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Estimation of the change in emissions of powered two-wheelers due to new legislation

Contents

1) ABSTRACT

The impact of road traffic emissions on the environment and human health has been growing in importance in recent years. Most countries and manufacturers agreed to emission standards for vehicles to reduce their pollutant emissions, particularly in urban areas with high traffic density. Unlike to passenger cars the emissions of powered two wheelers (L-category vehicles) have not been considered intensively for a long time but it is assumed that their share of hydrocarbon emissions to the total hydrocarbon emissions of road traffic is disproportionately high.

Due to the new regulation (EU) 168/2013 vehicles of L-category have to fulfill new emission standards from 2016 (Euro 4) and 2020 (Euro 5) onwards. Besides new limits for the tailpipe emissions there is a regulation for pollutants caused by fuel evaporation for the first time, as the share of evaporative hydrocarbon emissions in this vehicle class is deemed to be rather high.

The Federal Highway Research Institute (BASt) analyses the emissions of road traffic in Germany in order to support political decisions scientifically and to assess regulations. For that purpose we use the emission and calculation tool TREMOD (Transport Emission Model) which provides baseline data and calculated results for pollutants in almost every differentiation i. e. vehicle class, traffic situation and road type. Moreover, estimations to future emission trends, stock information and mileage distribution can be made.

This paper investigates the impact of the upcoming emission standards Euro 4 and Euro 5 on the exhaust hydrocarbon emissions from motorcycles. One significant aspect is to generate scenarios with TREMOD to show the reduction potential for hydrocarbon emissions of this vehicle class in a defined period. As a result of our research we can give a first estimation of the influence of the new emission regulation (EU) 168/2013 on the total hydrocarbon emissions of motorcycles by means of modeling.

Keywords: pollutant emissions, L-category vehicles, powered two-wheelers, fuel evaporation, modeling

2) INTRODUCTION

The road transport is in addition to the energy sector and the industry the largest emitter of air pollutants and carbon dioxide (BMWi, 2013). The management of increasing traffic, especially in the freight section and in urban area and the associated impacts on infrastructure and environment represent major challenges to legislators and infrastructure planners. Despite of major efforts to reduce the environmental impacts by regulations or agreements at national and international level (Kyoto Protocol, emission standards) the economic damage due to air pollution that causes problems for people and nature are growing steadily worldwide (UNEP, 2014). In this context, the calculation and forecast of road transport emissions are important to verify compliance of climate targets and to assess the reduction potential of technical systems or organizational measures. This requires detailed information on the emission behavior of all road users as well as their driving performance to derive vehicle segment-related emissions for the relevant pollutant components. In this way, it is possible to detect those vehicle classes and segments, whose emissions contribute disproportionately to environmental pollution.

The emission legislation for powered two-wheelers has not been adjusted since 2006, although their share of hydrocarbon emissions to the total hydrocarbon emissions from road traffic in Germany is disproportionately high. Hydrocarbon emissions result from missing or incomplete combustion processes within a combustion engine and pass through the exhaust system into the atmosphere if no exhaust gas aftertreatment system is installed. While passenger cars are equipped with catalytic converters since the mid-80's, the installation of exhaust gas treatment systems for motorcycles is practically necessary since introducing new emission limits within Euro 3. For this reason, older motorcycles that have been built up to this date emit significantly higher hydrocarbon emissions than newer vehicles that fulfill Euro 3 standards as these last ones are equipped with catalytic converters. In particular, mopeds, which are often equipped with two-stroke engines, produce more hydrocarbon emission than four-stroke engines due to their more inefficient operation process. As their driving mileage can be expected in urban areas mainly their contribution to the deterioration of air quality in cities is rather high. The formation of ground-level ozone and strong smell nuisance are the direct result of this.

Due to the regulation (EU) 168/2013 (EU Regulation 168/2013) new emission standards for powered two-wheelers will be introduced in 2016 (Euro 4) and 2020 (Euro 5). Besides stricter emission standards for the tailpipe emissions the evaporative emissions are limited for the first time, as the share of evaporative hydrocarbon emissions in this vehicle class is estimated to be rather high.

In this research project the evolution of exhaust hydrocarbon emissions from motorcycles after the introduction of new emission standards is investigated based on statistical estimations. The change in the share of evaporative emissions to the total share of emissions in this vehicle class should become clear as well. As a result, the possible saving potential of harmful exhaust gases (in this case hydrocarbons) of motorcycles after introducing the new legislation should be shown. The calculation and modeling of emissions is carried out with the emission calculation tool TREMOD (IFEU, 2012) which is used by the Federal Highway Research Institute in the field of energy and emissions.

3) MATERIALS AND METHODS

3.1) TREMOD

The availability of correct data of emissions and energy consumption from the traffic sector is an essential basis for environmental reporting, the preparation of laws and policy decisions. Due to continuously evolving environmental regulations, detailed information on the emissions of road users are increasingly required in order to verify their effectiveness. For this reason, the development of the emission calculation model TREMOD was initiated in the early 90's on behalf of the Federal Environment Agency in Germany, in order to query detailed information concerning emissions, fuel- and energy consumption for road-, rail-, air-, and waterway transport in Germany. Due to the importance of the road traffic sector (the share of CO_2-Emissions caused by road traffic to the total CO_2-emissions in Germany was 17,4% in 2010) this sectior is implemented in detail (UBA, 2012). TREMOD therefore contains very extensive information of annual traffic from passenger- and freight transport, differentiated with regard to road category and traffic situation, as well as on emissions and fuel consumption for all road users differentiated according to motorization, emission standard, displacement etc. Table 1 lists few of the differentiation criteria for road traffic used in TREMOD.

