Balancing Transport Greenhouse Gas Emissions in Cities – A Review of Practices in Germany

Final Report

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The Project Context

China's economic growth over the past three decades has had some undeniably positive effects on the country's development but it has also led to a massive increase in motor vehicle travel and associated traffic problems, especially in large cities. In Beijing, over five million cars cause severe local air pollution and traffic congestion as well as increasing parking problems and accident costs.

Transportation GHG emissions have become a key challenge for sustainable development in China and globally. Neither roadway expansion nor the development of new car technologies alone can solve these problems; in fact, these strategies often reduce one problem but aggravate others. Transport Demand Management (TDM) offers truly sustainable solutions which will help in achieving multiple planning objectives.

The aim of this project is to build capacities and competencies to enable Beijing municipal authorities to quantify and model the impact and benefits of various TDM strategies. This will help officials in Beijing and other major urban centers in China identify and implement the most effective and beneficial set of TDM measures.

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Beijing Transportation Research Center (BTRC) are the implementing partners. GIZ is a global service provider in the field of international cooperation and professional training for sustainable development. BTRC's mission is to conduct systematic research on transport development strategies for policies and planning in Beijing and to present recommendations on these measures and action plans to the People's Municipal Government of Beijing.

The project is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Beijing Municipal Commission for Transportation (BMCT).

In order to achieve the aims, the project is organized along three work streams

- Work Stream 1: TDM Policies and Measures – BTRC and GIZ cooperate to identify at least three TDM measures for GHG reduction in Beijing and learn from Chinese and international best practice

- Work Stream 2: Emission Scenarios, Modelling and Monitoring – A monitoring system for GHG emissions will be developed

- Work Stream 3: Dissemination – Measures and tools will be discussed with and disseminated to at least 5 other Chinese cities

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Introduction and Background

Global transport volumes and related greenhouse gas emissions have strongly increased over the last decades. A further increase is expected in the next years, mainly in emerging and developing countries [IEA 2010]. Due to the continuing urbanization, this development will largely take place in growing agglomerations and megacities. These will, thus, have to be the focus of measures to limit the further growth of transport related GHG emissions.

Also in Beijing, motor transport is increasing rapidly, bringing several environmental challenges such as increasing greenhouse gas emissions, air and noise pollution. Improvements in vehicle technology alone will not be sufficient to solve these problems, but further measures will be required. Appropriate Transport Demand Management (TDM) strategies can reduce energy consumption and emissions considerably by affecting travel behaviour (avoiding traffic, shifting to environmentally friendly transport modes, optimizing traffic flows). The Sino-German project "Transport Demand Management (TDM) in Beijing – Emission Reduction in Urban Transport"[1] aims to identify suitable non-technical measures for Beijing and evaluate GHG emissions reductions.

An important basis for the TDM project is the assessment of Beijing transport volumes and related GHG emissions in sufficient extent and detail. Target-oriented measures can only be developed and monitored with adequate knowledge of the local emission situation.

The present expertise shall support the TDM project by giving an overview of common methods and practical experiences with modelling GHG emissions from transport in German cities and by providing information on good practice in Germany. This information on good practice in Germany is intended to enable stakeholders to estimate and monitor GHG emissions of transport in Beijing. The expertise consists of the following sections:

- The first chapter deals with important basic information on the calculation of transport GHG emissions, central influencing factors on calculated emissions as well as a range of methodological aspects.

- The second chapter presents emission factor databases and inventory models used in Germany. Additionally a short comparative overview on emission factor databases and models outside of Germany is given.

- Chapters 3 and 4 focus on GHG emission balancing for the transport sector of cities. Chapter 3 explains different balancing methods commonly used in cities, such as system boundaries and differentiation of transport activity data. Also the available transport data sources for Germany are discussed.

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[1] On behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Beijing Municipal Commission for Transportation (BMCT). Implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Beijing Transport Research Center (BTRC).

- Chapter 4 is a subsequent analysis and comparison of current balancing practices in selected major German cities. The used balancing methods and important data sources are explained and their suitability for different balancing objectives is discussed. In addition, the transport-related parts of the recent Energy and GHG Inventory for Greater London area as non-German metropolis are analysed.

- The final chapter 5 draws conclusions from the German experiences: What should be considered for GHG balancing of the transport sector in the city of Beijing or a similar megacity and which balancing methods are most suitable? Data requirements are discussed taking into account deviating data availabilities in China and Beijing.

1 Calculation of GHG Emissions from Transport Activities

The amount of GHG emissions caused by motorized transport on one hand depends on the extent of transport activities. On the other hand it depends on the specific energy consumption of the used means of transportation and on the specific GHG emissions of the final energy carriers. This relation is illustrated in Figure 1.
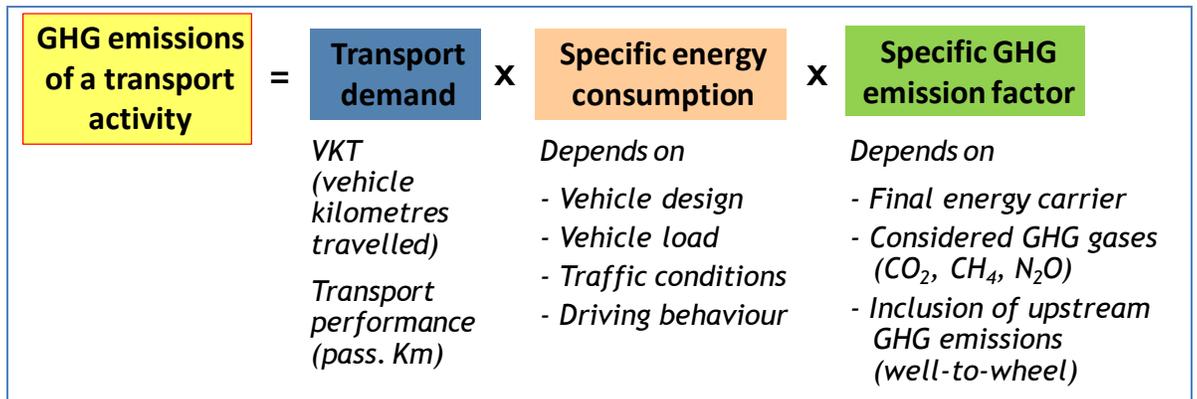
Figure 1: *GHG emissions calculation scheme for motorized transport activities*

1.1 Transport Demand

The transport demand is basically described by the **vehicle kilometres travelled (VKT)**, i.e. the distance covered by a vehicle within a certain period of time.

