Implementation and Evaluation of the ARTEMIS Road Model for Sweden's International Reporting Obligations on Air Emissions

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Abstract
The aim of the present project was to implement and evaluate the new ARTEMIS road model for Sweden's international reporting obligations on air emissions. Fleet and traffic activity data on a national level, covering all years for the period 1990-2004, were compiled and adapted to fit the indata format required by the ARTEMIS model. The model outputs for the time period 1990-2004 for greenhouse and non-greenhouse gases were compared with outputs from calculations with the national road emission model presently used in Sweden, using the same fleet and traffic activity input data as for the ARTEMIS model. Furthermore, the results from the calculations with the ARTEMIS model were compared with real-world emission data available from on-road optical remote sensing measurements. The results show a reasonable agreement between the ARTEMIS model and the national model as regards CO_2-emissions, whereas for the regulated pollutants CO, HC, NO_X some significant discrepanices between the two models were observed. Furthermore, there was in general a fairly good agreement between the ARTEMIS model and the on-road emission data. However, the differences in HDV NO_X emissions between the Euro 1, 2 and 3 classes predicted by the model, was not observed in the on-road data.
***Keywords**:* Emissions, road vehicles, emission models, ARTEMIS model.

Introduction

The UNFCCC (United Nations Framework Convention on Climate Change, the UNECE CLRTAP (United Nations Economic Commissions for Europe Convention for Long-range Transboundary Air Pollution), and the EU NEC (National Emissions Ceiling) Directive, require yearly reporting of national emissions to air of a number of pollutants for the parties concerned. The compiling of the national emission inventories follows dedicated guidelines for the reporting in order to fulfil international quality objectives such as data being transparent, consistent, comparable, complete and accurate. The compilation and reporting of the national emissions are made on a sectoral level (e.g. transport) as well as on sub-sectoral levels (e.g. road transport, passenger cars, diesel fuelled road vehicles). In order to comply with all the quality objectives of the reporting, sectoral and sub-sectoral emission models are very useful. Both national (country-specific) and international emission models may be used, as long as the quality objectives are reached. Until reporting year 2003, Sweden has used a national emission model for road traffic for the international reporting obligations. However, a national strategic decision was recently taken by the Swedish Road Administration to switch to a EU-common model, with the first choice being the new emission model for road traffic developed within the EU 5th FP project ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems). Since according to the Kyoto protocol no changes in methods are allowed in the reporting to UNFCCC after 2005 for the Kyoto first commitment period, extending until reporting year 2012, the implementation of the ARTEMIS model in Sweden, at least for the direct greenhouse gases CO_2, N_2O and CH_4, needed to be completed before the end of 2005 and to cover the whole timeseries 1990-2004.

1 - Objectives

The aim of the present project was to implement and evaluate the new ARTEMIS road model for Sweden's reporting obligations on air emissions to the UNFCCC (the Kyoto protocol), the EU NEC Directive, and the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP).

2 - Methods

The ARTEMIS road model

The ARTEMIS road model has been developed within the framework of the EU 5th FP project ARTEMIS, "Assessment and Reliability of Transport Emission Models and Inventory Systems". The model provides emissions and emission factors for segments and subsegments of six main vehicle categories (PC, LCV, HCV, Urban bus, Coach, and MC including mopeds) for a large number of traffic situations, as well as for average speeds, based on emission measurements according to different sets of real-world driving cycles, representative for typical European driving (Keller et al, 2005). The model's calculated emissions are separated into hot emissions, cold start emissions and evaporative emissions. The results presented in this report are from the version 0.2T of the ARTEMIS model.

Fleet data

The vehicle fleet is described by means of the number of vehicles on category level, along with segment and age distributions, derived from the Swedish national vehicle register. This register is updated with new registrations and scrapped vehicles on a daily basis. Fleet data should be representative for each year 1990-2004. A simplification could be to use the vehicle register data available by June 30 for each year. However, in the Swedish case vehicle register data available by December 31 is used. This approach requires special efforts for the youngest age class.

As for segment and age distributions some problems arise when vehicle concepts or vehicle definitions according to the ARTEMIS model are not recognised in the national vehicle register. For instance, for passenger cars, information on swept engine volume is not available in the register. Swept volume for different car models sold in Sweden are however available in a fuel consumption data set provided by the Swedish Consumer Agency. This dataset has been matched against the vehicle register for 2004, with approximately 1 million hits out of the approximately 4 million passenger cars registered in the national vehicle register. Based on this matched dataset, swept volume functions were estimated for diesel and petrol cars separately. Swept volumes are expressed as a function of year of registration; engine power, and vehicle weight.