Table 1: Differentiation criteria in TREMOD

Differentiation criteria	
Vehicle category	Passenger car, heavy duty vehicle, motorcycle…
Motorization / fuel	Gasoline, Diesel, LPG, CNG, …
Emission standard	Euro 1, Euro 2, Euro 3, Euro 4, …
Displacement class / engine capacity (for PC)	<1,4l, 1,4-2,0l, >2,0l
Displacement class / engine capacity (for PTW)	<50cm³ (mopeds), <150cm³, 150-249cm³, 250-750cm³, >750cm³
Pollutant components	HC, NO_x, CO, CO_2, SO_2, CH_4, …
Traffic situation	Stop & Go, Saturated, Free, …
Road gradient	0%, +/- 2%, +/- 4%, +/- 6%

The input database in TREMOD consists of real emission- and fuel consumption data of all road traffic vehicle categories in terms of emission factors, as well as on detailed information of annual traffic, differentiated for vehicle category, type of road and area, which are collected as a part of driving performance surveys and counting stations. As it is almost impossible to measure real emissions and energy consumption for all vehicle categories including their sub segments for all relevant traffic situations, emission factors are derived for a wide range of driving patterns from an engine-map based computer-tool (PHEM, Passenger car and Heavy duty Emission Model), which generates specific emission rates (usually given in grams per kilometer) for one vehicle type for a given pollutant in a specific driving situation (PHEM, 2009). In addition to these so called "hot" emission factors, which describe the emission rate of a vehicle at operation temperature, effects like cold start or different payloads (heavy duty vehicles) on the emission behavior can be simulated within the tool. The calibration of the tool requires a broad set of emission measurements of different vehicle concepts and it is needed to be adapted to new vehicle technologies and exhaust gas after treatment systems (e.g. selective catalytic reduction system, SCR). The emission factors are collected within the Handbook of Emission Factors of road traffic (HBEFA), which provides emission factors for almost all current vehicle categories for a wide range of traffic situations (HBEFA, 2013). Due to different country specific parameters like fleet compositions or ambient conditions (temperature distribution) some kinds of emission data like cold start excess emissions or fuel evaporation are adapted to the situation in the HBEFA member states. The continuous updating of the database of HBEFA by means of measuring new vehicles on exhaust test benches and the following generation of emission factors is mainly promoted by national authorities from Germany, Switzerland, Austria, France, Sweden, and Norway.

Provided that emission rates for one vehicle segment in relevant traffic situations are known the total emissions for this class are determined in TREMOD by multiplying the emission rates with the annual traffic of this vehicle class taking into account the vehicle stock evolution of this class. Information on vehicle stock and fleet distribution in TREMOD are taken from the Federal Motor Transport Authority (Kraftfahrt-Bundesamt) and are implemented in TREMOD annually. The prediction of future vehicle stock in TREMOD is done based on estimations of future registrations and on survival curves for actual vehicles. The survival curves describe the percentage decrease within the vehicle stock over a defined period. Based on the survival curves, the proportion of those vehicles that are eliminated from the market due to age can be determined.

The continuous updating of the input data in TREMOD by generating emission factors of new vehicle types on the one hand as well as the implementation of actual traffic mileage and vehicle stock information is necessary to ensure the usefulness of the calculated results. The results are presented in annual steps retrospectively from the year 1960 up to the current date based on real emission data and as well real information of driving performance and fuel consumption and as a trend scenario up to 2030, in which assumptions on future trends in vehicle technology, emission standards and traffic density are made. The actual TREMOD database which is used in this study at hand is the version 5.52.

3.2) Background Calculations

The emission standards of powered two-wheelers have been regulated by the European commission by introducing the emission standard Euro 3 for motorcycles (MC; Powered two-wheelers with a displacement >50 ccm) in the year 2006 and Euro 2 for small motorcycles (SMC; Powered two-wheelers with a displacement <50 ccm) in the year 2001. In the frame of this regulation the limits for the pollutants hydrocarbons, nitrogen oxides and carbon monoxide were fixed. Since this date there has not been a further adjustment of the limits of powered two-wheelers, while the emission limits for passenger cars and trucks have been reduced successively during this period. Due to the regulation (EU) 168/2013 the emission legislation for powered two-wheelers will change with the introduction of new emission standards in 2016 (Euro 4) and in 2020 (Euro 5). Beside to the previously regulated pollutants additional limits for particulate matter PM (Euro 4) and non-methane hydrocarbons NMHC (Euro 5) are fixed. In addition to that the evaporative emissions are regulated separately for the first time, as they contribute to a high proportion of the total HC emissions in this vehicle class. The evaporative emissions can be divided into three types:

- Running losses: fuel fractions which evaporate on hot components of the engine or exhaust system during the vehicle is running
- Hot soak emissions: fuel fractions which evaporate on hot components of the vehicle after switching off the machine
- Diurnal losses: Such fuel components that evaporate through the fuel system when the vehicle is parked for a longer time

The measurement of evaporative fuel fractions is based on the SHED testing procedure (sealed housing for evaporative emission determination,) (EU Regulation No 134/2014) in which vehicles are investigated in gas-tight air chambers on the outlet of hydrocarbon vapors. In addition to the new emission limits the durability of emission control systems (on-board diagnosis system, oxygen sensor, catalytic converter) is prescribed for the first time. Moreover, the regulation includes a timetable for the implementation of new limit values and test procedures. Figure 1 shows the successive reduction of the pollutant limits for motorcycles. The limits of the Euro 5 emission standard of motorcycles are similar to those for the Euro 6 emission standard for passenger cars with a gasoline engine.

