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4 authors:

Leonidas Ntziachristos
Aristotle University of Thessaloniki

Dimitrios Gkatzoflias
European Commission

Chariton Kouridis
Aristotle University of Thessaloniki

Zissis Samaras
Aristotle University of Thessaloniki

COPERT: A European Road Transport Emission Inventory Model

Leonidas Ntziachristos[a], Dimitrios Gkatzoflias[b], Chariton Kouridis[b] and Zissis Samaras[a]

[a] Laboratory of Applied Thermodynamics, Aristotle University Thessaloniki, PO Box 458, GR 54124, Thessaloniki., Greece.
[b] EMISIA SA, Antoni Tritsi 15-17, PO Box 20640, GR 55104, Thessaloniki, Greece.

Abstract

This paper presents the main characteristics of COPERT 4 software, a European tool to calculate emissions from road transport. The paper presents the main methodological elements of the application, the sources of primary information, the software architecture, and demonstrates an example of application for the Greek national road transport vehicle stock. COPERT 4 is being downloaded by ~100 users per month and is being used in a large number of applications, including air emission inventorying, input to air-quality studies, and academic research.

Keywords: vehicle emissions, air pollutants, emission inventories, road transport

Introduction

The European Commission and the Council have set forward a Directive which sets National Emission Ceilings (NECD – 2001/81/EC) to regulate the total amount of pollutants that can be produced annually in each country, with a target in year 2010. The Commission is also working on the revision of this directive, which would target year 2020 and would include $PM_{2.5}$ ceilings. In addition, several other policy frameworks and interna-

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tional protocols exist that require each member state to report total national emissions of air pollutants from all anthropogenic sources. These are either part of the 1979 Geneva Convention on Long-range Transboundary Air Pollution (CLRTAP) or, more recently, part of the United Nations Framework Convention on Climate Change (UNFCCC).

Road transport is a significant source of air pollution, especially in urban areas. According to a review of the CLRTAP data by the European Environment Agency [1] road transport is the most significant source of NO_x, CO, and Non-Methane Volatile Organic Components (NMVOCs), and the second most important source of PM_{10} and $PM_{2.5}$ emissions. In 2006, road transport alone was responsible for 39.4% of total NO_x, and 17.8% of total $PM_{2.5}$ in the 27 European Union countries (EU27).

Due to the large contribution, the calculation of road transport emissions needs to be detailed and precise. Errors in the calculation will be directly reflected on the accuracy of the complete national inventory. Hence, the emission trends and the impact of policies will be misjudged.

There are several methods and tools used by different member states to calculate road transport emissions. However, most of them (22 out of the EU27) use the COPERT model. Its development has been coordinated by the Laboratory of Applied Thermodynamics (LAT) in the Aristotle University of Thessaloniki and has been funded by the European Environment Agency, through the European Topic Centre on Air and Climate Change. COPERT is also part of the EMEP/CORINAIR Air Emissions Inventory Guidebook while COPERT-derived emission factors of greenhouse gases are also used in the IPCC 2006 revised guidelines. COPERT is also part of the TREMOVE software (www.tremove.org) which is used by the European Commission to provide input to impact assessment studies related to transport policy measures.

This paper discusses the main input sources for the development of the methodology in COPERT, presents the software application and demonstrates a typical national road transport inventory that can be compiled with the latest version of the software, COPERT 4.

Methodology

This section describes the main methodological items of COPERT, that is the distinction in emission processes (hot, cold-start, evaporation, non-exhaust), and the formulation of the emission factors used in the software.

Total emissions

COPERT includes a methodology to estimate vehicle fleet emissions on a country level. The methodology tries to balance the need for detailed emission calculations on one hand and use of few input data on the other.