The distinction between coaches and urban buses is based on the measure p/w: p=max allowed number of passengers/w=gross vehicle weight. An urban bus is defined as p/w>3,75. All other buses are coaches.

In order to describe trucks, two segment levels are used: with and without trailers. In the Swedish national vehicle register there is no information about the use of trailers. Trucks with trailers are described by means of vehicle transformation patterns. The transformation pattern describes distribution of mileage in each weight class with and without trailer. The segment level "with trailer" is split further into different sizes of trailers expressed as the total weight class of the vehicle combination.

For motorcycles swept engine volume is available from the national vehicle register, however not the type of engine (2- or 4-stroke). Type of engine was estimated based on year of registration, swept volume, engine power and manufacturer.

For each segment in each category there will be an age distribution including 60 year classes. The definition of the age of a vehicle is based on the first date of registration according to the national vehicle register. For privately imported cars, which is a growing phenomena in Sweden, the year of first registration is replaced by the year of manufacturing when estimating age distribution.

For each vehicle segment, each year class of first registration is assigned one or more emission concept groups by means of the indata function "Introduction schemes of emission concepts" in the ARTEMIS model. The code representing a vehicle's emission concept group in the national vehicle register is sometimes missing. In such cases codes have been assigned based on the year of first registration together with dates for introduction of new exhaust regulations.

Traffic activity data

Mileage etc.

The ARTEMIS model requires yearly mileages per vehicle category. For Sweden these are calculated by means of a national road mileage model. Important inputs to this model are mileage on roads administrated by the Swedish Road Administration based on traffic measurements, along with the number of vehicles in different categories. The annual mileage per vehicle category is derived by dividing the total mileage per category with the number of vehicles per category. By supplying the same number of vehicles together with the derived mileage, the ARTEMIS model will provide the same mileage as the national road mileage model.

Yearly mileages per vehicle subsegment level is used to distribute the total mileage on subsegments. Statistics Sweden has developed a method which can assign all vehicles in the register an annual mileage, based on yearly odometer readings within the Swedish inspection & maintenance (I/M) programme. These data has been used for deriving both the subsegment level mileage, and for estimating mileage as a function of vehicle age.

Load patterns as a function of age is used for heavy commercial vehicles on segment level. The ARTEMIS model requires for each segment a mileage distribution on load factor 0% and 1-99% for 60 age classes. These data have been estimated based on a major national survey:"Swedish domestic road goods transport" from 1997, including detailed information about both truck and trailer loads.

In order to estimate evaporative and cold start emissions data on trip lengths, parking times, and seasonal and diurnal variation of ambient temperature are needed. Trip lengths and parking times can be derived from surveys, or from data from instrumented cars. For Sweden an average trip length according to surveys is 12 km, and from instrumented cars 7 km. Instrumented cars give the length from engine start to engine stop, i.e. the form of data requested. Even if instrumented car data just represents a few vehicles and use in few families, this data set has been considered more reliable and thus used in the Swedish application.

The function FuelQuality in the ARTEMIS model is used for correction of emissions from diesel engines and for estimations of evaporative emissions (RVP) and SO_2 emissions. The Swedish EPA used to take representative samples and analyze fuels at filling stations until 1990. From year 2000 there is again data available on an annual basis, provided by Swedish Petroleum Institute. In the ARTEMIS model diesel fuel qualities are described as classes Euro 0 to Euro 4. However, by mainly using the sulphur content for classification the deviation at least for SO_2 should be minor.

Traffic situations

The ARTEMIS model includes 276 traffic situations, i.e. combinations of 69 road categories and for each of those 4 classes of traffic conditions. Furthermore it is possible to add different level of grade, however this was not done for Sweden. The national vehicle mileage for year 1990, 1995, 1998, 2000 and 2004 had initially been estimated through the VM-Model (SIKA and VTI, 2005). Procedures were established to allocate the total vehicle mileage over 1) urban and rural roads, 2) road categories, 3) traffic flow conditions, and to fit the result to the traffic situations in ARTEMIS.