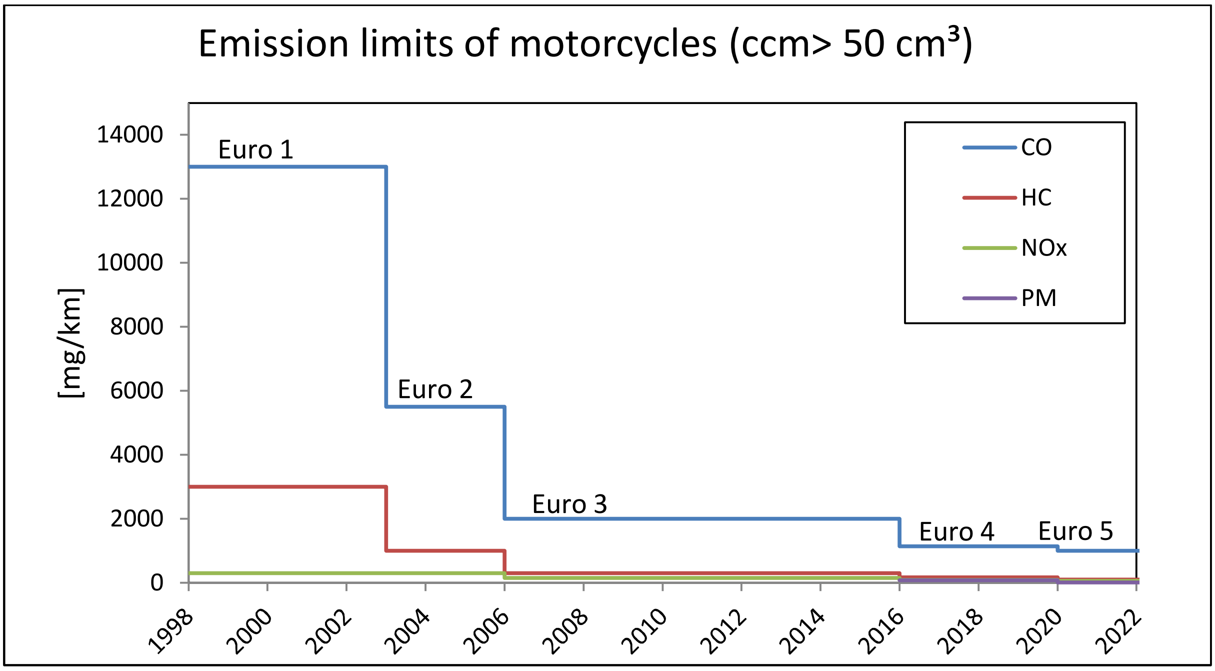

Figure 1: Comparison of the emission limits for the various pollutants for motorcycles for different Euro limits (CO = Carbon Monoxide, HC = Hydrocarbon, NOx = Nitrogen Oxide, PM = Particulate Matter)

Currently, about 5 million powered two-wheelers are registered in Germany, which corresponds to a share of approximately 10 % of all registered vehicles on the road (Figure 2 a). Their share to the total annual mileage or traffic on German roads is only about 2 – 3 % (Figure 2 b.). This is due to the increase of the annual mileage of passenger cars and heavy duty vehicles, whereas the annual mileage of powered two-wheelers stagnated. In addition, powered two-wheelers are increasingly used for leisure purposes, whereas other modes of transport are used for the daily commute to work predominantly (IFEU, 2004). Furthermore a large proportion of this vehicle class is used only in the summer months, so that their period of use is limited.

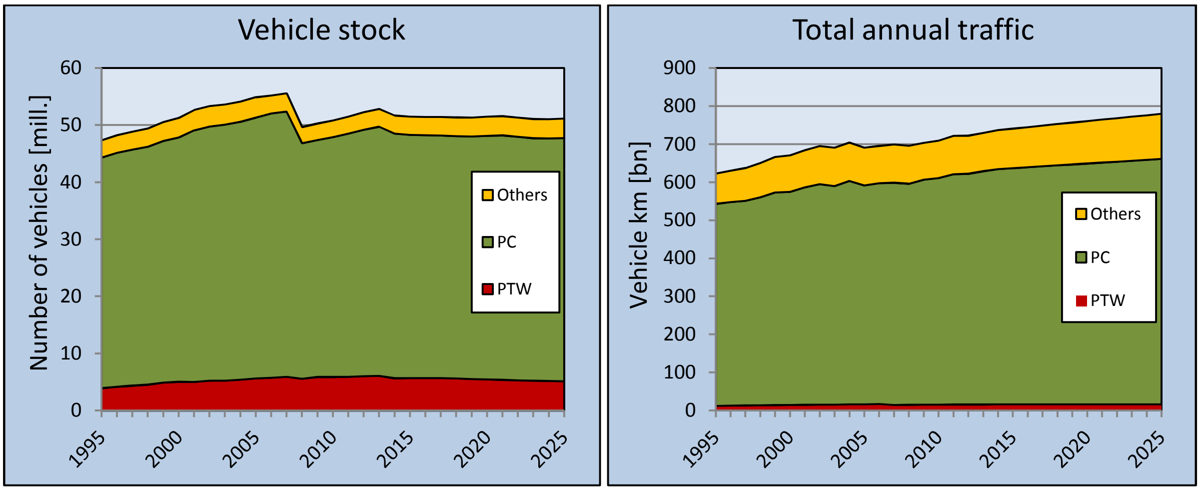

Figure 2: Vehicle stock (a) and total annual traffic (b) in Germany differentiated by vehicle class (PC = Passenger cars, PTW = Powered two-wheelers)

