.
- The emission models proposed are also based on the statistical data available. Thus the vehicle types used and the available statistics are related to the legislation (e.g. vehicle licensing) in these countries. Other countries may well have different vehicle classifications and statistical data available and so this will need some adjustment to fit with the emission factor information.

However, there is only limited guidance on how the information should be used outside these areas. Indeed the tables on the US data explicitly state that they themselves should not be used but that the underlying information should be used to estimate emission rates and hence emissions for other countries. Data for vehicle types that do not occur in Europe or the USA are not included, neither are the impacts of different fuel quality, maintenance and age distributions in these countries.

This paper first considers the activity data and emissions data available and then the selection of good practice methods. Following this reporting, issues about inventory quality are considered.

2 METHODOLOGICAL ISSUES

2.1 Fuel consumption

Fuel consumption is often better known than the distance travelled by vehicles. However, while the total of each fuel used by road transport may be well known, the amounts used by each vehicle type are less well known. In some countries, fuels other than petrol and diesel are significant. These can include LPG, CNG and methanol. It is important to know how much of each of these fuels is used by transport. CO_2 emissions can be estimated from the total amount of fuel consumed.

The approach proposed in the COPERT II manual is to use fuel consumption factors and distance travelled to estimated fuel use. This is then compared with the actual total fuel used and the vehicle kilometres adjusted to match the total fuel use.

Thus the total fuel use gives the total CO_2 emission and the split between different vehicle types is determined by the vehicle kilometre data for each vehicle category.

The CO_2 emission factors proposed in the guidelines are:

TABLE 1
CO_2 EMISSION FACTORS FOR ROAD TRANSPORT IN THE IPCC GUIDELINES

(g CO_2/kg of fuel)	Petrol	Diesel
US	3172.31	
Europe	3180	3140

In fact the emission factor can be estimated from the ratio of carbon to hydrogen in the fuel (Equation 2):

EQUATION 2

$$EF = 44.011 \bullet \frac{1000}{12.011 + 1.008 \cdot r_{H/C}}$$

Where:

EF: mass emission of CO_2 factor (g/kg)

$r_{H/C}$: ratio of carbon to hydrogen atoms in the fuel (~1.8 for petrol and ~2.0 for diesel).

It should be noted that fuel consumption data may not be as clear as it appears at first sight. The following questions should be addressed:

- Is all the fuel used sold for road transport? Is any sold for off-road use or for small machinery (such as domestic appliances such as lawn mowers and garden equipment or small agricultural and forestry use such as chain saws, or even small generators)?
- Do some vehicles get their fuel from other sources (such as commercial or agricultural supplies or other direct supplies to consumers)?
- How are vehicles that transit a country without refuelling dealt with in the statistics?

These are important issues. They may be particularly important with small countries, those with large through traffic from neighbouring countries or those with large fuel price differences with their neighbours. Off-road sources should be estimated separately.

2.2 Activity data

In order to use the best method to estimate emissions, the types of information available need to be identified. The activity data available in a country will determine the approach to be adopted.

2.2.1 Vehicle Types

Emission rates depend on the type of vehicle. The vehicle types defined in the *IPCC Guidelines* follow the USEPA definitions. Other countries will need to match their vehicle data to these categories. Table 2 compares categories in the *IPCC Guidelines* with those used for emission estimation in Europe (COPERT II).

TABLE 2

ROAD VEHICLE TYPES: COMPARISON OF IPCC AND COPERT CLASSES

IPCC Vehicle type	Definition	COPERT class	Definition
Light-duty passenger cars	Vehicle with gross weight less than 8,500 lbs. (3,855kg) designed to carry 12 or fewer passengers.	Passenger Cars	Vehicles with four wheels(or three where the maximum weight exceeds 1,000kg) and being less than 2,500kg
Light-duty trucks	Vehicle with a gross weight of 8,500lbs. (3,855 kg) or less designed primarily for the transportation of cargo or 12 or more passengers, or are equipped for off-road operations. This includes most pick-up trucks, passenger and cargo vans four-wheel drive vehicles and derivatives of these.	Light Duty Vehicles	Vehicles used for the carriage of goods having a maximum weight not exceeding 3,500kg.
Heavy duty vehicles	Vehicles with a manufactures gross vehicle weight greater than 8,500lbs (3,855kg).	Heavy Duty Vehicles	Vehicles used for the carriage of goods exceeding 3,500kg
		Urban Buses and Coaches	Vehicles used for the carriage of passengers and having more than 8 seats
Motorcycles	2 and 4 stroke motorcycles	Motorcycles	Two-wheeled vehicles and three-wheel vehicles not exceeding 1,00kg and motorcycles with sidecar.

While these definitions will give the same results for most vehicles there are some differences. In particular, the IPCC passenger cars can be larger than under the COPERT definition and the IPCC light-duty vehicle class includes some types (e.g. four-wheel drive vehicles) that may be passenger cars under the COPERT II definitions. These differences arise for the local national legislation and the way it defines vehicles for licensing purposes. Data in a country is usually collected in line with the national legislation on road transport.

In many cases, it is probably not worth trying to adjust the vehicle data to meet the IPCC definitions exactly: this is only likely to add additional errors. However there may be cases where a national expert feels that some allocation of the national data to the IPCC classes is necessary and if this is done it should be clearly documented and the assumptions underlying it explained.

In estimating the emissions, these vehicle types may be sub-divided. In particular the heavy-duty vehicle category cover a wide range of vehicles from 3 500 kg to well over 30 000 kg. Sources such as COPERT II and MOBILE5 give detailed emission rates for possible sub-classes by vehicle weights and engine capacity.