In order to relate energy consumption and emissions to the benefit of a trip (i.e. transported passengers or freight), the **transport performance** (passenger-kilometres resp. ton-kilometres) is used, which combines the VKT with the vehicle capacity and the load factor (see Figure 2). Another option for calculating the transport performance without further information on vehicle parameters is to multiply transport volumes (number of persons, amount of tons) by the travel distances. Relating to the transport performance is a basic precondition for the comparison of environmental effects between means of transport with different characteristics (car with few seats vs. bus/tram with several seats).
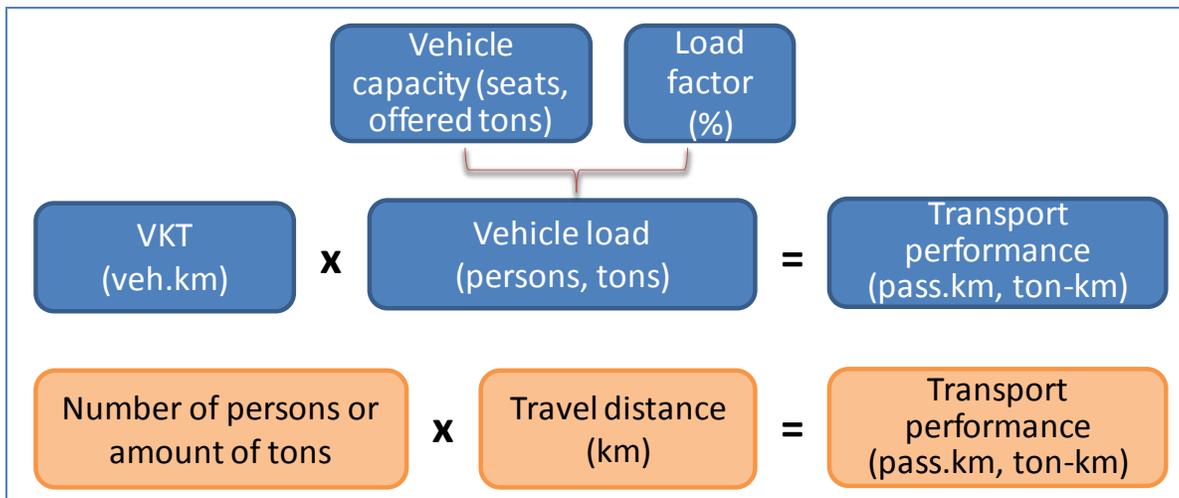
Figure 2: *Relation between different transport demand parameters*

1.2 Specific Energy Consumption of Vehicle Use

The specific energy consumption of a trip depends on different parameters. Primarily, it depends on the **means of transportation** and its **technical characteristics** (e.g. drive concept, engine performance, vehicle age). In addition, **operation conditions** (velocity, traffic flow, driving behaviour) affect the energy demand.

The specific energy consumption for a certain transport performance (pass.km, ton-km) first of all depends on the chosen **means of transport** (e.g. passenger car, bus, local train). These differ not only in specific energy consumption per vehicle kilometre travelled, but also in potential transportation capacity and the realized load factor. Both parameters have to be considered for a comprehensive balancing approach as is illustrated in Figure 3 for urban passenger transport:

- Trams may have much higher energy consumption per kilometre travelled compared to passenger cars, but they also offer a much higher seating capacity. Energy consumption of buses and trams per seat-km is therefore much lower than for passenger cars.

- However, the offered capacity is only partly used. The average occupancy of passenger cars in cities in Germany is about 1.3 (26%) [SrV 2008]. The average occupancy rate of public transport in Germany is even lower (21%) for public buses and about comparable for tram and metro systems. Nevertheless, public transport modes tend to have considerably lower energy consumption per passenger-km (see Figure 3).
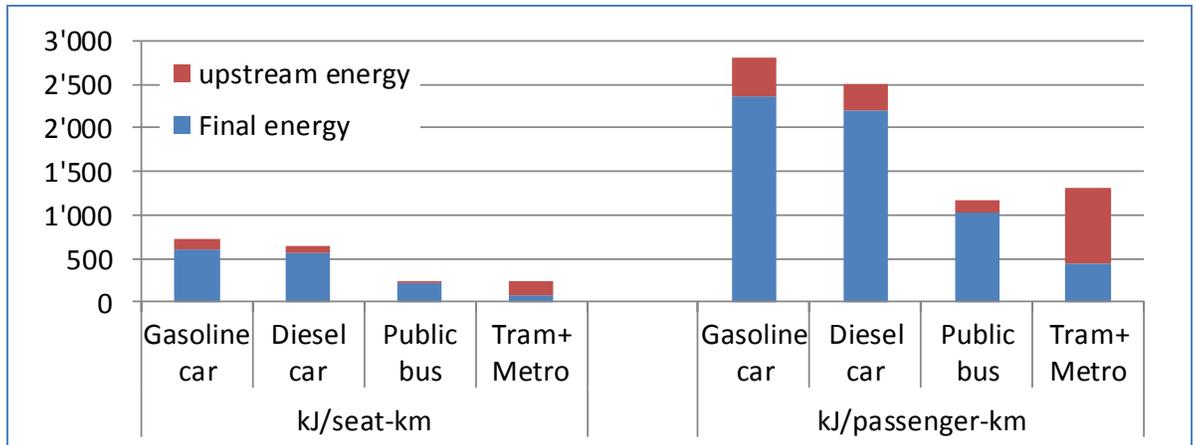
Figure 3: *Energy consumption factors for different means of urban passenger transport*

Source: TREMOD data for 2010, IFEU Heidelberg 2012

At the vehicle level, the specific energy consumption of vehicles per kilometre travelled depends on technical parameters such as the physical resistance factors on the one hand and the efficiency of energy conversion on the other hand. Furthermore, auxiliary consumers such as air conditioning, lights etc. are of relevance.

- Main factors for **physical resistances** are the vehicle weight, its aerodynamic characteristics (front area, air drag) and the rolling resistance. The importance of these factors also depends on the vehicle operation: Vehicle weight is more important in urban areas with a lot of start-stop situations, aerodynamics in turn are more important at higher speed and can be almost neglected in stop-and-go-traffic.

- For **energy conversion**, the vehicle (i.e. the engine) efficiency and the upstream efficiency have to be distinguished. While electric vehicles have a very high energy efficiency on a vehicle level, energy is mostly lost in upstream processes if conventional combustion power plants are used. For combustion vehicles (gasoline, diesel, gas) in turn, the highest energy losses occur at the combustion engine level.

These factors vary between transportation means (road, rail), model types (e.g. rigid truck, articulated truck) and also propulsion type (gasoline, diesel etc.) and size (e.g. engine displacement) (see Figure 4). Besides, temporal and regional differences have to be considered:

- Temporal developments are mainly driven by technological advancements. This applies to vehicle technology (e.g. light-weighting, engine improvements), as well as upstream processes (e.g. construction of more efficient power plants or refineries).

- Regional differences mainly stem from the composition and age of the vehicle fleet and the composition and age of power plants and refineries. Driving factors can be the local resource bases (e.g. deposits of oil or coal) and political policies. In Europe, for instance, a further improvement of vehicle energy efficiency can be expected due to the successive introduction of EU CO_2 emission limits after 2012.
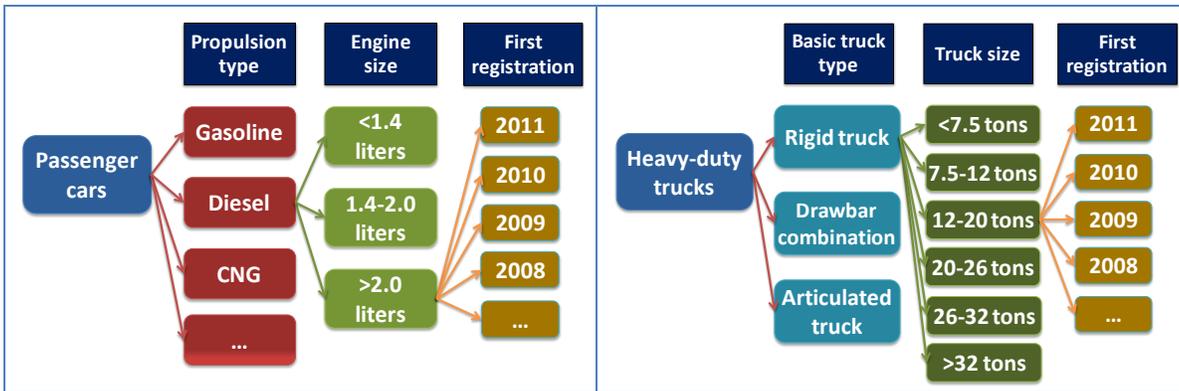
Figure 4: *Fleet composition: Differentiation of road vehicle subsegments (exemplary)*