The importance of pollutant emissions from powered two-wheelers to the total road traffic is demonstrated by following Figures 3 a-c. The total amount of hydrocarbons, nitrogen oxides and carbon monoxide and the share of these emissions for the period 1995 - 2025 differentiated according to passenger cars (PC), powered two-wheelers (PTW) and the other road traffic users (Others) is shown.

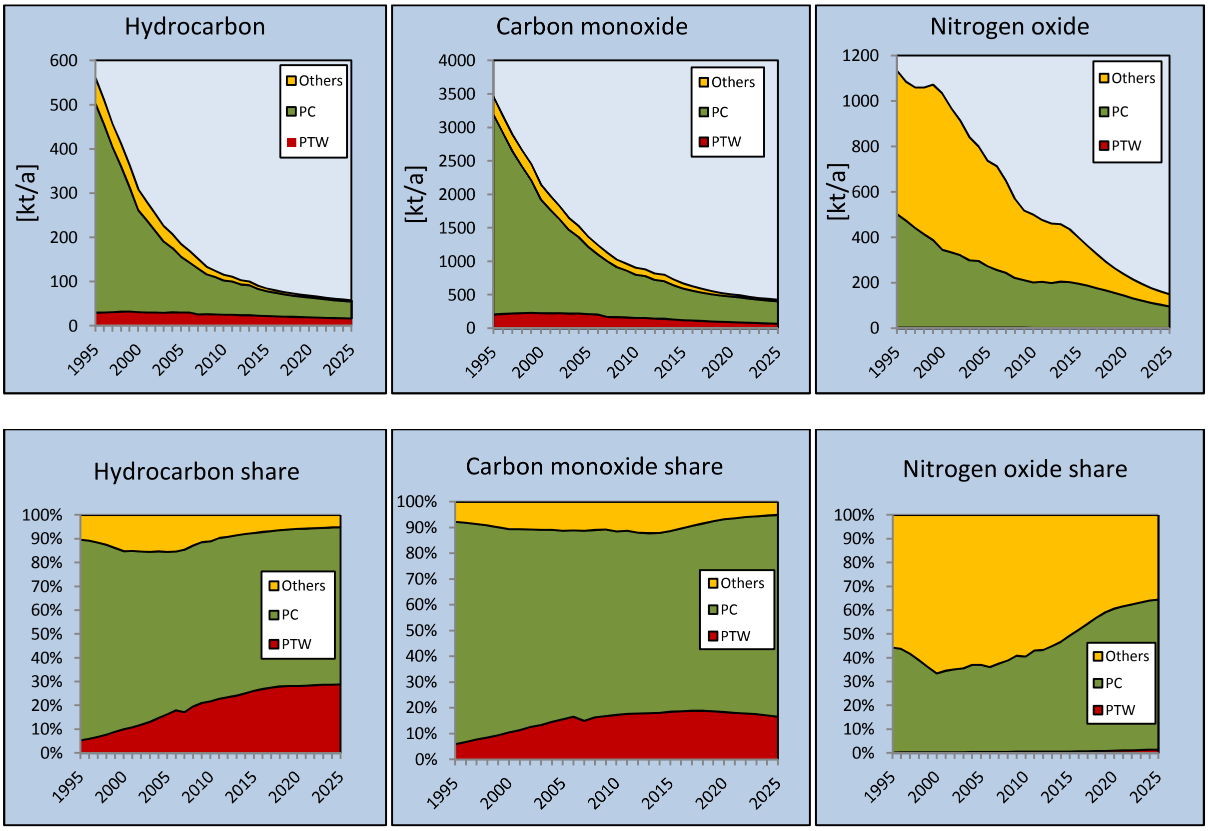

Figure 3: Total annual emissions and their share of road traffic vehicle categories in Germany: hydrocarbons (a), carbon monoxide (b) and nitrogen oxide (c)

It turns out that despite of the small driving mileage of powered two-wheelers of around 2 – 3 % of the total driving mileage of road traffic, their share of hydrocarbon emissions to the total hydrocarbon emissions from road traffic increases up to 25 % by 2025 (Figure 3 a). The growing share of hydrocarbon emissions from motorcycles is analogous to the situation of their carbon monoxide emissions. Due to the use of exhaust gas aftertreatment systems in passenger cars their total amount of hydrocarbons and carbon monoxide emissions has been reduced about 80 % up today (Figure 3 b). Consequently, the proportion of carbon monoxide emissions that is caused by motorcycles that do not have exhaust gas aftertreatment systems to the total quantity of carbon monoxide emissions from road traffic is rather high (approx. 18 % in 2015). In contrast to that the proportion of nitrogen oxide emissions from powered two-wheelers is at a very low level, as these kinds of emissions occur mainly in engines which are burning fuel with an excess of air (diesel engines, gasoline engines with direct fuel injection). Their share of nitrogen oxides to the total road transport emissions is approximately < 1 %

(Figure 3 c). In the context of this paper, all further investigations therefore relate to the hydrocarbon emissions from motorcycles.