This vehicle fleet information is essential in order to estimate emissions (other than CO_2) from road transport.

In the US, Gross Vehicle Weight Rating is the value specified by the manufacturer as the maximum design loaded weight of a single vehicle. In Europe, this is the subject of plating and testing regulations but is essentially the same - the design (and legal) maximum laden weight. Emission factors for HGV may not assume that the vehicles are fully laden (for example, COPERT II assumes that HGVs are 50% full, with conversion factors provided for other loads, while the GVW is used to classify HGVs).

2.2.2 Emission controls

Different types of emission control technologies are fitted to vehicles; this must be taken into account. In Europe and the US this can be done by the age of vehicle. Emission controls were introduced in response to legislation and so the age of a vehicle indicates the legislation for the vehicle was designed and built to meet and hence the emission controls fitted. (Care must be taken to account for the early introduction of new vehicles that meet a future regulation and any 'grace' periods allowing manufacturers to dispose of unsold stock.)

In other countries, the link between vehicle age and emission control may not be as strong so that additional effort may be needed to estimate the numbers of each vehicle type built with each emission control type.

The introduction of three-way catalysts has led to a significant change in the emissions of some pollutants. While they are aimed primarily at gases such as NO_x, CO and NMVOCs, they also have an impact on the direct greenhouse gases. Fuel consumption generally increases a small amount with the fitting of a catalyst. However, other changes to vehicle design may counteract this. For example, cars with three-way catalysts also have fuel injection and electronic engine management systems fitted. These are far less likely to drift out of tune, thus they may have better fuel consumption over their lifetime. In any case, differences in driving patterns may swamp any increases in fuel consumption due to catalysts.

Catalysts reduce hydrocarbon emissions. This is true for methane. However, the reduction in CH_4 emissions is less than for other gases because of its relative inertness to catalytic reduction. On the other hand, N_2O emissions are increased by catalysts. Typically, road transport, in places where catalysts are fitted to petrol cars, is the only significant source of N_2O from fuel combustion. (The large sources are agriculture and process emissions.) Thus the proportion of petrol cars fitted with catalysts is an important parameter in the estimation of N_2O emissions.

Catalysts are poisoned by leaded fuel and fail to work. While cars with catalysts that have failed may emit more than vehicles made without catalysts, there is little information on their emission rates. It is often assumed that vehicle with failed catalysts emit at the same rate as vehicles built to the last pre-catalyst legislation. However, if better information is available this should be used.

In the USA, the MOBILE model takes account of inspection and maintenance (I&M) programmes. Clearly the emission rate depends on the standard of vehicle maintenance and where specific programmes are in place emissions are expected to be lower. Where a range of emission factors are given, where there is no I&M programme, the high end of the emission factor range should be used.

In Europe the emission factors are based on in-service vehicles. Hence the standard of maintenance is included in the measurements. This approach is fine for estimating current emissions where the measurement sample is representative of the national fleet, but where forecasts are made, changes in I&M should be accounted for using the expected improvements in the emission rates. In the UK, in-service testing is accounted for by assuming that catalysts fail and are mostly detected and repaired at an annual test.

Catalyst performance may degrade over time. Where information is available on the vehicle fleet age distribution, this effect can be included by using emission rates dependent on age (or mileage).

Where emission control efficiency is related to vehicle age it may be the case that older vehicles do lower annual mileage. This needs to be taken into account when emissions are estimated. This vehicle fleet emission control information is essential in order to estimate emissions (other than CO_2) from road transport.

As well as emission control technology, the type of fuel the vehicle runs on is required. For example, petrol cars emit very differently to diesel cars. The proportion of vehicle type (especially cars and vans) running on petrol and diesel fuel needs to be known. Also the number of vehicles running on other fuels is also required (e.g. LPG, CNG, ethanol or biofuels).

2.2.3 Vehicle kilometres

The distances driven by different vehicle types are needed for some approaches to estimate emissions. This data is often of poor quality being derived from sample vehicle counts and modelling.

Usually only the main types of vehicle are counted and kilometres driven need to be allocated to vehicle sub-types and by type of emission control according to their proportion in the fleet. Ideally, the distance driven annually by each vehicle sub-type and emission control type should be estimated and taken into account in the calculations.

The different road types need to be defined. The COPERT II approach is based on the average speeds on different road types. Emission factors are given as functions of speed for each vehicle type broken down by emission control and engine size. If this data is available then this approach can be used with estimates being made for each road type. However this level of detail is unlikely to be available for every Party to the UNFCCC. In this case vehicle kilometres need to be estimated for the different road types: typically urban, rural and highway have been used as these three have very different driving patterns and average speeds.

2.3 Emission Factors

The tier I approach in the *IPCC Guidelines* gives fuel-based emission factors. This is a very simple approach that can be misleading if used directly, as major emission controls are not included. Thus a best practice approach should at least be based on tables 1-25 to 1- 46, if not using more detailed approaches.

The simplest approach to estimating emissions from road transport is based on the amounts of each fuel consumed. The approach for CO_2 is indicated above in Section 2.1. This is based directly on the carbon content of the fuel.

For other gases (see section on N_2O below), tables 1-25 to 1-46 give emission rates for US and European fleets, for vehicles at different stages of emission control. These emission factors are averaged over driving patterns and speeds typical of the US or Europe and so the guidelines state they should not be used directly. However there are situations where this may be appropriate where users have no information of vehicle kilometres driven on different road types, of vehicle speeds and of driving patterns.