Finally, the **traffic situation** and the **driving behaviour** have to be considered. Stop-and-go traffic, for instance, leads to a higher specific energy consumption because it requires much braking and accelerating and, thus, forces combustion engines to operate more frequently in less efficient partial load. Traffic flow, therefore is an important factor for a vehicle's energy consumption (see Figure 5, left). Also the use pattern is of importance since only warm engines operate in optimum conditions, while significantly higher pollutant emissions and fuel consumption occur after cold starts (see Figure 5, right). In the end, also the individual vehicle operator has an influence on the specific energy consumption. Courses in fuel efficient driving have shown a reduction potential of up to 30%[2].
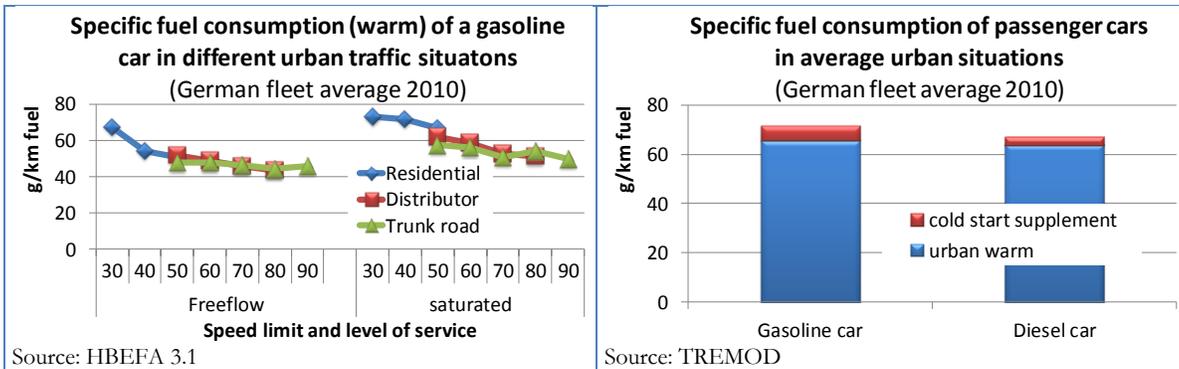
Figure 5: *Specific final energy consumption of passenger cars in urban traffic situations*

1.3 Specific GHG Emissions

The specific GHG emissions depend on the **final energy carrier** used in the vehicle, thus from the mean of transportation (e.g. car, rail, metro) and the drive concept (gasoline or diesel fuel, CNG, electric propulsion etc.). So far, motorized traffic in Germany is based almost entirely on fossil fuels made of mineral oil. Only in the last 10 years the share of alternative fuels, especially

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[2] UBA 2009 UBA Umweltbundesamt (Hrsg.): "Sprit sparen und mobil sein." Dessau-Roßlau: Eigenverlag. 2. überarbeitete Auflage 2009: http://www.umweltdaten.de/publikationen/fpdf-l/3705.pdf

biofuels has increased considerably. Rail transport largely runs on electricity. In future, a substantial increase of electric mobility is expected also in road transport.

In order to calculate the GHG emissions from vehicle use two different emission origins have to be considered (see Figure 6):

- Direct emissions (**tank-to-wheel**) during vehicle use,
- Upstream emissions (**well-to-tank**) from energy supply.

When fossil fuels are used, most of the greenhouse gases are directly emitted during the fuel combustion in the vehicle.

Further emissions result from the upstream energy supply (exploration of oil and gas, transportation, refinery processes). Using electricity there are no direct emissions on the local level. All GHG emissions result from the upstream energy supply, especially when generating electricity out of carbon containing energy sources (coal, gas). Hence, complete **well-to-wheel** emissions from vehicle use and upstream energy supply should be considered for covering all relevant GHG emissions from transport activities as well as for objective comparisons of GHG emissions from vehicles with different energy sources.
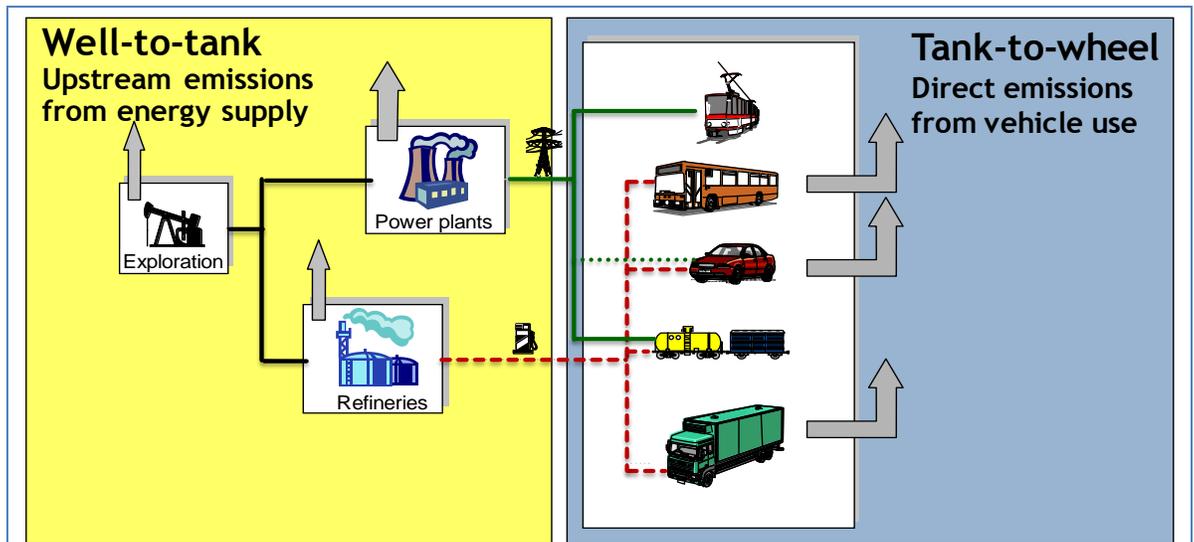
Figure 6: *Origin of GHG emissions from transport activities (schematic)*

GHG emitted by transport mainly consist of carbon dioxide CO_2 (about 99 %). The amount of CO_2 per energy consumption depends on the carbon content of the fuel (see information box on the next page). Furthermore, small amounts of methane (CH_4) and nitrous oxide (N_2O) are emitted. In order to compare the effect of different GHGs, the global warming potential (GWP) is used that compares the amount of heat trapped by a GHG to the amount of heat trapped by a similar mass of CO_2 (see Table 1). In this way, the sum of all GHG emissions can then be indicated as **CO_2 equivalents**.