In addition to the exhaust emissions there is a further fraction of hydrocarbon emissions, which is emitted due to fuel evaporation by gasoline powered engines. Figure 4 a shows a trend for the total amount of evaporative emissions and exhaust hydrocarbon emissions of powered two-wheelers, differentiated by motorcycles and small motorcycles for the period 1995 – 2025 without considering the effect of the new regulation (Euro 4/5).

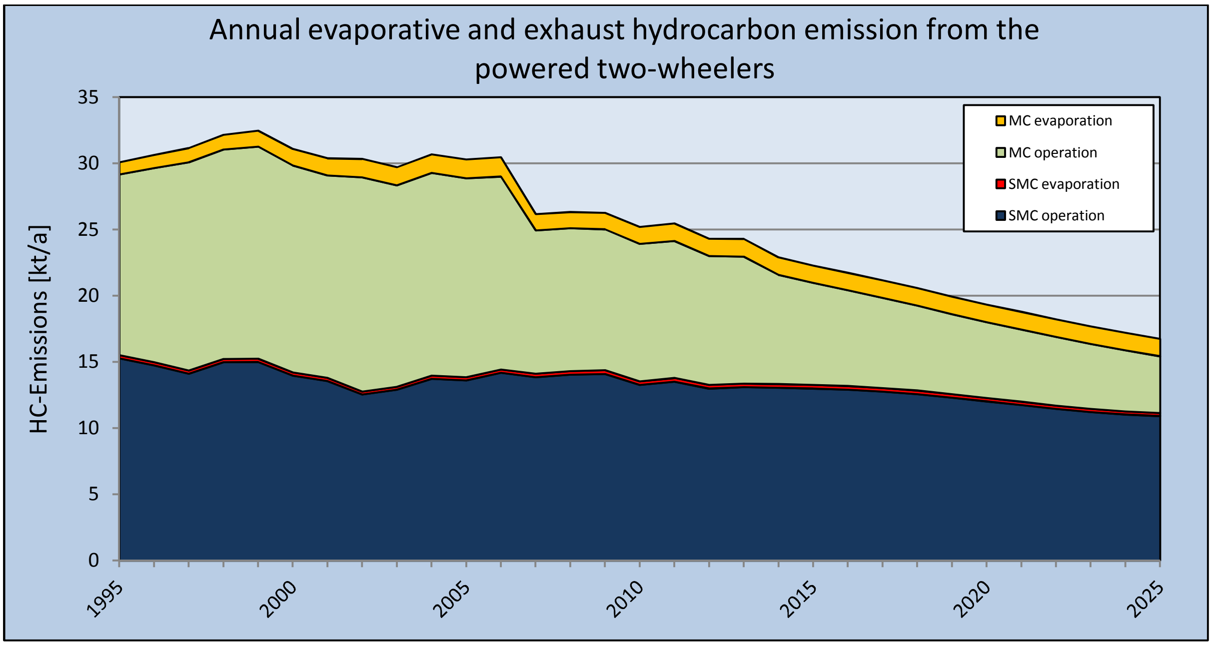

Figure 4: Annual Evaporative and exhaust hydrocarbon emissions from the powered two-wheelers

Figure 4 shows that the total amount of hydrocarbon emission of powered two-wheelers is reduced approximately by half in the period from 1995 to 2025. It becomes clear that the total decrease of hydrocarbon emissions is caused by the decline of hydrocarbon emissions from motorcycles due to technical efforts in the context of stricter Euro limits mainly, while the proportion caused by small motorcycles decreased only slightly.

Taking regard to the vehicle stock ratio within the vehicle class of powered two-wheelers shown in figure 5 it becomes clear that about two thirds of this vehicle class belong to the motorcycles while the market share of small motorcycles is about only one third during the investigated period.