Two national GIS road databases were employed. The first, VDB, contains all state road links attached with information about: length, road function, speed limit and ADT (average daily traffic) split on light and heavy vehicles. The second, NVDB, were used for municipal and private roads links. NVDB contains road classification and length but lacks ADT. Traffic simulations were performed for four regions to represent the distribution of vehicle mileage over road categories for municipal and private roads. To separate between urban and rural road links a GIS layer with polygons for built-up areas (delivered by SCB, 2005) were utilized. Through this, the study was able to presents new figures concerning the distribution of vehicle mileage over urban and rural roads in Sweden: 41% respective 59%. Furthermore, a model for distributing the urban vehicle mileage on cities of different sizes is presented. Ranking curves for different road types from Björketun et al (2005) and Jensen (1997) were employed for the yearly variation of ADT (monthly, weekly, daily and hourly). Calculations of traffic flow and vehicle mileage at different hours (using ranking curves) for each link of the state road network was performed. Similar calculations were carried out for the municipal and private road links in the test-regions. The results, traffic flow per lane and hour at different rank classes, were related to volume-delay functions according to Matsoms (2004). Hypotheses were formulated concerning the distribution of vehicle mileage for stop & go (level of service 4), which can not be estimated from volume delay functions alone. The work resulted in a distribution of the vehicle mileage (light and heavy vehicles) over road categories and traffic conditions for the Swedish road network for the years 1990, 1995, 1998, 2000 and 2004.

Swedish road categories were translated to ARTEMIS traffic situations based on the description of road hierarchy, speed limit, function and design. Then it was possible to sum the vehicle mileage in Sweden over the traffic situations in ARTEMIS for different years. Eighty-five of ARTEMIS's 276 TS were identified in Sweden in 2004. They consisted of 33 road categories where most of them rarely exceeded traffic condition free flow or heavy traffic. As much as 94% of the vehicle mileage in Sweden is driven at free flow conditions. Stop and go (0.05%) only occurred in the cities >2000000 inhabitants. In Larsson and Ericsson (2006) is reported more details concerning the methodology and results e.g. the most common traffic situations in Sweden.

Verification data

Calculations with the national EMV model

The nationally developed road vehicle emission model EMV has been used since the mid 1990's for Sweden's international reporting obligations on air emissions (Hammarström & Henriksson, 1997; Hammarström & Karlsson, 1998). The EMV model is considered a top-down model, which calculates emissions of regulated and some unregulated compounds for different vehicle categories divided on mainly two traffic situations: urban och rural driving. Besides hot emissions, the EMV model calculates cold start and evaporative emissions taking into account Swedish climate, vehicle fleet etc. For light-duty vehicles the hot emissions and cold start are taken from measurements according to the US FTP driving cycle. Cold start emissions from US FTP are adjusted for Swedish conditions based on most detailed background data. For heavy duty vehicles emission data comes to a large extent from the same sources that feed into the ARTEMIS model, i.e. the COST 346 project, and for the Swedish fleet and road conditions. Thus, the main differences between the two models are the number of traffic situations available, and the driving cycles representing the emissions for light-duty vehicles. The EMV model calculates emissions down to a level formed by the combination: vehicle type, engine type, year model, emission concept level and fuel quality. A change in fuel quality parameters will result in a change of emission factors.

For the present project the activity data in the EMV model was updated to be as equivalent as possible to the activity data fed into the ARTEMIS model.

On-road emission data

The on-road emission data were from a major remote sensing measurement campaign carried out in Göteborg, Sweden, in 2001 and 2002, originally applied for an evaluation of the COPERT III model (Ekström et al, 2004), therefore only a brief description will be given here. The dataset comprised of instantaneous emissions of CO, HC and NO expressed as grams pollutant released per liter fuel burnt for some 18,000 gasoline passenger cars, some 1,000 diesel passenger cars, and some 600 heavy commercial vehicles. The two measurement sites were classified according to the ARTEMIS traffic situation scheme as Urban Distributor with posted speed 50 km/h and slightly uphill grade of about 2% (one of the sites actually had posted speed 70 km/h, but the actual, measured average speed was closer to 50 km/h, cf. also the Results section).

3 - Results

Comparison of ARTEMIS results with results of the EMV model

Compared to the EMV model, the ARTEMIS model yields 3 percent higher CO_2-emissions in 1990 and 6 percent higher in 2004, cf. Figure 1. The observed differences are mainly due to higher fuel consumption for HDVs according to the ARTEMIS model, especially for those older than 1990, and higher fuel consumption for new passenger cars according to ARTEMIS. The decrease in fuel consumption over the years is also smaller according to the ARTEMIS model than according to the EMV model. The fuel consumption for cars with cylinder volume larger than 2 liters is actually increasing over the years according to the ARTEMIS model, most likely because the average engine size within this vehicle segment increases.