Table 1: *Global warming potentials of carbon dioxide, methane and nitrous oxide*   Source: IPCC 2007

CO_2	CH_4	N_2O
1	25	298

Relevance of the carbon (C) content in fossil fuels

CO_2 emissions can be calculated by the specific fuel consumption rate; however, depend on the fuel types' carbon content. In many countries, fuel is provided in different qualities (e.g. different octane numbers for petrol; summer and winter quality for diesel), which vary in carbon content. This should be considered if "average" fuel types such as gasoline or diesel are used in GHG emission modelling, by weighting the average fuel composition. For example, in the German national emission inventory a CO_2 rate of 72 g/MJ gasoline (85,6 % C) and 74 g/ MJ diesel (86,8 % C) is considered [FEA 2009].

Biofuels

In case of biofuels, usually no direct GHG emissions are charged in emission calculations as they are regarded as carbon neutral (CO_2 emitted when combusting biofuels has been previously taken up by the plants). However GHG are still produced upstream due to the cultivation of the energy crops and transport of the biofuels. Therefore, European RES directive [EC 2009] defines as sustainability criteria for biofuels that the total GHG emission savings (CO_2 equivalents) compared to replaced fossil fuels shall be at least 35% (at least 50% from 1. January 2017 resp. 60% from 1. January 2018 for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017).

2 Emission Factor Databases and Inventory Models for Transport-related GHG Emissions

2.1 Overview of the Most Important Models for Germany, Europe and the USA

This chapter describes some important national and international emission inventory models in Europe and the USA whose development partly reaches back to the 80s. These are:

- TREMOD for Germany
- HBEFA for a number of EU countries
- COPERT for the EU and EU countries
- TREMOVE for the EU
- MOVES for the USA

While these models typically are more than only GHG emission models, they represent the state of knowledge in emission modelling for transport in the previously described methodology (see chapter 1). An overview of models and calculation tools for city specific GHG emission inventories is given in chapter 3.4.

Table 2 gives some basic information about the different emission inventory tools. HBEFA and COPERT have a greater focus on emission factors, while TREMOD and TREMOVE focus on emission inventories and policy scenarios for specific regions. All models cover a timeframe for past and future emissions and use a high resolute emission calculation approach considering different vehicle, road, fuel, emission categories and components. While road transport and tank-to-wheel emissions are covered by all models, additional transport modes (train, ship and aircraft) and well-to-tank emissions are only considered in TREMOD and TREMOVE. COPERT, TREMOVE and MOVES are freely available for download while HBEFA is distributed for a fee. Access to TREMOD is limited to a number of German authorities and corporate stakeholders.

Table 2: *Overview of the chosen emission inventory models*

	HBEFA	TREMOD	COPERT	TREMOVE	MOVES
Latest version	HBEFA 3.1 (2010)	TREMOD 5.2 (2012)	COPERT 4, v. 9.1 (2012)	TREMOVE 3.3.2 (2010)	MOVES 2010b
Developer	INFRAS AG	IFEU Heidelberg	EMISIA	TML, KU Leuven	US EPA
Commissioner	Several federal environmental authorities in Europe	Federal Environmental Agency Germany (UBA)	European Environment Agency (EEA)	European Commission, DG Environment	EPA (United States Environmental Protection Agency)
Purpose	- Database for emission factors - Emission Inventory and Scenario Calculation (Exp. Version)	- Emission Inventory and Scenario Calculation - Database for emission factors and transport activity data	- Emission Inventory - Database for emission factors and transport activity data	Emission Inventory and Scenario Calculation	- Emission Inventory and Scenario Calculation - Database for emission factors and transport activity data
Transport Modes	Road	Road, Rail, Inland Water and Aircraft	Road	Road, Rail, Inland Water, Maritime	Road
Timeline	1990-2030	1960-2030	1970-2030	1995-2030	1990, 1999-2050
Resolution (Road)	Vehicle, road and fuel type	Vehicle, road and fuel type	Vehicle, road and fuel type	Vehicle, road and fuel type	Vehicle, road and fuel/powertrain type
	Tank to wheel	Well to wheel	Tank to wheel	Well to wheel	Tank to wheel
Software requirements	MS ACCESS	MS ACCESS	MS ACCESS	MS ACCES and EXCEL, WINZIP, GAMS	MySQL and JAVA
Software availability	Order by registration, fee: 250 € www.hbefa.net Expert version for ERMES-members	Available for several public authorities and cooperation partners	Order by registration, fee for country data (300 € each) http://www.emisia.com/copert/General.html#	Free download http://www.tremove.org	Free download (GNU license) http://www.epa.gov/otaq/models/moves/index.htm
Data availability	Europe- individual purposes	Germany- national level	Europe- national level	Europe- national level	USA- national and county level
Typical application	Micro to macro scale inventories (street, city, national level) for EU emission standards	National inventory and scenarios for Germany	Macro (country level) scale inventories for EU emission standards	Macro scale (country/ EU level) inventories and scenarios for EU emission standards	Micro to macro scale (federal, state, county, city) inventories with US emission standards

2.2 Principles in the Derivation of Emission Factors

In the previous section, it was shown that all models can produce emission inventories for specific regions and provide emission factor databases at the same time. A further focus should be given to the methodology for emission factors. These play a key role in emission inventory models and should be consistent with the available transport data.

The emission factors in Europe are based on data from test labs and a number of research programmes which are coordinated by the European Research group on Mobile Emission Sources (ERMES) While HBEFA and COPERT are directly linked to these research programmes, TREMOVE and TREMOD – and other applications – use their emission factor databases.

Therefore, emission factors and driving patterns are considered for different approaches, first, a "**Traffic Situation approach**" which is used in HBEFA and, second, an "**Average speed approach**" which is used by COPERT (Figure 7).

The traffic situation approach bases on vehicle speed fields in a second per second resolution. This way for different road types and speed limits four levels of service (Freeflow, heavy, saturated and Stop+go) can be described. Alternatively, these individual traffic situations can be weighted, thus, providing aggregated traffic situations for typical road categories, e.g. "rural motorways", and specific countries. The average speed approach, on the other hand, uses emission factors for average speeds in which the different kind of traffic situations are already integrated.

The traffic situation approach is typically appropriate for micro scale emission modelling, e.g. city or street level and also for national level modelling, whenever data availability allows a very detailed description of traffic situations. For macro scale emission modelling, e.g. national or international emission inventories, the average speed approach can be considered suitable.

The emission factors for MOVES base on test data from various U.S. sources, e.g. I/M (inspection and maintenance) programmes, engine certification tests and individual research and test programmes. This original data is collected and processed by the EPA and used to generate modal emission rates, by assigning them to "**operating modes**" that characterize different speed and engine power classes[3]. Contrary to the other models, hot emission factors in MOVES are not expressed in mass per distance but in mass per time.

A general overview of the test data processing and the derivation of emission factors is given in Figure 7.