Different calculation processes are included for exhaust and non-exhaust pollutants. Exhaust pollutants (E_{EXH}) are gases and particulate matter (PM) emitted by the vehicle engine. These are calculated based on the equation:

$$E_{EXH} = E_{HOT} + E_{COLD} \qquad (1)$$

That is exhaust emissions consist of two parts; one part where the engine and the emission control system are thermally stabilized (E_{HOT}). In the technical jargon, these emissions are called "Hot", because the engine and the aftertreatment devices have reached their normal operation temperature (i.e. they are hot). The other part refers to cold-start emissions (E_{COLD}).

For a given activity level (NM), expressed in total veh-km driven by stock vehicles for the period concerned, hot emissions are calculated by means of equation (2). The emission factor (e_{HOT}) is the mean emission level of the stock vehicles, and it is expressed in g km^{-1}.

$$E_{HOT} = NM_r \times e_{HOT} \qquad (2)$$

The other part in eq. (1) refers to cold-start emissions, which occur before the vehicle subsystems have reached their normal operation temperature. During this phase emissions are higher and strongly depend on ambient conditions. Gradually, as the vehicle heats up, cold-start overemission zeroes and only hot emissions are produced. Cold-start emissions importance increases with decreasing temperature and for intermittent vehicle operation which allows the engine to cool down when it is switched off. Equation (3) is used to calculate cold-start overemissions. In this, ® is the fraction of the total activity ran before the engine reaches its normal operation temperature, and it is a function of the vehicle technology, the ambient temperature and the mean duration of the trips performed by the particular vehicle types. The term in parentheses (e^{COLD}/e^{HOT}-1)expresses the overemission level compared to hot emissions.

$$E_{COLD} = \beta \times NM \times e_{HOT} \times (e^{COLD} / e^{HOT} - 1) \qquad (3)$$

One source of non-exhaust emissions is fuel which evaporates via the fuel system (evaporation losses). Evaporation losses so far have been important only for gasoline-fuelled vehicles, due to the relatively high vapour pressure of the fuel. Lately, diesel vehicles have been receiving attention as evaporation becomes relatively more important in the light of the continuous reduction of the exhaust emission levels. Evaporation losses can occur through the fuel canister, which is used to vent the fuel reservoir, through the non-metallic fuel lines or plastic fuel reservoir walls, or through losses in fuel line connectors and fittings. Evaporation occurs both when then vehicle operates but also when the vehicle is stationary in its parking position. In COPERT, evaporation is considered to originate from three operation phases, as described in equation (4). Fuel losses may occur diurnally as temperature varies during the day ($E_{DIURNAL}$), after operation (hot soak) when hot fuel is contained in the reservoir (E_{SOAK}), and during vehicle operation (running losses) when warm fuel is returned back to the reservoir ($E_{RUNNING}$).

$$E_{EVAP} = E_{DIURNAL} + E_{SOAK} + E_{RUNNING} \tag{4}$$

Particulate matter (PM) from the wear of tyres and brakes is a second source of non-exhaust emissions. A large fraction, but not all, of the tyre and brake pads worn becomes airborne and contributes to ambient PM concentrations. COPERT does not calculate the amount of dust deposited on the road surface which becomes airborne by resuspension of passing-by vehicles, but primary PM emissions occurring by the vehicle. For the calculation, a similar to equation (2) is used, with appropriate emission factors.

Emission Factors

The calculation of emission factors is the core of the COPERT methodology. Emission factors describe the emission performance of a vehicle and depend on the vehicle operation (e.g. momentary speed), particular processes (e.g. acceleration, deceleration), ambient conditions (most importantly temperature) and environment (e.g. altitude). Fig. 1 shows the instantaneous emission rate of a vehicle (in mg/s), over a specified driving sequence, which corresponds to an urban driving cycle.

The calculation of instantaneous emission level for all vehicles of a country and then integration to calculate an annual inventory is neither feasible nor of any practical application. Hence, COPERT is built around the average-speed approach. That is, emission factors are expressed as functions of the mean travelling speed over a complete driving cycle.