For NO_X, the ARTEMIS model yields 4 percent higher emissions in 1990 and 19 percent higher in 2004 compared to the EMV model, cf. Figure 2. The main reason is that the ARTEMIS model in general yields higher emissions for in particular gasoline passenger cars.

For HC, the ARTEMIS model yields markedly higher emissions than the EMV model in both 1990 and 2004: 59 and 42 percent, respectively. A comparison between the two models for gasoline PC HC emissions, separated into hot, cold start and evaporative emissions, are available for 1995 and 2005, cf. Figure 3. It can be seen that, whereas cold start emissions are fairly equal between the two models, the ARTEMIS model yields substantially lower hot emissions, and much higher evaporative emissions. The uncertainty of in particular the evaporative emissions is considered to be high, since both models in this case build on a very limited number of measurements.

Comparison with on-road data

Results from the comparison of output from the ARTEMIS model with on-road remote sensing emissions data are presented in Figures 4 and 5. For gasoline passenger cars hot emissions there was in general a good agreement between model and on-road data for all three pollutants covered (CO, HC and NO). Results for CO and NO show similar patterns as the one presented for HC in Figure 5. This is strong support for both the ARTEMIS model describing gasoline passenger cars' hot regulated emissions adequately, not only present but also historical emissions (e.g. 1990), as well as for on-road optical remote sensing being a powerful tool for verifying and evaluating road vehicle emission models. As can be seen by Figure 5, there is also a fairly good agreement between the ARTEMIS model and on-road data for HDV NO_X emissions, although the on-road data do not reveal any significant differences in NO_X emissions between the Euro 1, 2 and 3 classes.

Conclusions

This study has demonstrated a reasonable agreement between the ARTEMIS model and the national model as regards CO_2-emissions (present and historical), whereas for the regulated pollutants CO, HC, NO_X some significant discrepanices between the models were observed. In contrast, the ARTEMIS model agrees well with on-road emission data, although the differences in HDV NO_X emissions between Euro 1-3 classes predicted by the model, was not confirmed by the on-road data.

Acknowledgements

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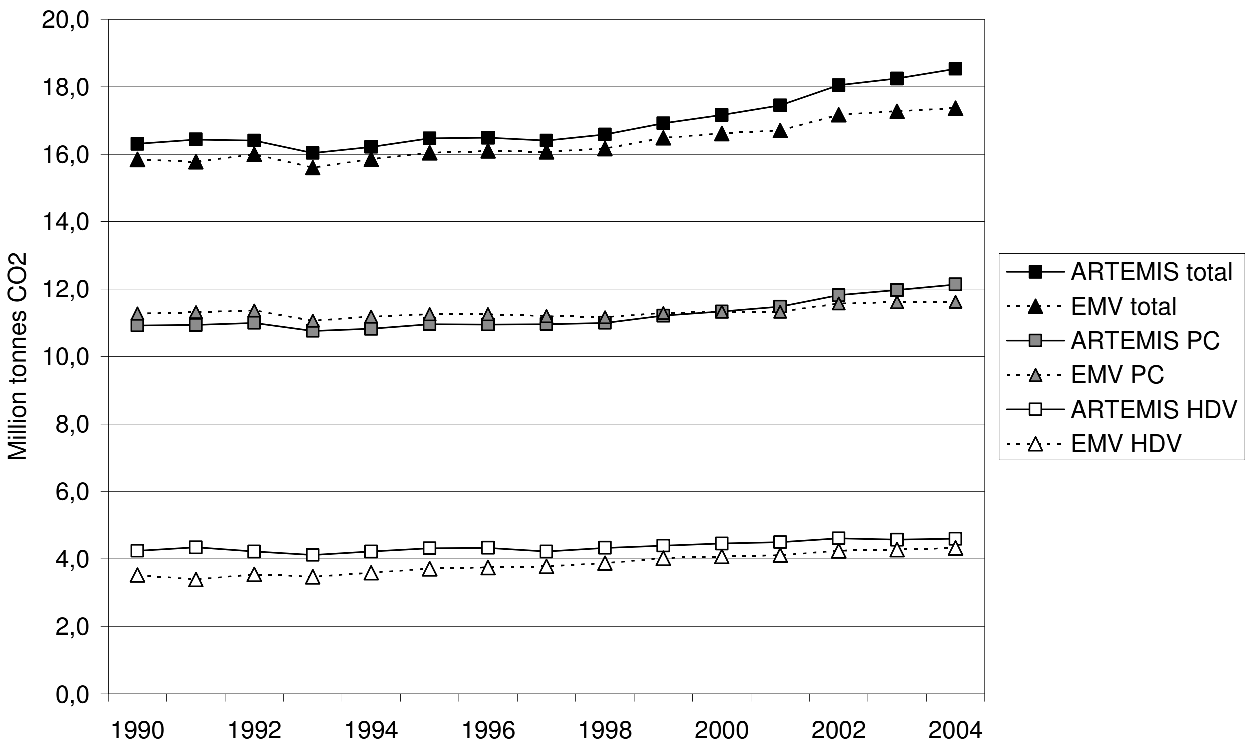