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[3] For light duty vehicles, power per vehicle weight or VSP (vehicle specific power) and for heavy duty vehicles STP (scaled tractive power) is used to characterize the operating modes ([EPA 2011] and [EPA 2012a])
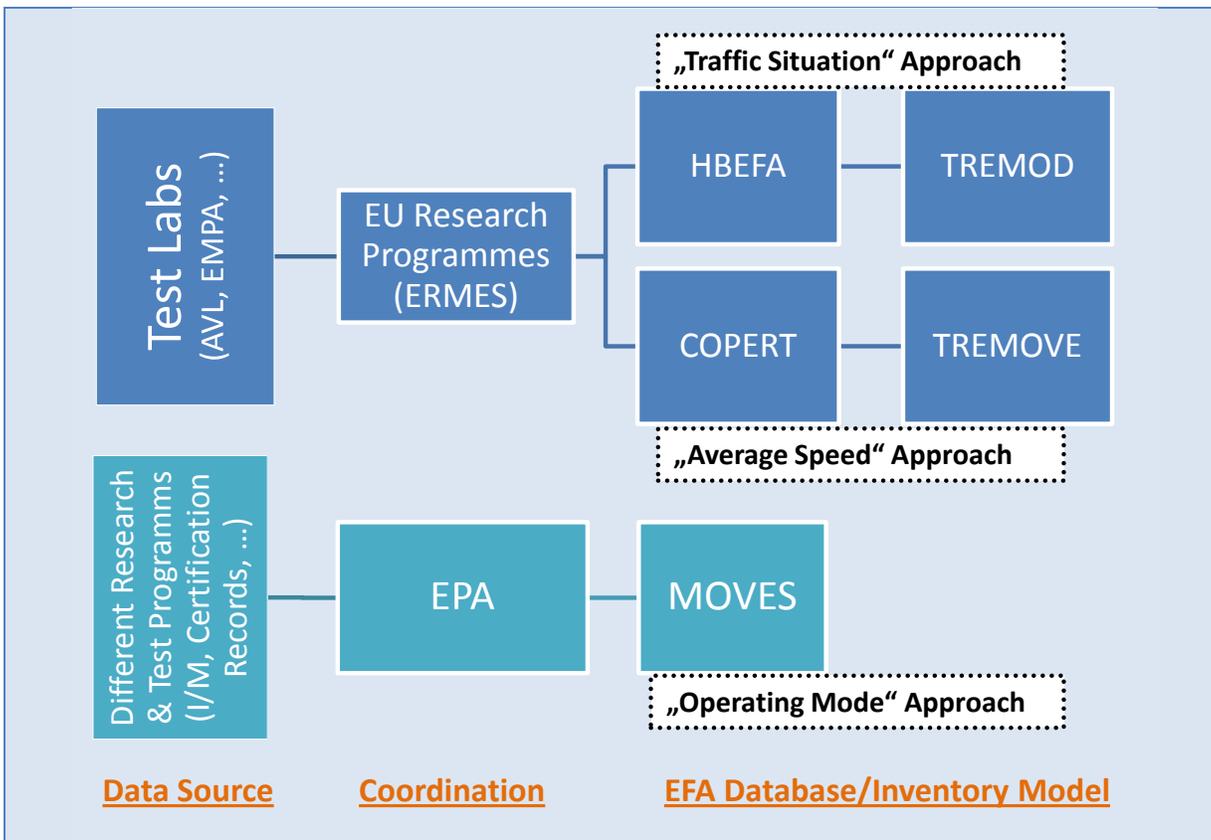
Figure 7: *General Scheme for the derivation of emission factors in the considered models*

2.3 Further Background and Details of the Chosen Models

2.3.1 HBEFA

The HBEFA (Handbook Emission Factors for Road Transport) was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria. In the meantime, further countries (Sweden, Norway, France) as well as the JRC (European Research Centre of the European Commission) are supporting HBEFA.

HBEFA provides emission factors, i.e. the specific emission in g/km for all current vehicle categories (PC, LDV, HDV, buses and motor cycles), each divided into different categories, for a wide variety of traffic situations Therefore, the original data from various test labs is collected and processed with the PHEM[4] Model by the Technical University of Graz to produce the emission factors [INFRAS 2010].

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[4] PHEM (Passenger car and Heavy duty Emission Model) can simulate emission factors for different driving patterns basing on characteristic emission diagrams

The first version (HBEFA 1.1) was published in December 1995, an update (HBEFA 1.2) followed in January 1999. Version HBEFA 2.1 was available in February 2004. The newest version HBEFA 3.1 dates from January 2010.

The current version of HBEFA of 2010 is based on European emission measurement data collected within the ERMES group (see chapter 2.2), which is also the emission data basis for European models such as COPERT and TREMOVE.

Table 3: *Overview: HBEFA*

Name	HBEFA (**H**and**b**ook **E**mission **Fa**ctors for Road Transport)
Purpose	■ Generate a reliable and harmonized database for „real world" emission factors of all vehicle categories in road transport ■ Share international experience and resources for emission measurement and modelling
Commissioner	Federal Environmental Agency (Germany) Federal Environmental Agency (Austria) Federal Office for the Environment (Switzerland) Swedish road Administration (Sweden) Norwegian Pollution Control Authority (Norway) ADEME (France)
Developer	INFRAS AG in cooperation with the following institutions: AVL (SE), EMPA (CH), IFEU (DE), INRETS (F), JRC (EU), LAT (GR), Statistics (N), TNO (NL), TU Graz (A), TU Lund (SE), TueV Nord (DE), VTI (SE)
Stakeholder	Ministries and other public authorities in several countries and European Union
History	HBEFA 1.1 – 1995 (D, CH) HBEFA 1.1A – 1998 (A) HBEFA 1.2 – 1999 (D,A,CH) HBEFA 2.1 – 2004 (D,A,CH) HBEFA 3.1 – Feb. 2010 (D, A, CH, SE, N, [F])
System boundaries	Road transport in different countries (D,A,CH,SE,N, F) Timeline 1990-2030 Vehicle categories: passenger car, light duty vehicle, heavy duty vehicle, urban bus, coach, motorcycles Different road categories and traffic situations Tank-to-wheels energy consumption and emissions Components: CO, HC, NOx, PM, several components of HC (CH4, NMHC, benzene, toluene, xylene), fuel consumption (gasoline, diesel), CO2, NH3 and N2O. New in HBEFA 3.1: NO2, PN and PM non exhaust
Model structure	Offline tool in MS ACCESS, Runtime (stand-alone) version. Model delivers emission factors per traffic activity (e.g. g/vehicle-km, g/Start) in high resolution (per vehicle subsegment and traffic situation) or different aggregation levels (as weighted emission factor for each country and year), dependent from user selection
Availability	Distributed by INFRAS, order by registration, fee: 250 Euro Information: www.hbefa.net
Model applications (examples)	Database for ■ TREMOD (German emission inventory model for transport) ■ Swiss emission inventory for road transport ■ Swedish emission inventory for road transport ■ Several local emission models and studies ■ Specific tools for transport planning and environmental impact estimation of individual transports (e.g. EcoTransIT, Map & Guide)

2.3.2 TREMOD

TREMOD (Transport Emission Model) was designed in the late 90s on behalf of the Federal Environmental Agency to build up a suitable tool that covers the state of knowledge for emission calculation in Germany at that time. It is constantly updated and used for Germany's national annual emission reports, the projection of past trends and future scenarios for all transport modes [IFEU 2010].

TREMOD is supported and funded by The Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt), some other activities to which it is linked are:

- **German Railways (DB AG)**: The emission calculation methodology for the railway sector was developed together with the DB AG since 1995. DB AG delivers all information for the yearly data update in TREMOD.