For the calculation of emission factors, a sample of vehicles is driven over several well-defined speed profiles (driving cycles) on a chassis-dynamometer. The mean emission level of each vehicle (in g/km) is then linked to the mean driving speed over each cycle. This produces a matrix of emission level values (g/km) over various mean speeds (km/h). By testing a large number of cars, representative emissions for the fleet can then be produced as a function of mean speed. An example of this approach is shown in Fig. 2, where each data point corresponds to the average emission level of the sample of vehicles measured over the particular driving cycle. The relatively large confidence intervals are due to the variable emission level of different cars, even when they share the same characteristics (size, fuel and emission standard). In addition, the mean emission level over some driving cycles differs from the level predicted by the trendline. This is a limitation of using the average speed as the only determinant of driving kinematics. However, the trendline has been derived as an unbiased predictor of the mean emission performance. This means that real-world deviations from the predicted values should, in principle, be cancelled out.

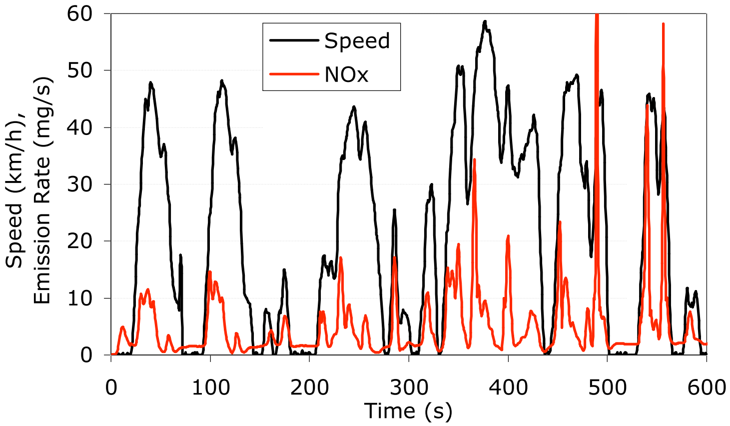

Fig. 1: Instantaneous speed and NOx emission rate of a Euro 4 passenger car over an urban driving cycle. The instantaneous emission rate varies by order of magnitudes, depending on the driving condition.

Sources of Information

COPERT offers emission factor functions for practically all widespread vehicle technologies in the European stock today. These functions have been derived in the framework of several research projects conducted by the Laboratory of Applied Thermodynamics and other research institutes in Europe. Major sources of information, between others, have been the FP4 MEET [2], the FP5 ARTEMIS [3] and PARTICULATES [4] projects, as well as individual work on evaporation emissions [5], biofuels [6] and hybrid vehicles [7]. The COPERT methodology has been included as the road transport calculation algorithm in the EMEP/CORINAIR Emission Inventory Guidebook [8], where more information and details on the emission factors can be found.

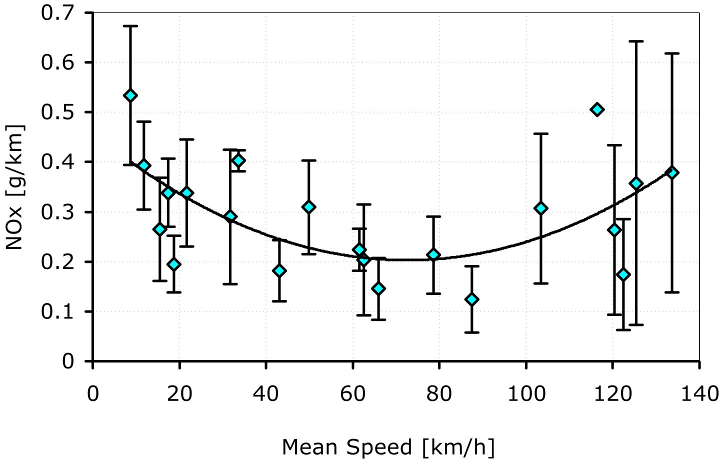

Fig. 2: Example of an emission factor function derivation. Each data point corresponds to the average emission level of a sample of Euro 3 gasoline passenger cars, driven over different driving cycles, each with a mean speed shown on the horizontal axis. Error bars correspond to the 95% CI of all vehicles tested (variable number of vehicles per cycle).