MOBILE 5 and COPERT II give detailed models that can be used to estimate emissions taking into account fleet types, road types and driving patterns. There is also an intermediate approach where the models are too complicated for the national data available but where the emission factors can be taken from the models to take account of national fleets and driving patterns. Table 3 shows the different approaches in order of increasing quality.

TABLE 3

EMISSION FACTORS FOR NON-CO_2 EMISSIONS

	Emission Factors	Notes	Quality
1	Fuel based factors in tables 1-1 and 1-7 to 11	Doe not take into account fleet characteristics, emission controls etc	Not good practice- useful for preliminary assessments only
2	Fuel Based Factors in tables 1-25 to 1-46	Takes into account fleet types and emission controls but NOT road types and nationals differences	Simplest Acceptable Practice
3	Use detailed factors from COPERT II or MOBILE	Estimate factors from these models to take account of road types and national differences	Good Practice
4	Use COPERT II or MOBILE or equivalent national models	Takes into account fleet types emission controls, road types, speeds and driving patterns	Best Practice

A country with information on the amount of fuel used by each vehicle type should instead use the more detailed emission factors. Countries should use the energy specific emission factors for all of the pollutants (the g/kg fuel or g/MJ factors). The following things should be kept in mind: countries that use leaded fuel will have vehicles that do not have operative catalyst control, as lead fouls the catalysts; and the ranges shown in the US emission factor tables reflect the difference between the existence of inspection and maintenance programmes (I/M) and no I/M programmes (there are few I/M programmes for diesel vehicles in the US). Therefore, a country with leaded fuel and no I/M programme would use the "Uncontrolled" or "Non-Catalyst Control" factors and the higher end of any range given. In most cases, the "Uncontrolled" category would be most applicable. In this example, the country would apply the US emission factors shown in Table 4.

TABLE 4

EMISSION FACTORS FROM THE USEPA FOR UNCONTROLLED PETROL ENGINED CARS

	NO_x	CH_4	NMVOCs	CO	N_2O	CO_2
Average (g/kg fuel)	9.76	0.82-0.90	39.88-42.09	181.14 -244.14		3172.31
Average (g/MJ)	0.222	0.019 -0.020	0.906-0.957	4.117-5.549		72.098

Note that all values except the N_2O values are from USEPA's MOBILE 5 model. N_2O values have been updated based on 1998 USEPA data.

It is also possible to use the factors in Tables 1-27 through 1-33 to more accurately reflect the average temperature in a particular country. This should be done if the average temperature matches well with one of the seasonal temperature figures given in Table 1-26. In this case, the g/km emission factor will be the starting point. This factor must be converted into an energy specific emission factor using the assumed fuel economy given in the applicable table. Use one of the following equations below:

EQUATIONS 3 AND 4

$$\text{Seasonal g/km} \bullet \text{X km/litre} \bullet 1.33 = \text{g/kg fuel}$$

$$\text{Seasonal g/km} \bullet \text{X km/litre} \bullet 0.0302 = \text{g/MJ fuel}$$

This same approach can be used for countries that do have vehicles with operational emissions control equipment, if the vehicle kilometre travelled or the amount of fuel consumed in these vehicles is known and the control technology can be matched to the descriptions given in the guidelines. However, countries with this level of data may wish to use emissions factors that have been developed locally or the COPERT factors if those are likely to be more applicable. Countries that do wish to use the MOBILE model, but run it to reflect their local conditions (such as temperature and average speed, for example) should contact the USEPA for a copy of the model and instructions on how to use it. In this case, the steps taken by the country in using MOBILE should be clearly documented in their inventory submission. Some cities and some countries have taken this approach including China (for Beijing and Guangzhou), Mexico (for Mexico City and Monterrey), Bangkok, Thailand and Kuala Lumpur, Malaysia.

2.3.1 N_2O

Compared to regulated tailpipe emissions, there exist relatively few data that can be used to estimate nitrous oxide emission factors for gasoline highway vehicles. Nitrous oxide is not a criteria pollutant, and measurements of it in automobile exhaust are not routinely collected. Many of the recent measurements have been part of research efforts attempting to understand why and under what conditions three-way catalysts produce nitrous oxide, rather than trying to characterise the U.S. fleet.

The current *IPCC Guidelines* show markedly increased emission rates for vehicles with catalyst control. In reviewing the literature data, and methods used to develop these emission factors, however, USEPA found they are very limited, as described below:

- All the emission factors originate from testing done on five cars using European test cycles. Fuel sulphur content for these tests was unspecified.
- The new and aged three-way catalyst emission factors are based (90% of the data) on a single study using a single car with eight non-production catalysts, new and bench-aged, with the catalysts located 1.4m from the engine. The other 10% of the data for the three-way catalyst emission factors came from two studies and three more cars, all tested on European driving cycles only.
- The non-catalyst emission factors were derived from four cars.

- The emission factor for oxidation catalyst vehicles does not appear to be based on testing, but is instead the same emission factor used for new three-way catalysts.

In order to refine the N_2O emission factors, the USEPA Office of Mobile Sources in June and July 1998, carried out a careful evaluation of available data supplemented by limited testing. They determined emission factors for Early three-way Catalyst and previous vehicles primarily from the published literature. For (advanced) three-way Catalyst vehicles and Low-Emission Vehicle Technology, data were used from the recent testing programme. USEPA also assessed the limited data that exist for trucks. Based on all of the above, recommendations for N_2O emission factors by vehicle type and control technology have been made. The following sections will summarise this effort.