- **Association of railway companies and industry "Allianz pro Schiene" (ApS)**: ApS conducts a database with specific environmental data of all transport modes in Germany. The database was developed by IFEU and is directly linked to TREMOD.

- **German Automotive Industry (VDA)**: The VDA supports TREMOD since 1995 and uses TREMOD results for several activities, e.g. annual report, special publications.

- Other organizations supporting TREMOD are e.g. ADAC, Mineral Oil Industry (MWV), Deutsche Lufthansa.

- **COPERT and TREMOVE**: The European models also use traffic activity data for Germany from TREMOD.

In the road transport sector TREMOD has a close cooperation with the HBEFA: TREMOD uses the methodology and database of the HBEFA for the emission factors of road transport. Vice versa the HBEFA uses traffic activity data for Germany of TREMOD. The emission inventory, therefore, covers the same layers as the HBEFA with a high resolute calculation procedure. The following figure shows the basic elements of the calculation in TREMOD for road transport.
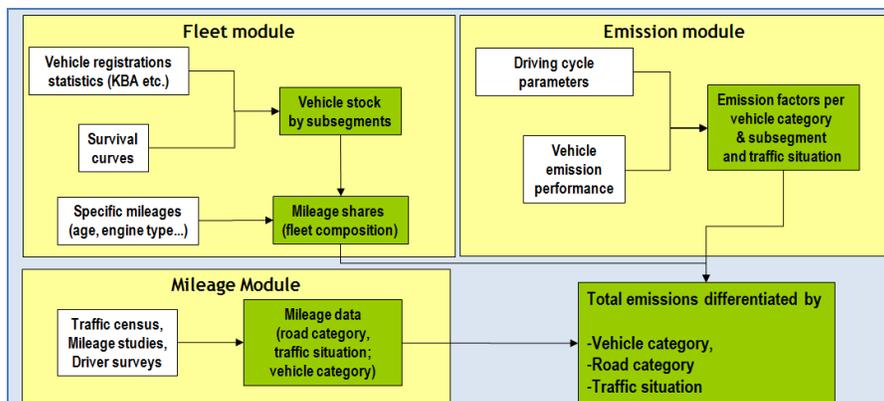
Figure 8: *Emission calculation for road transport in TREMOD*

Table 4: *Overview: TREMOD*

Name	TREMOD (**Tr**ansport **Em**ission **Mod**el)
Purpose	Generate a reliable and harmonized database for the energy and emission inventory of all transport modes in Germany for various tasks e.g. statistical reports, political decisions, information of public, environmental reports, data base for life cycle assessments
Commissioner	Federal Environmental Agency (Germany)
Stakeholder	Ministry of Environment, Federal Highway Research Institute, Ministry of Transport, other public authorities, Automotive Industry (VDA), German Railways (DB AG), Oil industry (MWV), Deutsche Lufthansa
History	TREMOD 1.0 – 1997 TREMOD 2.0 – 2000 TREMOD 3.0 – 2003 TREMOD 4.17 – 2006 TREMOD 5.1 – 2010 TREMOD 5.2 – 2012
System boundaries	Road, Rail, Inland Water and Aircraft Transport in Germany Timeline 1960-2030 Well-to-Tank and Tank-to-Wheels energy consumption and emissions Components: CO, HC, NOx, PM, several components of HC (CH4, NMHC, benzene, toluene, xylene), fuel consumption (gasoline, diesel), CO2, NH3 and N2O. New in HBEFA 3.1: NO2, PN and PM
Model structure	Offline tool in MS ACCESS (MS ACCESS required), different databases. Different modules for each transport sector Input tables for differentiated fleet and traffic data and scenario designs Result forms with flexible possibilities of data selection with different aggregation levels for each transport mode and all modes
Availability	Not publicly available due to complexity Available for public authorities (Federal Environmental Agency, Ministry of Environment, Federal Highway Research Institute, Ministry of Transport) and cooperation partners (VDA, DB AG, Deutsche Lufthansa)
Model applications (examples)	■ National Inventory Report in Germany ■ Life cycle assessment tools and databases (Probas, Umberto, Railway Association "Allianz pro Schiene") ■ Tools for the estimation of the environmental impact of individual transports (EcoTransIT, EcoPassenger, UmweltMobilCheck) ■ National inventories of other countries, e.g. Belgium, China, different German Federal Lands ■ Delivery of German fleet data for the European TREMOVE- and Copert-model ■ Different studies with scenarios for the future development of energy consumption and emissions for the transport sector

2.3.3 COPERT

COPERT (Computer Programme to calculate Emissions from Road Transport) is an emission model developed by EMISIA and the laboratory of Applied Thermodynamics which is basically designed for Europe (commissioned by the European Environmental Agency) but also offers the possibility of a worldwide application.

Basing on the EMEP (European Monitoring and Evaluation Programme) methodology it is part of ETC/ACM (European Topic Centre for Air Pollution and Climate Change Mitigation) activities and research activates of the JRC (Joint Research Centre).

Starting in the late 1980s the first version was COPERT 85, followed by COPERT 90, COPERT I-III and the latest COPERT 4 v. 9.0 [EMISIA 2012].

The applications of COPERT range from national to local emission inventories, air quality impact assessments and provision of transport activity data and emission factors. The methodology bases on a bottom up approach with high resolute input data. These cover a timeline from 1970 to 2030, all important road vehicle categories and subcategories (fuel types, size), vehicle technologies and a large number of components.

Activity data can be manually entered or purchased for EEA member states, basing on statistics from Eurostat or the FLEET[5] project as well as a number of national sources. Emission factors are regularly aligned with data from the ARTEMIS (Assessment and reliability of transport emission models and inventory systems) project and the HBEFA group.

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[5] FLEETS is a EUROPEAN database for vehicle populations and mileage statistics, see also http://www.emisia.com/tools/FLEETS.html

Table 5: *Overview: COPERT*

Name	COmputer Programme to calculate Emissions from Road Transport (COPERT)
Purpose	National Emission Inventory Preparation and user-defined emission calculations for road transport with harmonized methodology after 2006 IPCC Guidelines and EMEP/EEA air pollutant emission inventory guidebook
Commissioners	European Environment Agency (EEA)
Developer	EMISIA Laboratory of Applied Thermodynamics, Thessaloniki
Stakeholder	European Topic Centre for Air Pollution and Climate Change Mitigation (ETC/ACM) Joint Research Centre (JRC)
History	COPERT 85 – 1989 COPERT 90 – 1993 COPERT II – 1997 COPERT III – 1999 COPERT 4 – since 2006 (latest version 9.1 in 2012)
System boundaries	Road transport in all EU 27 countries and user-defined situations Timeline 1970-2030 Vehicle categories: passenger car, light duty vehicle, heavy duty vehicle, moped, motorcycle Road categories: urban, rural, highway Components: CO, PM, VOCs (and fractions), NO_X (also NO, NO_2), PM (exhaust and abrasion), PN, N_2O; NH_3; Fuel consumption and related pollutants (CO_2, SO_2, Pb, Cd, Cr, Cu, Ni, Se, Zn; PAHs, POPs, PCDDs, PCDFs)
Model structure	MS-Office like Offline tool, with Data stored in ACCES files Model calculates emissions in high resolution (per vehicle subsegment and traffic situation) User-specific application allows change of input data and advanced settings (vehicle load, after treatment technology, etc.) Optional implementation of fuel consumption statistics and correction factors
Availability	Distributed by EMISIA, order by registration, no fee for the user interface, 300 € per country data, 3000 € for EU 27 data Information: http://www.emisia.com/copert/General.html#
Model applications (examples)	Most of European national emission inventories Road sector in the TREMOVE model Emission Data for RAINS (Regional Air Pollution INformation and Simulation) model

2.3.4   TREMOVE

TREMOVE is a policy assessment model developed for the European Commission by the Dutch research company Transport & Mobility Leuven (TML). It is designed to estimate impacts of political decisions on transport activity, emissions and welfare cost and covers both land based and maritime transport in currently 31 countries and 8 sea regions.