Software Application

Software Development

The COPERT methodology has been integrated into a software application, the latest version of which is COPERT 4 version 6.0 (December 2008). COPERT 4 is being developed under the Microsoft Visual Studio .NET 2003 environment and the programming language used is Microsoft Visual Basic .NET.

Microsoft Windows is required for the application to function and additional software requirements would be Microsoft .NET Framework v1.1 and an HTML browser (e.g. Microsoft Internet Explorer), that are freely distributed by Microsoft Corporation. The reports that are automatically created by the application use the Crystal Reports for Visual Studio .NET programming library, that is integrated into the software application.

The source code is divided into two main sections. The first section includes the user interface forms while the second section includes the programming code, which implements all the calculations the COPERT methodology requires. Using this programming code structure, the updates of the COPERT methodology can be easily integrated into the software and the changes in the user interface do not interfere with the calculation code.

All necessary data, such as input data, calculation parameters, intermediate calculation factors, and final results are stored in a Microsoft Access database file, although Microsoft Access is not required to be installed on the host computer. Since all the data are saved in a single file, the user can work on the file on different machines and send or receive files from other users for further process.

System Architecture

COPERT 4 is a stand-alone software application that uses Microsoft Access database files mainly as input. When the user opens a database file or creates a new one with COPERT 4, automatically a temporary file is created, where all the changes that are made during the process are saved. After the user completes the necessary calculation steps and saves the changes, the input file becomes the output one that can be used again as an input file by the same or another user (Fig. 3).

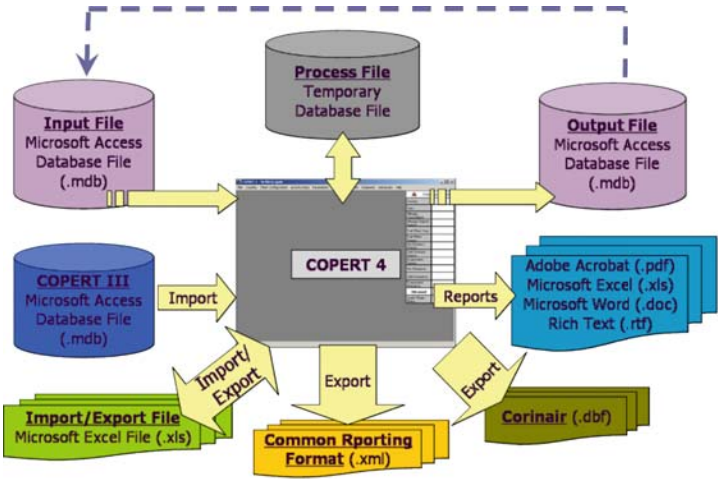

Fig. 3: COPERT 4 version 6.0 system architecture.

The user can provide input data to the application either by using the application's window forms, or by importing data from files that are created with earlier versions of the software, or from Microsoft Excel files. The results can then be exported in various formats, including Portable Document Format (pdf), Microsoft Excel, Microsoft Word, and Rich Text Format (rtf), for use in other applications. Furthermore all results can be exported into ready-to-import format for CLRTAP CollectER (DBF format) and the UNFCCC CRF Reporter (XML format).

User Interface

The user interface of COPERT 4 follows the standard Windows applications approach, since most of the users are familiar with such programs. The main screen (Fig. 4) of the software is divided in three areas. At the top there is the main menu bar from where the user can navigate through all the available forms. On the right there is the "run details" table showing to the user the stage of the inventory process, for example which factors and emissions are calculated or need to be calculated. At the bottom there is a bar showing the progress of any time-consuming procedure.