Figure 1: Yearly national CO_2 emissions from road traffic in Sweden for the period 1990-2004 according to the ARTEMIS model and the national model (EMV), respectively.

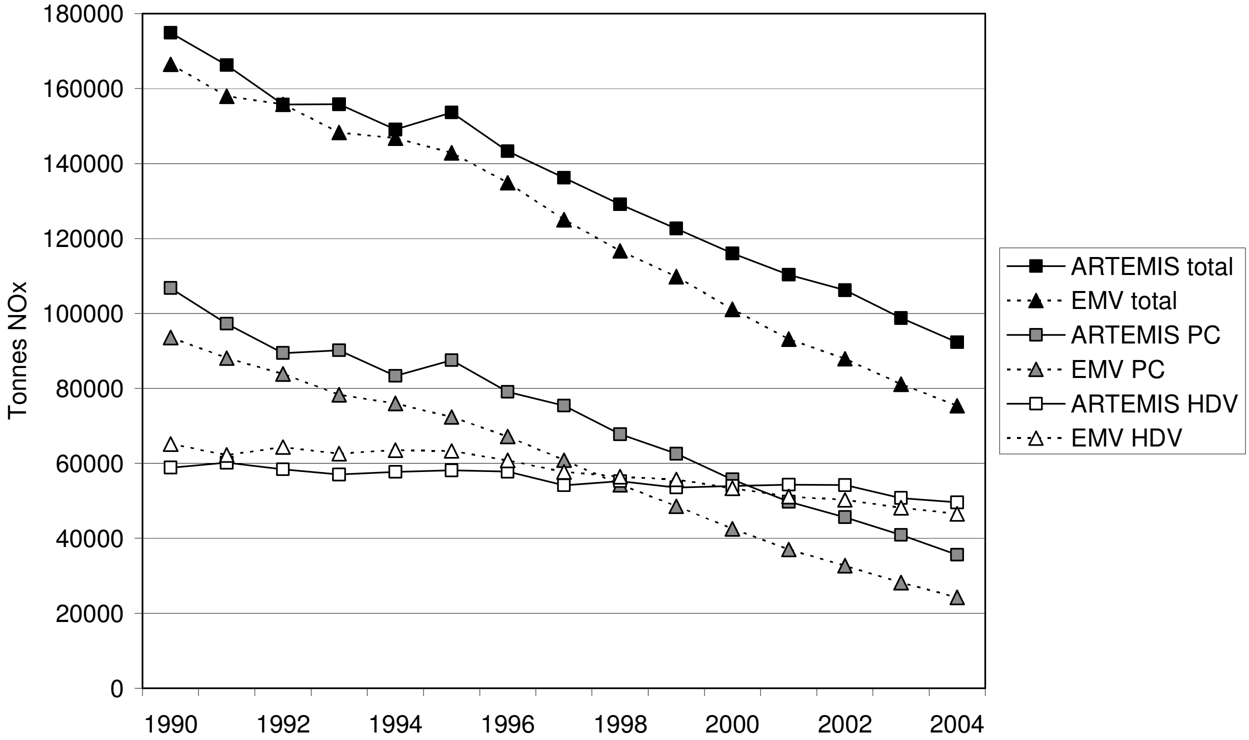

Figure 2: Yearly national NO_X emissions from road traffic in Sweden for the period 1990-2004 according to the ARTEMIS model and the national model (EMV), respectively.