As with the emission factors from the Mobile model, these newer factors developed by the USEPA for nitrous oxide reflect the conditions in the United States. For example, in conducting the literature search, USEPA reviewed only published values for the composite of the standard US federal test procedure, since it is the standard driving cycle for the U.S. Still, the results of USEPA's recent testing and literature review yields results that improve the nitrous oxide emission factors now included in the *IPCC Guidelines*.

Emissions were always higher with commercial (high sulphur) fuel than with Indolene (low sulphur).

In 8 cases, tests were repeated with both high and low sulphur fuels. Six of the tests were with Low Emissions Vehicles, and two with Advanced TWC vehicles. All showed higher emissions with commercial fuel (285 ppm sulphur) than with Indolene (24 ppm sulphur). The ratio of nitrous oxide emissions using commercial fuel to those using Indolene ranged from 1.2 to 4.4 and averaged 2.6. The mean of the ratio was significantly larger than 1 ($p<.01$). EPA believes that the basis for this difference is fuel sulphur content. The emission factors shown below reflect the test results using the commercial, higher-sulphur fuel, as this is more representative of gasoline sold today in the United States. Other countries may use gasoline with even higher sulphur levels. It is not possible today to recommend that these countries scale up the N_2O emission factor given below, as there are no data to support this.

Emissions were usually higher with A/C On at 95°F than with A/C off at 75°F.

In 22 cases, tests were repeated under both A/C modes. In seventeen cases emissions were higher with A/C on, in five cases with A/C off. The ratio of nitrous oxide emissions with A/C on to those with A/C off ranged from 0.9 to 3.4 and averaged 1.5. The mean of the ratio was significantly larger than 1 ($p<.01$). The emission factors shown below reflect a weighted average of these results, based on U.S. activity data.

Nitrous Oxide was unrelated to the mileage of the vehicles.

A regression line of nitrous oxide emission factors against mileage for Advanced TWC passenger vehicles yielded a slight positive slope not significantly different from zero ($p<0.25$). R^2 was 0.06. Barton and Simpson (1994) similarly did not find a significant relationship between nitrous oxide emissions and mileage. Their slope was negative.

Tables in Annex A contain replacement values for the N_2O emission factors now shown in Tables 1-27 through 1-33 of the *IPCC Guidelines*.

2.4 Good practice methods

The *IPCC Guidelines* identify two methods to estimate emissions from road transport. These are the USEPA MOBILE5 and the European COPERT II methods. The data presented in the guidelines themselves are emissions per unit fuel used and distance driven in g/km and g/kg (and g/MJ) for each vehicle type. These emission factors assume a mix of driving on different road types (speeds and accelerations), an average cold start per trip, average evaporative emissions across the fleet, typical climate and fuel quality, and a specific age distribution for the vehicle fleet. As these assumptions are specific to Europe and North America these figures should not, in principle, be used directly (See Box 4, page 1.67, Revised *IPCC Guidelines* for National Greenhouse Gas Inventories: Reference Manual). If one or other of these methods cannot be used directly, and there is no equivalent national methodology, then it is better to refer to the basic emission factors in these models to estimate emissions.

Both these models have specific and extensive data requirements. However, the COPERT II model was developed to be applicable across Europe and so has to be useable in many countries. Therefore, the COPERT II model's data needs may be easier to satisfy.

To estimate emissions an appropriate emissions model should be used. The following approach is recommended:

Step 1 – Action data collection

Fuel consumption by road transport is REQUIRED. This can be total petrol, diesel and any other fuels used but not broken down by vehicle type. (It is unlikely that fuel consumption by each type of vehicle separately is known rather than being estimated in a similar manner to the emission estimates made below.) This information is usually known as such fuels are often taxed. Estimate CO_2 emissions from fuel use.

Notes: Data must be specific for fuel type used and then check the following:

- All fuel sold is for road transport use not off road vehicles and machinery, and
- That all the fuel used is included. Tax exempt and agricultural vehicles may not appear in data depending on where and how they obtain their fuel.

For some countries fuel purchased outside the country and used inside (or vice versa) may be significant. As this fuel is in the tanks in ordinary vehicles, there will be records of it crossing a border. Luxembourg is an example. For these countries it may be more appropriate to estimate fuel consumption from knowledge of the vehicle mileage within the country. This should only be done where exports or imports are significant.

Step 2 - Action data collection

Vehicle kilometre data of the distance travelled by each vehicle type on different types of roads should be collected. Where vehicle kilometre data is not available, then it will be necessary to use fuel related emission factors and the total amount of fuel consumed. If no other information is available then the total emission should be allocated to the vehicle type by number of vehicles. However, this will result in an emission estimate with a higher uncertainty and a lower quality.

Notes: Data should be specific for each fuel type used. Vehicle types should follow those used in the IPCC Guidelines. However, national data may have to be mapped onto these IPCC classes using local expertise. In some cases the IPCC classes may not be suitable and additional classes will have to be used. The road types used will depend on the local situation and traffic data that has been collected. The road type should reflect the driving modes in the country, hence the widely used grouping of Urban, Rural and Highway (Motorway). Typically, traffic data may not be available for all the possible vehicle and road type combinations. The local expert should attempt to allocate the vehicle kilometres. For example counts of total cars may be available but usually not the number of a specific type of car (e.g. with catalyst).