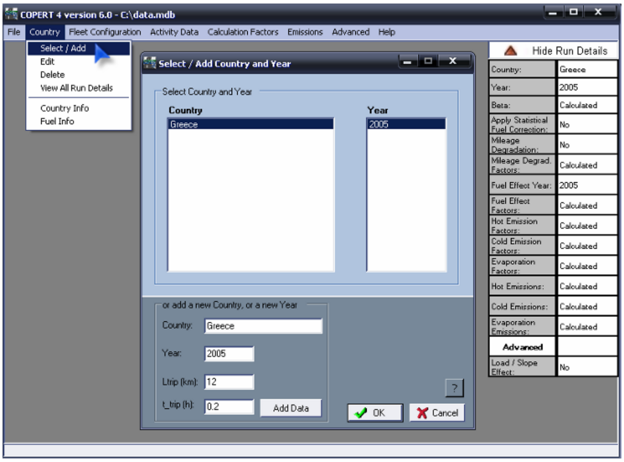

Fig. 4: COPERT 4 user interface.

Special forms exist to introduce all input, such as number of vehicles, annual mileage, travelling speeds, fuel properties, etc. The same interface is then used to process the information and to present the results either in list, or in more aggregated reports. The software contains viewers to see the reports and graphs to demonstrate main trends and conclusions.

Web-site

COPERT is supported by a website (http://lat.eng.auth.gr/copert/), where the users can download COPERT 4, the user manual, find quick start instructions, and all the necessary additional software. The users can also be informed about new and older software versions and the main aspects of the updated versions. A "Bugs and Frequently Asked Questions" section is also available, where the user can be informed for any problems that are located in the software and how these can be solved. Finally, a "Data" section has been recently added, where the users can download data which are required to run COPERT in different countries. These data have been collected in the framework of the project "European Database of Vehicle Stock for the Calculation and Forecast of Pollutant and Greenhouse Gases Emissions with TREMOVE and COPERT" funded by the European Commission and executed by LAT [9].

Results and Applications

COPERT can be used in a number of applications. Its main function is to assist national experts to compile national inventories for each country. Since the COPERT methodology is based on detailed reports and experimental data it can be also used for scientific purposes, i.e studies on emission calculations for specific fleets (e.g. captive fleets) and areas smaller than countries (e.g. a city or a region) as input to air quality modeling. In addition, the user can run scenarios based on already compiled databases, to investigate e.g. the effect of policy measures and the introduction of new technologies on emissions.

Vehicle Types Coverage

COPERT includes a number of vehicle categories and respective vehicle technologies. The vehicle categories covered include

- Passenger cars
- Light Duty Vehicles
- Heavy Duty Vehicles
- Buses
- Power Two Wheelers

These categories are further split into classes specific to each vehicle category. Passenger cars are distinguished into gasoline ones, further split into three capacity classes, diesel cars are split into two capacity classes, and then some additional subcategories such as LPG driven cars, 2-stroke engines and hybrids are also included. Light duty vehicles contain vans and small trucks and are distinguished into diesel and gasoline vehicles. Heavy duty vehicles consist of 15 sub-categories in total, with distinction according to type of vehicle (rigid or articulated), gross vehicle weight

(>3,5 t to 60 t) and the fuel (gasoline, diesel). Busses include urban busses and coaches, in different weight classes. Finally two-wheelers include mopeds (<50cc) and three subcategories of motorcycles.

COPERT deals with a number of fuel types widespread in road transport and updates the list whenever the use of the fuel is becoming important to the overall calculations. Currently the fuel grades included in the software are Gasoline Leaded, Gasoline Unleaded, Diesel, LPG, CNG, Biodiesel. The emission level of different vehicles depends on their technological level, i.e. their emission standard. COPERT covers all relevant EU vehicle technologies for each vehicle category. The technology steps considered range from 1970s technologies (PRE-ECE) up to forthcoming technologies (Euro 6 – 2015). Allocation of the vehicle stock to different technologies is key in developing an accurate emission inventory. The technology availability for passenger cars and light-duty vehicles is shown in Table 1, while Table 2 shows the technologies for heavy duty vehicles and motorcycles. COPERT contains emission factors for all these technologies

Table 1. Vehicle technologies for Passenger Cars and Light Duty Vehicles.