The first version TREMOVE 1 was developed in 1997, followed by TREMOVE 2 in 2004 and version 3.3 which is available since 2010.

The program consists of several modules Emission inventory calculations are performed by the vehicle stock turnover and the fuel consumption and emissions modules. Additionally it models transport activity by a transport demand module and estimates welfare costs e.g. through tax revenues. Due to a life cycle emissions module the model also covers well to tank emissions.

Figure 9: *Model structure of TREMOVE*   Source: TML 2007

Vehicle categories cover the most important road, rail, water and air vehicles (passenger car; light and heavy duty vehicle; moped; motorcycle, vans, bus, metro/tram, trains, plain, and several types of inland waterway vessels). Emission standards and components are derived from the COPERT methodology in the road sector, rail and aircraft base on the TRENDS database, inland waterway vessels are described by data from the ARTEMIS project.

Table 6: *Overview: TREMOVE*

Name	TREMOVE
Purpose	Estimation of policy effects on transport (transport demand, modal split, vehicle stock turnover); emissions and costs (welfare and usage) in Europe
Commissioners	European Commission, DG Environment
Developer	Transport & Mobility Leuven and Catholic University of Leuven
Stakeholder	EU Commission
History	TREMOVE 1 - 1997-1999 TREMOVE 2 – 2004 (latest documented version 2.7b in 2009) TREMOVE 3 – (latest version 3.3.2 in 2010)
System boundaries	Land based and maritime transport in Europe (31 countries and 8 sea regions) Timeline 1995-2030 Vehicle categories: Road vehicles (moped, motorcycle, car, van, bus, light and heavy duty vehicles), Trains, plains, inland water- and maritime vessels Road categories: Urban, motorway, non-urban Model regions: Metropolitan, other urban areas, non-urban areas Components: based on COPERT methodology
Model structure	Offline tool based on DOS commands, linked to MS OFFICE elements, WINZIP and GAMS software Emission calculation in high resolution, linked to a stock and transport demand module as well as usage and welfare cost modules
Availability	Free download and information at http://www.tremove.org
Model applications (examples)	European policy implementations, e.g.: ■ Euro 5 and Euro 6 emission standards for cars ■ EURO VI emission standards for heavy duty vehicles ■ Fuel efficiency improvements beyond the 2008/2009 voluntary objectives of the car industry ■ Infrastructure charging ■ Fiscal measures for road transport vehicles

2.3.5   MOVES

MOVES (motor vehicle emission simulator) is a road emission calculation tool developed by the Office of Transportation and Air Quality of the EPA (United States Environmental Protection Agency). It is an EPA approved tool for local authorities to prepare state implementation plans (SIP) and can also be used for greenhouse gas emission inventories from national to local scale [EPA 2012b].

The current version is MOVES 2010, replacing the version MOVES 2009 and the previous MOBILE model.

Similarly to the European models the calculation methodology bases on a bottom up approach with high-resolute input data for vehicle and fuel types, technology, road types and meteorological data. Emissions are calculated for each layer and a variety of components and emission categories (e.g. exhaust, abrasion, evaporation).

Beside the creation of an emission inventory, MOVES allows input of road emission reduction strategies regarding fleet activity and composition or alternative fuels. Thus, strategy scenarios and mitigation effects can be projected for SIPs.

A default database provides input data that covers traffic activity, fleet composition, emission factors, etc. The model allows projection of these national data to the state or county level, however, the user can also enter individual input data if more detailed information, e.g. about local transport activity and fleet population, is available.

The software is freely distributed and available at EPA's website.

Table 7: *Overview: MOVES*

Name	MOVES (**Mo**tor **V**ehicle **E**mission **S**imulator)
Purpose	EPA approved emission model for road transport emissions and policy scenarios such as state implementation plan (SIP) development and transportation conformity determination
Commissioners	EPA (United States Environmental Protection Agency)
Developer	EPA's Office of Transportation and Air Quality (OTAQ)
Stakeholder	National Research Council (NRC)
History	MOBILE (MOBILE1 in 1978 to MOBIL 6 in 2004) MOVES 2009 MOVES 2010 (latest version MOVES 2010b)
System boundaries	Road vehicle emissions in the USA Timeline 1990, 1999-2050, time frame from year to daytime (hours) possible Emission categories: Exhaust, Abrasion, Evaporation, Crankcase emissions and further differentiations Vehicle categories: Motorcycles, Passenger Cars, Other 2 axle-4 tire vehicles, Buses, Single Unit Trucks, Combination Trucks Fuel Types: Gasoline, Diesel Fuel, Compressed Natural Gas (CNG), Electricity; and fuel subtypes Road Types: Urban Unrestricted Access, Urban Restricted Access, Rural Unrestricted Access, Rural Restricted Access, Off-Network Spatial application: National, State, County, Custom Project Energy and Fuel Consumption, Basic air pollutants (VOCs, NO_X, CO, PM_{10}, $PM_{2.5}$) and many others
Model structure	Offline software tool based on MySQL and JAVA Emission calculation in high resolution (per emission category, vehicle and fuel type, road category) and consideration of strategies (e.g. alternative fuels, vehicle retrofits)
Availability	GNU (general public) license Information and download at: http://www.epa.gov/otaq/models/moves/index.htm
Model applications (examples)	Region-wide travel demand management e.g., rideshare programs, employer-based programs Land use and smart growth strategies, e.g., transit-oriented development policies, policies to increase diversity and density of land uses Transit-promoting programs, such as increased transit frequency or lower fares Pricing strategies, such as parking pricing or mileage fees

3 GHG Balancing Methods for the Transport Sector of Cities

The GHG emission balance of the transport sector of a city can be calculated as the sum of GHG emissions from all transport activities attributed to a city. Hence, basis for the GHG emission balance are adequate emission calculations for each transport mode that shall be considered in the GHG balance (see Figure 10).