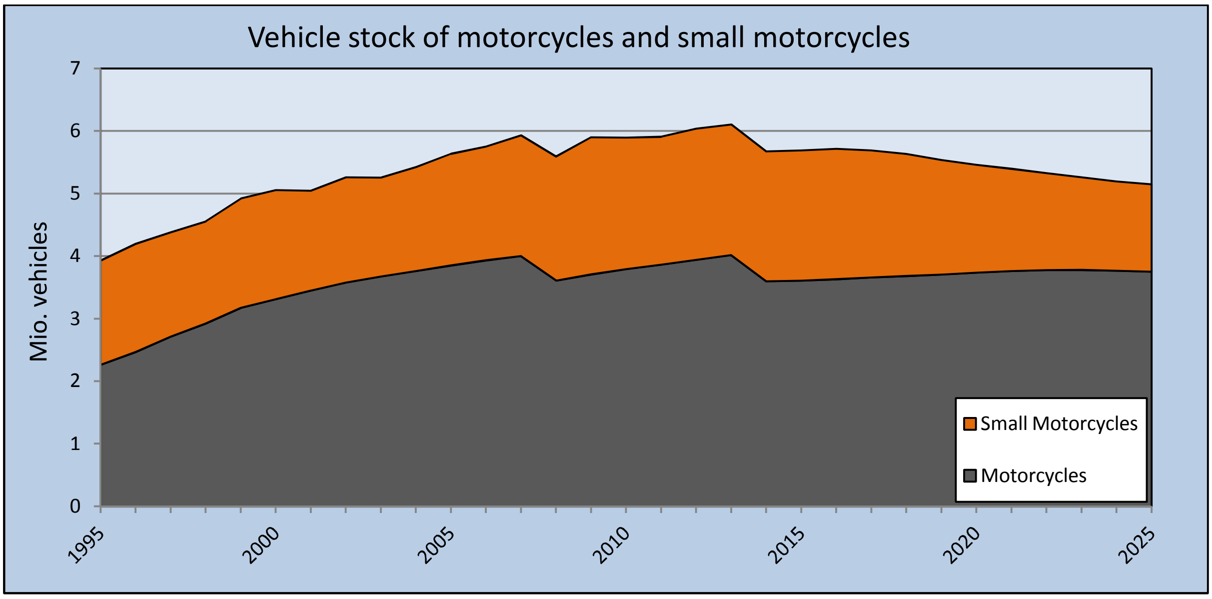

Figure 5: Vehicle stock of motorcycles and small motorcycles and its evolution from 1995 to 2025

So approximately one-third of the vehicles are responsible for about two-thirds of hydrocarbon emissions in 2015. Up to the year 2025 a further development in this direction is expected. In this context, a differentiated analysis of the shares of hydrocarbon emissions, which are generated during engine operation and those resulting from fuel evaporation, seems sensible. The proportions of the hydrocarbon emission types, differentiated by motorcycles and small motorcycles in the period from 1995 up to the year 2025 is shown in figure 6 a and 6 b (again without considering the impact of Euro 4/5 legislation).

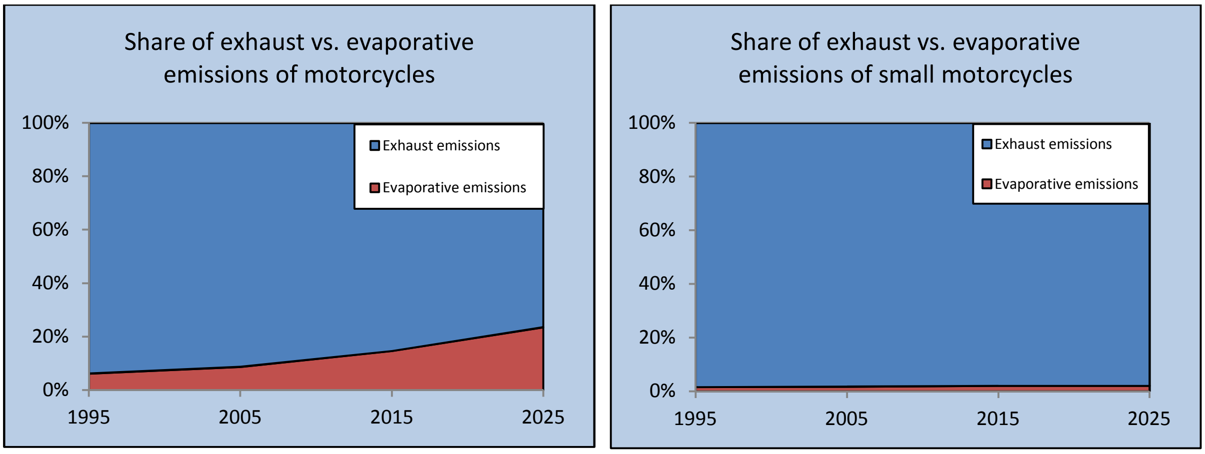

Figure 6: Share of the exhaust- vs. evaporative emissions of motorcycles (a) and small motorcycles (b)

It turns out that by 2025, nearly a quarter of hydrocarbon emissions of motorcycles are caused by fuel evaporation. The reason for the increase of the share of evaporative emissions is not an increase of the evaporative emissions itself, but rather the decrease in exhaust emissions due to new vehicle technologies and stricter operational limit values while the total amount of evaporative fuel fractions remains almost the same. In contrast to that there is no change of the share of evaporative and exhaust hydrocarbon emissions in the segment of small motorcycles within the investigated period. The share of evaporative emissions stagnated on a constant low level almost about 2 %. This raises the question how to explain the high share of evaporative emissions in the vehicle class of motorcycles. A more detailed analysis of the evaporative emissions differentiated by running losses, hot soak emissions and diurnal losses would be required, but will not be examined as a part of this research project.

3.3) Method

In the context of this paper an estimation of the change in operational hydrocarbon emissions of motorcycles after the introduction of the new emission standards Euro 4 and Euro 5 within the regulation (EU) 168/2013 is elaborated. Based on the results, initial estimations to assess the reduction potential of the operational hydrocarbon emissions of motorcycles are carried out on statistical assumptions. Finally trajectories for the operational hydrocarbon emissions from motorcycles, which already include the new emission levels, are generated for the period 1995 – 2025 by using TREMOD.

The adaptation of the database to the new emission standards Euro 4 and Euro 5 by use of TREMOD is done in several steps. First, basic data to generate emissions trajectories, which include vehicle stock information, annual traffic and operational hydrocarbon emissions from motorcycles for the period 1995 – 2025, are queried. The emission data base includes emission values for vehicles that are already available in the market. These emission values are based on exhaust gas measurement carried out on powered two-wheelers up to emission standard Euro 3. There are no emission data for Euro 4 and Euro 5 vehicles based on exhaust gas measurements available yet. So the estimations of Euro 4 and Euro 5 motorcycle emission data is executed on a theoretical basis with sound assumptions as a first approximation.