Step 3 - Action data collection

Estimate the fuel consumption from the vehicle kilometre data. This requires the use of fuel economy data. Compare this with the fuel consumption data collected in step 1. Except for countries where unreported imports and exports are significant, the vehicle kilometre data should be adjusted to make the two sets of fuel consumption data agree. Local experts should indicate the parts of the vehicle kilometre data that are least reliable and the range of figures that are credible. If the two sets of fuel consumption data cannot be reconciled then the original data be investigated to find the source of the problem - there is no point in continuing without confidence in the data. If the problem cannot be solved, then the fuel related emission factors should be used to estimate emissions. For countries where unreported imports and exports are significant, the experts may prefer to rely on the vehicle kilometre data rather the fuel use. In this case, they should estimate fuel use from the vehicle kilometre data so that CO_2 emissions can be estimated.

Notes: This is an important step as it gives some confidence that the vehicle data are realistic. Should the two estimates agree exactly or should a margin of error be allowed? Where it cannot be done, due to imports and exports then some justification for the vehicle used should be chosen. The chosen vehicle kilometres will enable an estimate to be made of the amount of fuel imported or exported. Where this is significant, it should be checked that the other country involved is aware of the size of the imports/exports of their own estimates. Who performs this check is unclear at present.

Step 4 - Action data collection

Does the car fleet most resemble that of the USA or Europe? Is there sufficient data available to use the models MOBILE5 or COPERT II? If so then emission estimates can be made using the appropriate model and data. If not then go to step 5.

Notes: The data requirements of these two models are fairly extensive and so they may not be suitable for many countries. It should be noted that the COPERT II model includes data on some Eastern European types in particular 2-stroke passenger cars.

Step 5 - Action data collection

Emission factors for each vehicle type and road type are needed. These can come from MOBILE5 and/or COPERT II. However some countries will find that they have additional vehicle types that are not covered by these models. In these cases, locally measured data can be used. It may be necessary to make some engineering judgements to extrapolate from measured vehicle types to the vehicle types used in certain places.

Notes: If measure emission factors are not available, these alternative approaches to emission factors will result in increased error and poorer quality inventories. The only way to improve the inventory is to make measurements.

The COPERT II model is based on combining emissions data from across Europe. This collaboration between many countries has improved emission estimates and could be copied in other parts of the world. Experts should monitor vehicle emission work in other countries as this may well provide data that will improve their own inventory.

Step 6 - Action data collection

The emissions factors from step 5 and the vehicle kilometres from step 3 are multiplied to estimate the emissions.

Notes: CO_2 should be estimated from the vehicle kilometres data and, provided there are no mistakes, this will be approximately equal to the estimate made in step 1 except in those countries where unreported exports and imports are significant. Some differences between these two estimates of CO2 are expected due to the uncertainties. HOW BIG ARE THESE?

Step 7 - Action data collection

An assessment of the emissions from cold starts and evaporative emissions is also needed.

Notes: This is only needed for some pollutants and is a minor contributor to greenhouse gas emissions.

2.4.1 Uncertainty

Assuming that the emission estimation process follows all the best practice the results will still be uncertain. This results from:

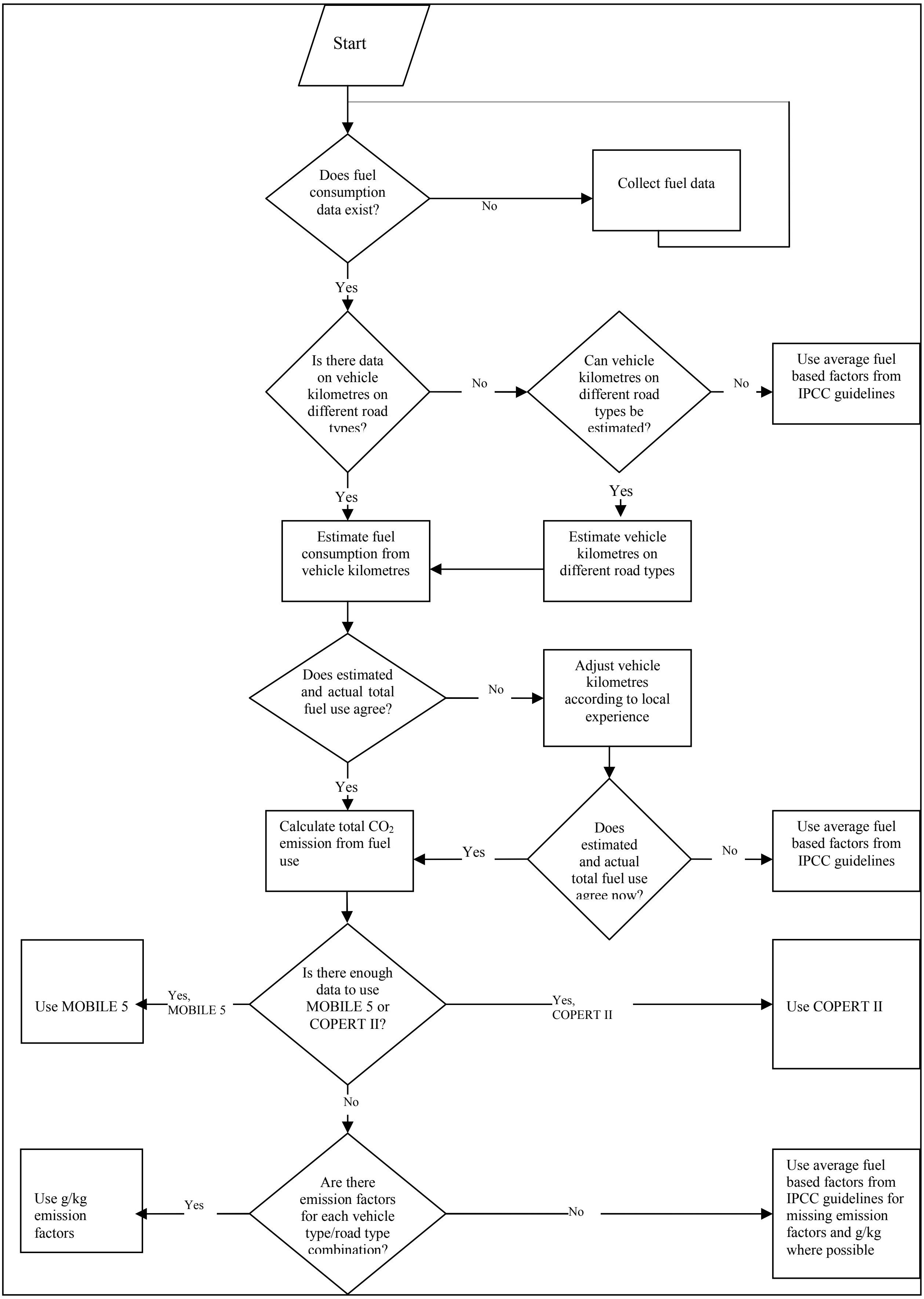
- Uncertainties in emission factors. These arise from a number of areas. Measurements themselves are uncertain. Most are laboratory-based dynamometer measurements that may not represent real road driving conditions. Not all the conditions found on the road may be replicated by the measurement procedures. Emissions vary from vehicle to vehicle and usually only relatively small samples of each vehicle type have been measured. Thus emission factors may differ from the real average emission rate for a particular vehicle type. In addition, some very high emitting vehicles, due to age or malfunctions, may evade the measurement programme altogether. (For example vehicles deemed unsafe or aggressive driving styles would not be measured but may be driven on the roads.)
- Uncertainties in activity rates. The activity rates are, like any statistical data, uncertain. In addition as they are not collected specifically for use in emission inventories they may not be exactly the data required by the estimation methodology. Assumptions may be needed to use the activity data. Some of the data may be very uncertain. Vehicle kilometres on different road types may be sound, based on detailed measurements, or they may be extrapolations from a small dataset with a high degree of uncertainty.
- Representativeness of the methodology. The methodology used to estimate emissions may not accurately reflect the true emission processes. This is difficult to assess theoretically but measurements may help. Some roadside measurements indicate that the estimates of emissions of regulated pollutants (NOx, CO and NMVOCs) are approximately correct while some indicate systematic differences. In any case, these comparisons are difficult to assess as the methodology takes emission factors for cycles (drives including starts, stops, acceleration and steady speeds) while the measurements are essentially spot measurements (or at least short periods with vehicles under one driving condition).

While experts may be able to assess the size and impact of the first two sources of uncertainty, the size of the third is more difficult to address.

An early study looking at the first two sources of uncertainties (Eggleston, 1993), indicated that the uncertainty in the estimated emission of NMVOCs was 50% (2 standard deviations as a percentage of the mean). While uncertainties in fuel consumption, and hence CO_2 emissions, are much lower, estimates of CH_4 and N_2O may have similar or higher uncertainties than for NMVOCs.

The estimate of total CO_2 from road transport may have a very small uncertainty. Fuel consumption statistics are often quite accurate and so the total emission may have an accuracy of 3-5% in many cases. However the allocation of this emission to specific vehicle types will be of much lower uncertainty. In other cases, the total fuel consumption is not well known, either because the statistics are distorted by imports and exports, or because the base data are not well known. Then the uncertainties could be much higher, relying on vehicle kilometre estimates and fuel consumption rates.

Figure 1 Decision tree for choice of method to estimate emissions from road transport



2.4.2 Completeness

It is very important that every effort is made for the estimate to be as complete as possible. There may be specific national issues that need to be considered in addition to the issues discussed below:

- Tax exempt vehicles. Some classes of vehicles may be exempt from tax for a wide range of reasons. However, they should be included in the estimates. Thus the numbers of these vehicles and the distances they travel need to be estimated;
- Agricultural vehicles. It is possible that in some countries agricultural vehicles are not included in the data. Some countries tax agricultural fuels differently and so it is important to be clear which vehicles are used on the public roads and how much fuel is consumed by them;
- Military Vehicles. It can be difficult to collect information on military vehicles. Particular issues concern where the fuel consumed is accounted for and how much such vehicles are used on the public roads;
- Import and export of fuel. This has been discussed above in section 2.1;
- Vehicle types. Are all the vehicle types that exist in a country included in the inventory?
- Fuel types. Are all the fuel types in a country included? Are all the different fuel qualities covered by the inventory?

3 REPORTING AND DOCUMENTATION

It is important not only to estimate the emissions in the best way but also to report and document the approach used. As was described above, the detail of the method used for the estimates depends on the statistical data available. Information about the inventory can be split into two parts:

- Reporting. This is information needed by users of the emission inventories to compare and contrast the emission estimates with those of other countries, and
- Documentation. This is more detailed information which will show an interested outsider exactly how the estimates have been made and any assumptions that have had to be made by the inventory compilers.

Therefore reporting should include:

1. Emissions according to the categories described in the IPCC reporting instructions and guidelines. As has been noted above, the national statistics and legislation may result in classes slightly different from those in the IPCC Guidelines. In this case, an attempt should be made to report in the IPCC categories as closely as possible;
2. Any differences between reported vehicle classes and the requested IPCC classes should be reported (e.g. differences in the treatment of four-wheel drive vehicles or in the maximum number of passengers in a car or light-duty vehicle.);
3. Any adjustments made to the estimated vehicle emissions in order to fit the results into the IPCC classes, and
4. The estimation method used. This will include the availability of data describing road transport.