Passenger Cars	Light Duty Vehicles
PRE ECE	Conventional
ECE 15/00-01	LD Euro 1 - 93/59/EEC
ECE 15/02	LD Euro 2 - 96/69/EEC
ECE 15/03	LD Euro 3 - 98/69/EC Stage2000
ECE 15/04	LD Euro 4 - 98/69/EC Stage2005
Improved Conventional	LD Euro 5 - EC 715/2007
Open Loop	LD Euro 6 - EC 715/2007
PC Euro 1 - 91/441/EEC	
PC Euro 2 - 94/12/EEC	
PC Euro 3 - 98/69/EC Stage2000	
PC Euro 4 - 98/69/EC Stage2005	
PC Euro 5 - EC 715/2007	
PC Euro 6 - EC 715/2007	

Table 2. Vehicle technologies for Heavy Duty Trucks/Buses and Mopeds/ Motorcycles.

Heavy Duty Trucks/Buses	Mopeds/Motorcycles
Conventional	Conventional
HD Euro I - 91/542/EEC Stage I	Euro 1 - 97/24/EC
HD Euro II - 91/542/EEC Stage II	Euro 2 - 97/24/EC
HD Euro III - 2000 Standards	Euro 3 – 2002/51/EC
HD Euro IV - 2005/55/EC	
HD Euro V - 2005/55/EC	
HD Euro VI - COM(2007)851	

Example of Application – Greece 2005

As an example, COPERT has been used to compile the national inventory for Greece for the year 2005. Data necessary for the calculations include activity (vehicle population and annual vehicle mileage), circulation (vehicle speed and urban, rural and highway driving mode share), and evaporation data. Country specific information (average monthly temperature, RVP) is also important. These data, gathered from statistical sources, national agencies and several relevant studies are summarized in [9] and have been introduced in the software. Then, the emission factors and the total emissions have been calculated by the software. Table 3 presents the operating stock of Greece in terms of aggregated vehicle categories. The diesel passenger cars stock in 2005 mostly includes taxis, as diesel private cars are banned in Athens and Thessaloniki. Table 4 presents the mean travelling speeds used for the calculation of emission factors. Speeds are distinguished into urban, rural, and highway.

Table 3. Vehicle population and annual mileage.

Vehicle Category	Population	Annual Mileage [km]
Passenger Cars Gasoline & LPG	4 468 034	13 977
Passenger Cars Diesel	63 138	84 152
Light Duty Vehicles	948 320	19 916
Heavy Duty Trucks	254 699	40 000
Buses	15 983	40 000
Mopeds	1 433 448	4 000
Motorcycles	1 106 221	9 000

Table 4. Vehicle speed (km/h).

Vehicle Category	Urban	Rural	Highway
Passenger Cars	19	60	90
Light Duty Vehicles	19	60	90
Heavy Duty Trucks	19	60	90
Buses	19	60	90
Mopeds	20	40	-
Motorcycles	30	60	60

Based on these input data and with appropriate vehicle allocation in different categories, the total emissions from road transport in Greece for the year 2005 are shown in Table 5. The table shows that ~50% of total fuel consumption and CO_2 emissions originate from passenger cars. Passenger cars are also responsible for most of the CO emissions. Interestingly, power two wheelers are the highest emitters of VOC, due to their large numbers in urban areas. On the other hand, diesel vehicles and, in particular, heavy duty trucks and busses are responsible for some 55% of total NOx and PM emissions, despite their relatively small stock (Table **3).**

Table 5. Annual emissions and fuel consumption per vehicle category in 2005.