It is assumed that all vehicles that are newly registered from 2016 and 2020 onwards fulfill the new emission standards Euro 4 and Euro 5 within type approval. The real average operational hydrocarbon emission values of the motorcycle fleet and its evolution is difficult to predict in this context. In addition the discrepancies between the real operational hydrocarbon emissions and those that are identified within the type approval cannot be assessed without real emission measurements. Therefore, the average fleet HC-Emission factors of Euro 4- and Euro 5 motorcycles are set in accordance to the new emission limits in regulation (EU) 168/2013 in this scenario (Euro 4: operational hydrocarbon emission limit: 170 mg/km, Euro 5: 100 mg/km). The average fleet emission factor describes the HC-emissions in g/km for all vehicles that fulfill the same emission standard, calculated over all vehicle concepts and driving patterns. It is calculated by dividing the total annual traffic of all motorcycles with the same emission standard by their total amount of HC-emissions.

Depending on the vehicle technology and the driving situation individual emission factors can exceed or lay below the average fleet emission factor. Figure 7 shows the comparison of the average fleet emission factors and the HC-Emission limits for motorcycles retrospectively from the year 2003.

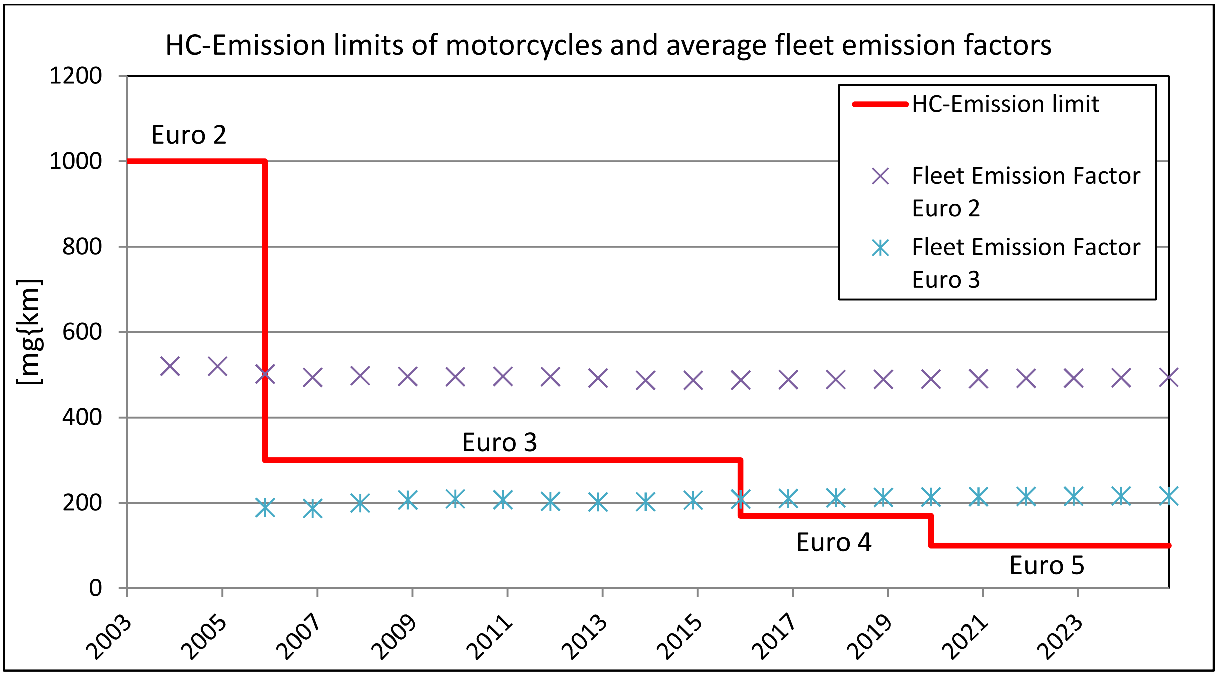

Figure 7: HC-Emission limits of motorcycles and average fleet emission factors

It turns out that the difference between the HC-emission limit of Euro 2 and the average fleet emission factor is about 50 % (Limit: 1000 mg/km, Emission factor: approx. 500 mg/km). Concerning the motorcycle fleet that fulfills Euro 3, the difference between the HC-Limit and the average fleet emission factor is less pronounced. The average fleet emission factor is around 200 mg/km. This corresponds to a difference of about 33% to the HC-Limit, which is 300 mg/km. Thus the adoption of the new operational hydrocarbon limits as assumed as new fleet hydrocarbon emission values generates a scenario which shows the minimal reduction potential of the new legislation as a first approximation. It is expected that the real average hydrocarbon emissions of the Euro 4- and Euro 5 fleet will lie below these virtually assumed emission values, as the average fleet emission factors of motorcycles with past emission standards did also lay below past limits.