Documentation should include all of the above and:

1. The statistical data used and its sources. Has any data been estimated or assumed?
2. The emission factors used and their sources and any assumptions that have had to be made to provide emission factors to each national vehicle type;
3. Vehicle fleet by type and emission control, legislation controlling vehicle emissions, technologies used for emission control, fuel types and any alternative fuels used;
4. A comparison of reported fuel use and estimated fuel use from vehicle mileages, and
5. Checks and reviews that have been performed.

4 QUALITY ASSURANCE AND QUALITY CONTROL

4.1 Introduction

To ensure the best possible inventory quality a clear quality assurance/ quality control (QA/QC) system is needed. This will need to cover a clear documented approach as follows:

- Checks and internal review of the data used for the calculations and the results;
- Comprehensive documentation;
- External audit of the entire inventory, and
- Inventory reviews including expert (peer review, stakeholder review and public review.

4.2 Internal inventory QA/QC systems

Internal checks should be made as part of the inventory QA/QC system. These should include checks that the procedures have been followed correctly as well as checks that the results are reasonable. The comparison of the reported fuel use and fuel use estimated from vehicle mileage is a check on the reasonableness of the estimates. All data used should be documented. Its source, data and use should be recorded. All assumptions about statistics should be recorded. Differences between these estimates and other emission inventories should be considered and explained.

4.3 External inventory QA/QC systems

4.3.1 Third party audit

This is a potential review mechanism that would give increased confidence in the emission estimates. An independent third party would review the estimates and their documentation to see if the results are reasonable. The first step in this would be the identification of widely accepted expert third parties to perform the audit. Such parties should be:

- Independent;
- Experts, and
- Accredited

4.3.2 Review

Publishing the inventory and inviting comments could perform peer review of the inventory. The three groups who should be addressed are:

- **Experts (Peer Review):** Those with the scientific and technical expertise to consider the data and emission factors used and criticise the assumptions and approach used from a scientific background. Expert (peer) review is needed to give the emission estimates scientific credibility;
- **Stakeholders:** Several groups have a direct interest in the results. These could include vehicle manufacturers and traders, government departments, motorist organisations and the petroleum industry. Giving these groups the chance to review and comment on the estimates will enable them to contribute the best information they have as well as increasing their confidence in the emission estimates, and
- **Public:** Review should attempt to include to widest range of input. Members of the public and groups such as NGOs will comment from different viewpoints that may reveal problems in the data or in the way it is reported and documented.

REFERENCES

Eggleston HS (1993) "*Uncertainties in the estimates of Emissions of VOCs from Motor cars*" Proceedings of the TNO/EURASAP working on the reliability of VOC Emission databases June 1993. TNO Netherlands

OPERT II(1997) *"COPERT II Computer Programme to Calculate Emissions from Road Transport.*

Methodology and Emission factors" Ahlvik P, Eggleston P, Gorissen N, Hassel D, Hickman A-J, Jourmard R, Ntziachristos, Rijkeboer R, Samaras Z, Zierock K-H, European Environment Agency, Copenhagen, November 1997.

ANNEX 1 N_2O EMISSION FACTORS

Note that Table 1-29 of the IPCC Guidelines seems to be mis-labeled – more work is needed to determine if this is true for all the emission factors in Table 1-29.

REPLACEMENT FOR N_2O EMISSION FACTORS – TABLE 1-27 ESTIMATED EMISSION FACTORS FOR US GASOLINE PASSENGER CARS	
Low-Emission Vehicle Technology; Assumed Fuel Economy: 8.5 km/litre (11.8 l/100 km)	
Average (g/km)	0.0176
Average(g/kg fuel)	0.199
Average(g/MJ)	0.00453
Three-way Catalyst Control; Assumed Fuel Economy: 8.3km/litre (12.01/100km)	
Average (g/km)	0.0288
Average (g/kg fuel)	0.320
Average (g/MJ)	0.00728
Three-way Catalyst Control; Assumed Fuel Economy: 8.0 km/litre (12.51/100km)	
Average (g/km)	0.057
Average (g/kg/fuel)	0.539
Average(g/MJ)	0.01225
Oxidation Catalyst Control; Assumed Fuel Economy: 6.2 km/litre (16.11/100km)	
Average (g/km)	0.0322
Average (g/kg/fuel)	0.266
Average(g/MJ)	0.00605
Non-Catalyst Control; Assumed Fuel Economy: 4.5 km/litre (22.21/100km)	
Average (g/km)	0.0103
Average (g/kg/fuel)	0.062
Average(g/MJ)	0.00140
Uncontrolled; Assumed Fuel Economy: 4.7 km/litre (21.31/100km)	
Average (g/km)	0.0103
Average (g/kg/fuel)	0.065
Average(g/MJ)	0.0047
Source: USEPA,1998.	