Vehicle Category	FC [Mton]	PM [ton]	NOx [ton]	VOC [ton]	CO [ton]	CO_2 [Mton]
Passenger Cars	4.37	387	32 535	41 121	312 618	13.8
Light Duty Vehicles	1.80	939	33 275	36 511	286 819	5.71
Heavy Duty Trucks	2.11	3 006	78 187	9 882	37 058	6.70
Buses	0.12	135	4 242	337	1 089	0.390
Mopeds	0.10	645	180	38 824	44 168	0.316
Motorcycles	0.27	207	1 770	17 375	140 802	0.873

Users

Users who wish to download the installation files from the COPERT website are asked to fill a form prior to downloading the software. This allows us to keep track of the downloads as well as the geographical coverage of the COPERT users, simply for statistical purposes. The software has been downloaded on average by 20 people per month in 2006, by 70 people per month in 2007, and by ~100 people per month in 2008. This brings the total number of users to a few thousand world-wide. Figure 5 shows the continent distribution of the users, and Figure 6 brings more detail into European users. The majority of users comes from Europe, with Italians, Spanish and French users being the more active.

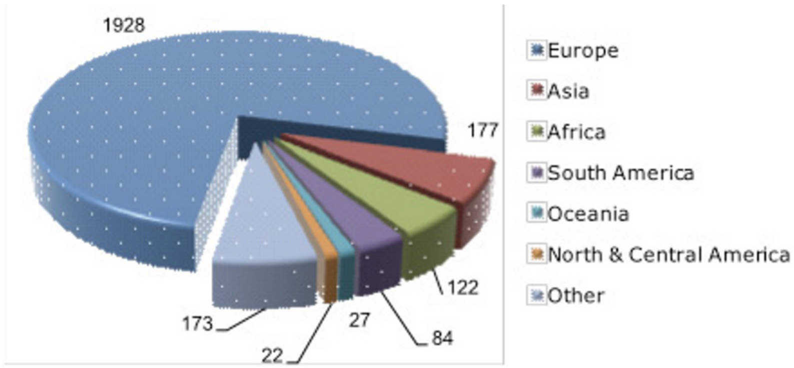

Fig. 5: Downloads per continent (in total for years 2006, 2007 and 2008).

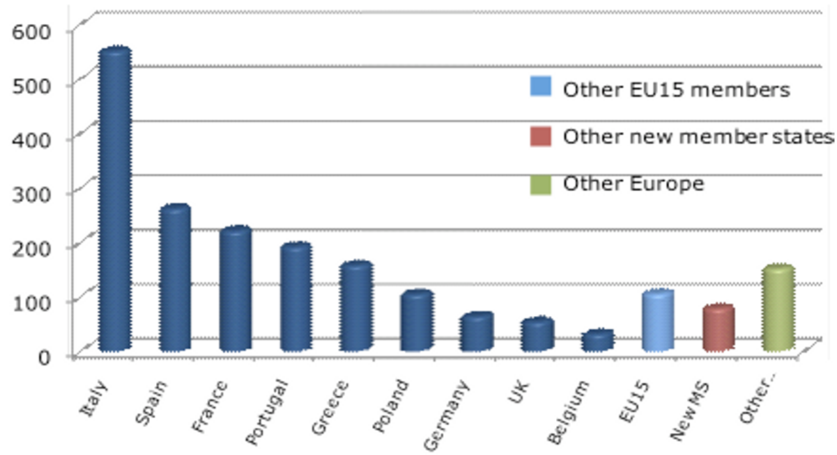

Fig. 6: Downloads per country (Europe, years 2006, 2007 and 2008).

Conclusions

COPERT is a user friendly software developed to calculate emissions from road transport at a national level. Its methodology can be also applied at a higher resolution. The programme is officially used by 22 out of the EU27 countries for the submission of the national inventories to CLRTAP. In addition, thousand of users worldwide have downloaded COPERT to use in own studies.

Application of the software to calculate the total emissions from road transport in Greece (Year 2005) revealed the contribution of the different vehicle categories to total national emissions. Passenger cars are the most important contributors to CO and CO_2, heavy duty trucks and busses are the most important NO_x and PM emitters, and power two wheelers are the highest contributors in VOCs. Appropriate application of COPERT can assist in determining effective policies for the reduction of air pollution from road transport and to provide useful input in air quality studies.

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