Concerning the evolution of the motorcycle stock it is assumed that the database in TREMOD is appropriate for the considered time period. On this basis, it is assumed that the absolute number of registrations of motorcycles after the introduction of the new limit levels does not change, but that those vehicles newly registered from 2016 and 2020 onwards belong to new stock segments (namely Euro 4- and Euro 5 vehicles). As a result, the fleet of Euro 3 motorcycles decreases due to age according to their survival curves, as no further new registrations of Euro 3 vehicles take place. The adaptation of population trends for Euro 3 motorcycles from the years 2016 onwards to the survival curves was carried out manually using the basic data base. The same procedure is applied to Euro 4 motorcycles from the year 2020 onwards as their vehicle number decreases due to the introduction of emission standard Euro 5.The total annual traffic of one vehicle class is the product of the individual driving performance of one vehicle and the total stock number. The total annual traffic of Euro 4 and Euro 5 vehicles can be generated then by multiplying these data. Therefore it is assumed that the annual traffic of Euro 3 vehicles correspond to vehicles that fulfill Euro 4 and Euro 5.

4) RESULTS

Figure 8 shows the emission evolution of exhaust hydrocarbon emissions of motorcycles differentiated by emission standard without (a), and with (b) the introduction of the new emission levels. One can see that the share of hydrocarbon emission emitted by Euro 3 vehicles decreases from 2016 onwards due to the decline of their stock- and driving mileage values. At the same time Euro 4 vehicles contribute their share of emission to the total amount of hydrocarbon emissions. The same applies for Euro 5 vehicles from 2020 onwards. The total expected decrease in operational hydrocarbon emissions of motorcycles in the period 2015-2025 is approximately about 50 % or 3850 t/a (starting in the year 2015 at a level of about 7700 t/a). Excluding the new emissions levels the total decline of the operational hydrocarbon emissions would only be approximately 44 % or 3400 t/a. Thereby a reduction potential of hydrocarbon emissions of about 6 % or 450 t/a can be expected due to new emission levels by 2025. However, it is to be noted that this is the minimal expected decrease in operational hydrocarbon emission in this vehicle class. One reason for the low appearing reduction potential of total hydrocarbon emission is the steady decline of the overall hydrocarbon emissions of pre-Euro 3 vehicles since for the one hand the mileage of those old motorcycles decreases and on the other hand older motorcycles of especially pre-Euro 1 standard are replaced by new ones.

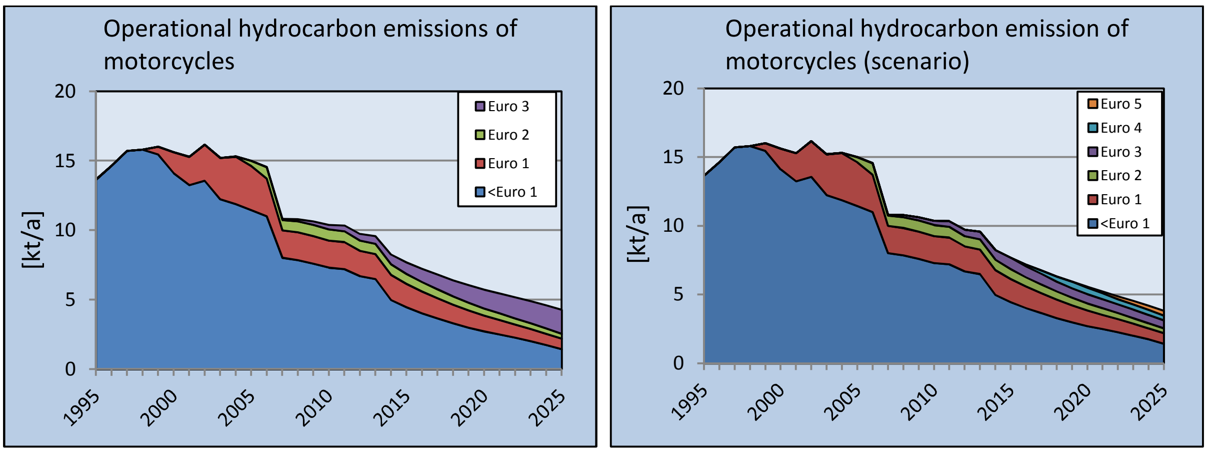

Figure 8: Emission evolution of exhaust hydrocarbon emission of motorcycles without (a) and with (b) the introduction of Euro 4 and Euro 5 emission standard

5) DISCUSSION

The emission trajectories identified in this project provide a first estimation of the development of operational hydrocarbon emissions in the vehicle segment of motorcycles by 2025. These are based on past experience and on assumptions about the development of future vehicle stocks, driving performance as well as hydrocarbon emissions of motorcycles. In particular, the fact that no vehicles that fulfill the new emission standards are available on the market makes it difficult to make estimations of the real emission behavior of these vehicles as no exhaust gas measurements could have been performed. For this reason, just statements concerning the minimal expected saving potential in operational hydrocarbon emissions of motorcycles are made as a first approximation. Based on experience the real emissions of newly registered motorcycles are below the limit values and decrease steadily with the introduction of new models and vehicle technologies with the years.

The emission trajectories obtained in this research project are to be verified after the introduction of the new emission levels in following research projects. For this purpose vehicles that fulfill the new emission limits Euro 4 and Euro 5 are to be measured on exhaust dynamometers in order to make statements about their real emission behavior. In a next step new emission data bases are to be generated and implemented in the calculation tools like TREMOD. Based on these emission data and due to revised mileage information, which is collected in the context of current driving performance surveys, the emission trajectories shown here are to be verified.

It is expected that also first measurement-based data of evaporative emissions in this vehicle class are available at this time, so that initial trends for the development of these emissions can be generated as well. Due to the further differentiation of the emission and mileage data bases, it should also be possible to make statements concerning the share of the various types of evaporative emissions and on which road category they are mainly emitted.

6) LITERATURE

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