REPLACEMENT FOR N_2O EMISSION FACTORS – TABLE 1-28 ESTIMATED EMISSION FACTORS FOR US LIFHT DUTY GASOLINE TRUCKS	
Low-Emission Vehicle Technology; Assumed Fuel Economy: 6.0 km/litre (16.7 l/100 km)	
Average (g/km)	0.0249
Average(g/kg fuel)	0.199
Average(g/MJ)	0.0049
Three-way Catalyst Control; Assumed Fuel Economy: 6.0 km/litre (16.71/100km)	
Average (g/km)	0.0400
Average (g/kg fuel)	0.320
Average (g/MJ)	0.00728
Three-way Catalyst Control; Assumed Fuel Economy: 4.8 km/litre (20.81/100km)	
Average (g/km)	0.0846
Average (g/kg/fuel)	0.539
Average(g/MJ)	0.01225

REPLACEMENT FOR N_2O EMISSION FACTORS – TABLE 1-28 (CONTINUED) ESTIMATED EMISSION FACTORS FOR US LIFHT DUTY GASOLINE TRUCKS	
Oxidation Catalyst Control; Assumed Fuel Economy: 4.8 km/litre (20.81/100km)	
Average (g/km)	0.0418
Average (g/kg/fuel)	0.266
Average(g/MJ)	0.00605
Non-Catalyst Control; Assumed Fuel Economy: 4.0 km/litre (25.01/100km)	
Average (g/km)	0.0117
Average (g/kg/fuel)	0.062
Average(g/MJ)	0.00140
Uncontrolled; Assumed Fuel Economy: 4.7 km/litre (21.31/100km)	
Average (g/km)	0.01018
Average (g/kg/fuel)	0.065
Average(g/MJ)	0.0047
Source: USEPA,1998.	

REPLACEMENT FOR N_2O EMISSION FACTORS – TABLE 1-29 ESTIMATED EMISSION FACTORS FOR US HEAVY-DUTY GASOLINE VEHICLES	
Early Three-Way Catalyst; Assumed Fuel Economy: 2.3 km/litre (43.5 l/100 km)	
Average (g/km)	0.1729
Average (g/kg fuel)	0.539
Average (g/MJ)	0.01225
Oxidation Catalyst; Assumed Fuel Economy: 2.3 km/litre(43.5l/100km)	
Average (g/km)	0.0870
Average (g/kg fuel)	0.266
Average (g/MJ)	0.00605
Uncontrolled; Assumed Fuel Economy: 1.8 km/litre(55.6l/100km)	
Average (g/km)	0.0262
Average (g/kg fuel)	0.064
Average (g/MJ)	0.00144
** The current Table 1-29 seems to be mis-labeled,at least as far as the N_2O factors are concerned. The headings below are labeled as they should be for N_2O. The other factors need to be checked. Source: USEPA, 1998.	

REPLACEMENT FOR N_2O EMISSION FACTORS – TABLE 1-30 ESTIMATED EMISSION FACTORS FOR US DIESEL PASSENGER CARS	
Advanced Control; Assumed Fuel Economy: 10.0 km/litre (10 l/100 km)	
Average (g/km)	0.01
Average (g/kg fuel)	0.134
Average (g/MJ)	00304
Moderate Control; Assumed Fuel Economy: 9.6 km/litre(10.4l/100km)	
Average (g/km)	0.01
Average (g/kg fuel)	0.134
Average (g/MJ)	0.00304
Uncontrolled; Assumed Fuel Economy: 7.5 km/litre(13.3l/100km)	
Average (g/km)	0.01
Average (g/kg fuel)	0.134
Average (g/MJ)	0.00304
Source: USEPA, 1998.	

REPLACEMENT FOR N_2O EMISSION FACTORS – TABLE 1-31 ESTIMATED EMISSION FACTORS FOR US LIGHT DUTY DIESEL TRUCKS	
Advanced Control; Assumed Fuel Economy: 7.2 km/litre (13.9 l/100 km)	
Average (g/km)	0.02
Average (g/kg fuel)	0.192
Average (g/MJ)	00437
Moderate Control; Assumed Fuel Economy: 7.2 km/litre(13.9l/100km)	
Average (g/km)	0.02
Average (g/kg fuel)	0.192
Average (g/MJ)	0.00437
Uncontrolled; Assumed Fuel Economy: 5.7 km/litre(17.5l/100km)	
Average (g/km)	0.02
Average (g/kg fuel)	0.192
Average (g/MJ)	0.00437
Source: USEPA, 1998.	

REPLACEMENT FOR N_2O EMISSION FACTORS – TABLE 1-32 ESTIMATED EMISSION FACTORS FOR US HEAVY DUTY VEHICLES	
Advanced Control; Assumed Fuel Economy: 2.4 km/litre (41.7 l/100 km)	
Average (g/km)	0.03
Average (g/kg fuel)	0.096
Average (g/MJ)	0.00219
Moderate Control; Assumed Fuel Economy: 2.4 km/litre(41.7l/100km)	
Average (g/km)	0.03
Average (g/kg fuel)	0.096
Average (g/MJ)	0.00219
Uncontrolled; Assumed Fuel Economy: 2.2 km/litre(45.5l/100km)	
Average (g/km)	0.03
Average (g/kg fuel)	0.096
Average (g/MJ)	0.00219
Source: USEPA, 1998.	

REPLACEMENT FOR N_2O EMISSION FACTORS – TABLE 1-33 ESTIMATED EMISSION FACTORS FOR US MOTOR CYCLES	
Advanced Control; Assumed Fuel Economy: 10.8 km/litre (9.3 l/100 km)	
Average (g/km)	0.042
Average (g/kg fuel)	0.062
Average (g/MJ)	0.00140
Moderate Control; Assumed Fuel Economy: 8.9 km/litre(11.2l/100km)	
Average (g/km)	0.00054
Average (g/kg fuel)	0.065
Average (g/MJ)	0.00147
Source: USEPA, 1998	