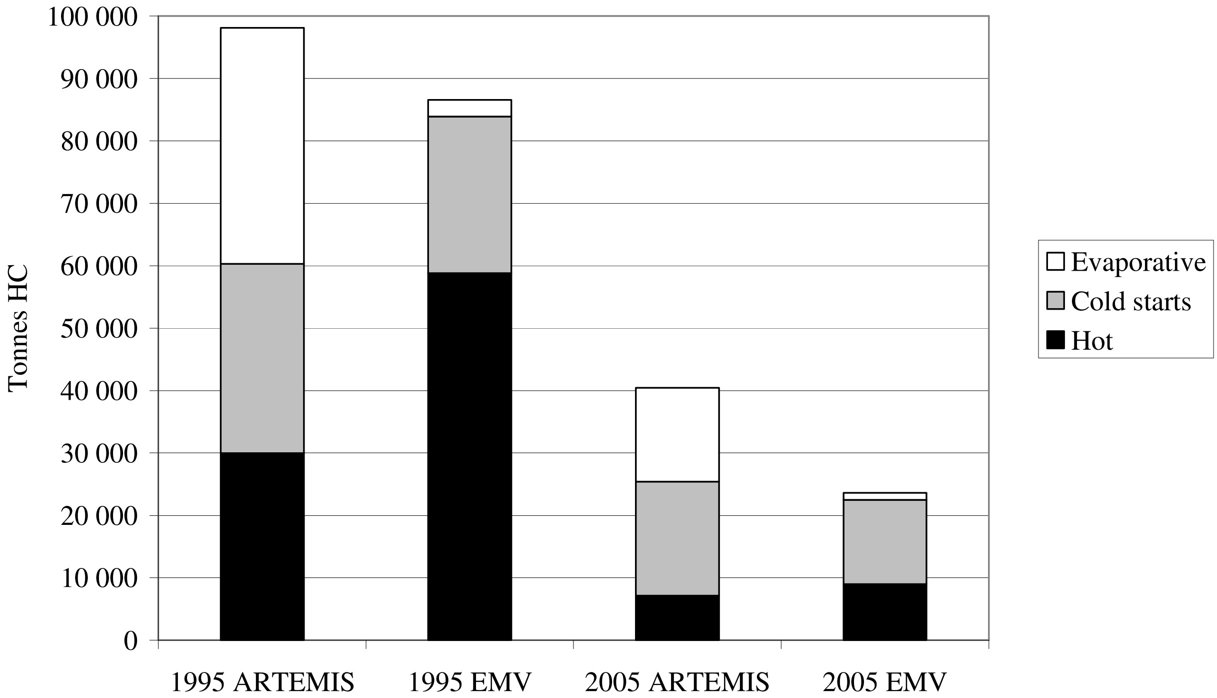

Figure 3: HC emissions from gasoline passenger cars in Sweden in 1995 and 2005 according to the ARTEMIS road model and the national model (EMV), respectively.

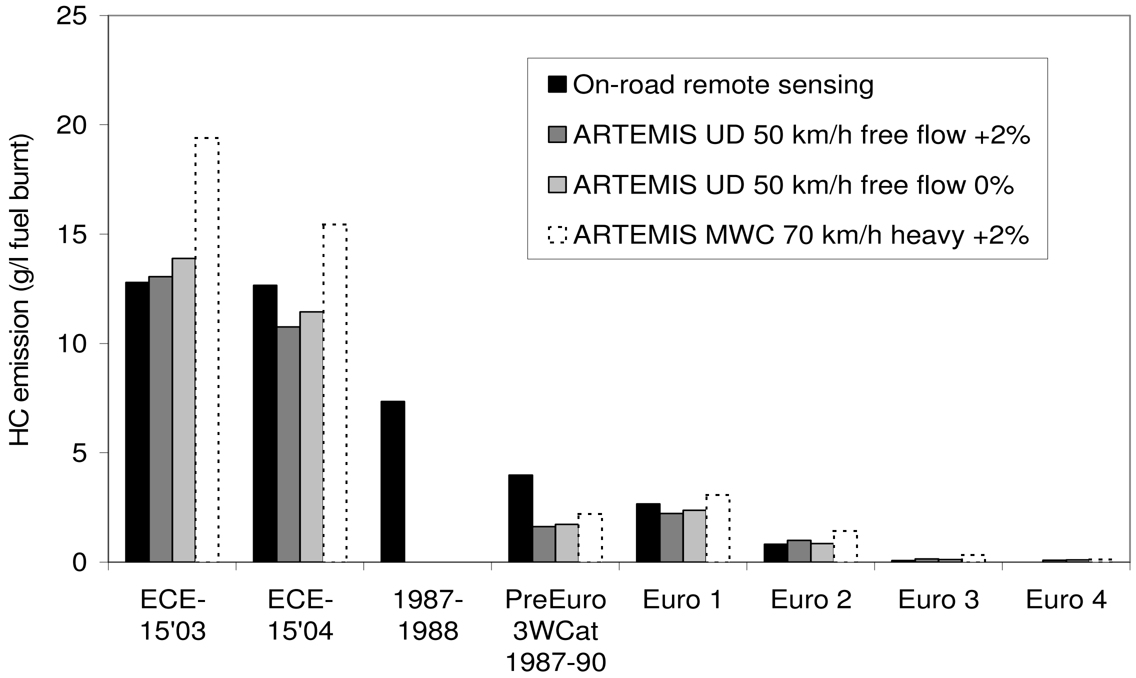

Figure 4: HC hot emission factors (expressed as gram pollutant emitted per liter fuel burnt) for gasoline passenger cars according to on-road remote sensing measurements and according to the ARTEMIS model (UD = Urban Distributor, MWC = Motorway City, 50/70 km/h = posted speed, free flow/heavy = level of service, %-figures = applied road grade according to ARTEMIS road model traffic situations definitions).

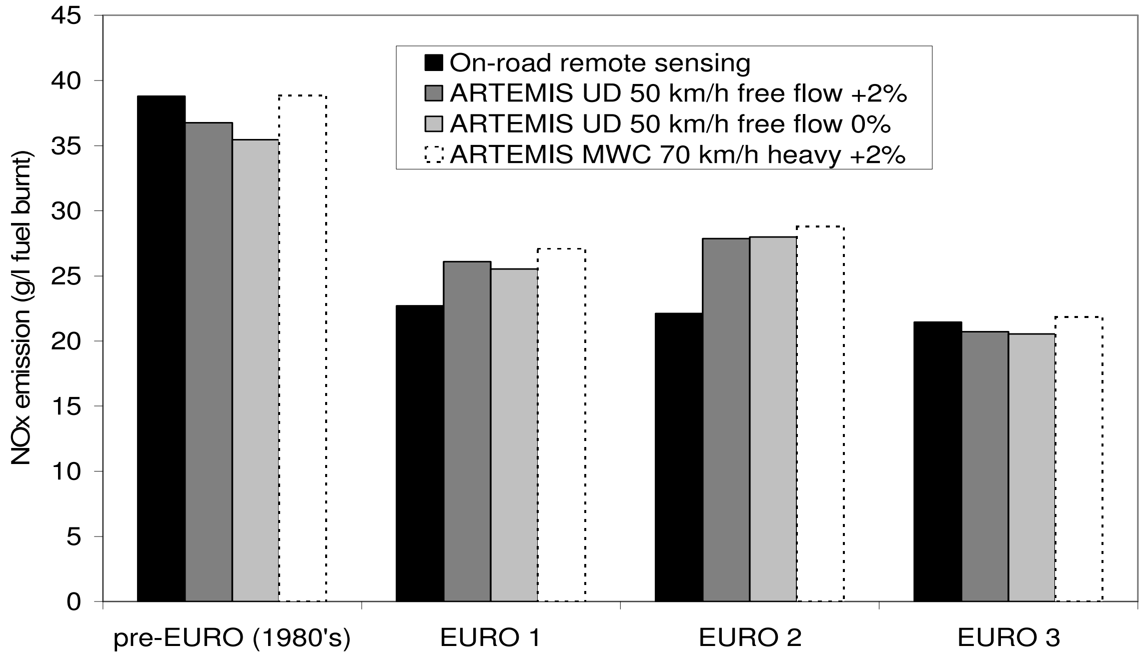

Figure 5: NO_X emission factors (expressed as gram pollutant emitted per liter fuel burnt) for heavy goods vehicles (HGV) according to on-road remote sensing measurements and according to the ARTEMIS model (UD = Urban Distributor, MWC = Motorway City, 50/70 km/h = posted speed, free flow/heavy = level of service, %-figures = applied road grade according to ARTEMIS road model traffic situations definitions).