The calculation scheme in Figure 10 is basically similar to the emission inventory models presented in the previous chapter, and is referred to as a "bottom up" methodology. Alternatively, GHG emissions can be calculated "top down", if data on a city's fuel or energy consumption in transport is available, in combination with fuel specific GHG emission factors. The advantage of this method is that GHG emission balances directly refer to the overall fuel consumption from statistics. However, only few details on where the fuel is consumed, e.g. the transport carrier, can be given. This makes it especially difficult to evaluate emission reduction potentials of measures and estimate future GHG emissions due to political actions. Also, system boundaries may be inaccurate since fuel sold within a city can be consumed outside or the other way round. Within this study, the "bottom up" method is therefore suggested as the preferred tool for GHG emission balancing and further elaborated.
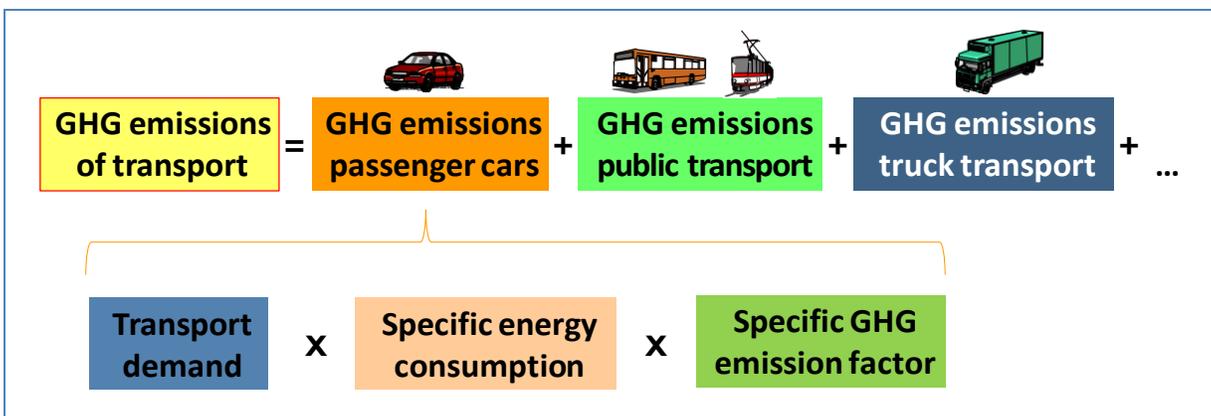
Figure 10: *Calculation scheme for an urban transport GHG balance*

There are several methodological approaches, which transport activities are attributed to a city. Basic decisions for the balancing are:

- Which transport activities are attributed to the city (system boundaries)
- What means of transportation are considered in the balance

Furthermore, different levels of detail can be chosen within the system boundaries in order to specify the origins and causes of transport activities and to consider local-specific traffic characteristics (regional fleet composition, traffic situations).

The methodological approach should, in principle, be coordinated with the subsequent use of the balancing results. In Practice, however, in many cases also the availability of locally adapted data is a decisive factor for the balancing method.

As a first step of the detailed explanation of GHG balancing practice in German cities, an overview of typical application fields of GHG balances for the transport sector is given in chapter 3.1. Then, common balancing methods in Germany are presented and compared with focus on system boundaries and characterization of transport activities. In this context, the suitability for different application fields of the balance as well as required input data on transport activities and available data sources are explained (chapter 3.2).

Beside the transport demand, specific energy consumption of the vehicles and used final energy carriers are relevant for the calculated GHG emissions (see chapter 1.2 & 1.3). At this point, cities can use extensively harmonized average emission factors in Germany. However, if adequate local-specific basic data are available, cities can also base their balance on regional fleet compositions and detailed traffic situations (chapter 3.3).

In the recent years, some few calculation tools have become available in Germany that can support cities in the modelling of local-specific GHG emissions. These tools have very different ranges of function and application fields. An overview of selected calculation tools that can be used for city-specific GHG emission inventories of transport is given in chapter 3.4.

3.1 Application Fields of Urban Transport GHG Emission Balances

Several application fields for GHG emission balances of urban transport can be seen, e.g.:

- Monitoring of GHG emissions of the transport sector
  - Contribution of the transport sector to the total GHG emissions in city's responsibility → Need of climate protection measures in the transport sector.
  - Assessment of past development trends
  - Monitoring and reporting of future developments of transport-related GHG emissions
  - Comparison of the emission situation between cities
- Setting focuses, estimating potentials and evaluating success of measures
  - Main contributors to transport-related GHG emissions and setting focuses of measures
  - Analysis of emission reduction potentials of local measures
  - Future emission scenarios (trend, measures) as support for setting emission reduction objectives
  - Success-Monitoring for realised measures
- Additional guidance for political planning and decision processes
  - Indicators for climate-friendly transport planning
  - Assessment of traffic and emission related effects of political decisions

Each application field has different requirements on the results of GHG emission balancing. E.g. the contribution of transport to the total GHG emissions in city's responsibility and, thus, the general need of climate protection measures in the transport sector can be estimated by one single figure, capturing the sum of all transport-caused GHG emissions.

However, to set focuses of measures within the transport sector, further differentiations of transport activities and related emissions are necessary in order to identify main causes of high emissions and promising target groups for measures. For the estimation of existing GHG mitigation potentials and to evaluate the possible success from local measures, the GHG balance must be built on city-specific basic information to the extent possible, reflecting the actual situation and action fields of the city.

Role of local authorities in Germany for climate protection in the transport sector

Fundamental options regarding mitigation of GHG emissions are the avoiding of motorized transport, the shift to more environment-friendly transport modes, the increase in energy efficiency due to technical improvements, the optimization of traffic flow as well as the implementation of alternative energy carriers with lower specific GHG emissions.

In Germany, the general framework for technical improvements and the introduction of alternative drive systems and energy carrier is set up by the EU and the German Federal government. As a supplement to this, local authorities can optimize the local traffic flow and support a fuel-saving driving-behaviour.

The focus of GHG mitigation measures on local level, however, is on modal-shift to more environmentally friendly means of transportation and on developing traffic-avoiding settlement and economic structures. Therefore, in Germany, for the evaluation of local GHG reduction measures, primarily *city-specific transport activity data* are required. In some cases, additional *city-specific adjustments of specific energy consumption and GHG emission factors* can be useful.

3.2 Characterisation of Transport Activities

3.2.1 System Boundaries: Which Transport Activities are Assigned to a City?

In Germany, different methods are applied in order to attribute transport activities to a city. These are based on the judgments of the cities, which transport activities fall in their area of responsibility and thus in the field of action for emission reducing measures, but also on local availability of basic data. There are no official guidelines in Germany, which system boundaries should be applied. An overview of common boundary definitions is given in Figure 8.

- The **territorial** principle covers all transport activities in the communal district. With this geographic definition, it corresponds broadly with the political sphere of influence of a city. In order that a territorial balance can provide suitable information about the causes of transport-related emissions and helps to identify promising emission reduction opportunities further differentiations of transport activities within the territory are necessary.

- The **inhabitants** principle covers only transport activities from inhabitants of the city, however usually not only on city's territory but also including trips to regional destinations and sometimes long-distance trips. This approach is often applied if only information on inhabitants' mobility, e.g. from household surveys, is available. In many cases, the balance is not even based on city-specific mobility information but on national average values.

- The "**city-induced**" principle focuses on transport-related GHG emissions caused by the city's role for living, working, supply of goods and services etc. Hence, it covers trips of inhabitants as well as of non-inhabitants (e.g. in-commuters, visitors). Emissions of originating+destination traffic are only partly assigned to the city considering the shared responsibility with that municipality the traffic comes from or goes to. No transit traffic is considered in the GHG balance.

- On special principle is the calculation of GHG emissions based on the **sales of energy** on the territory for the transport sector. In Germany, this approach works only for the federal city states having own energy statistics on city's level.

Elements of different methods can also be mixed in the emission calculations.
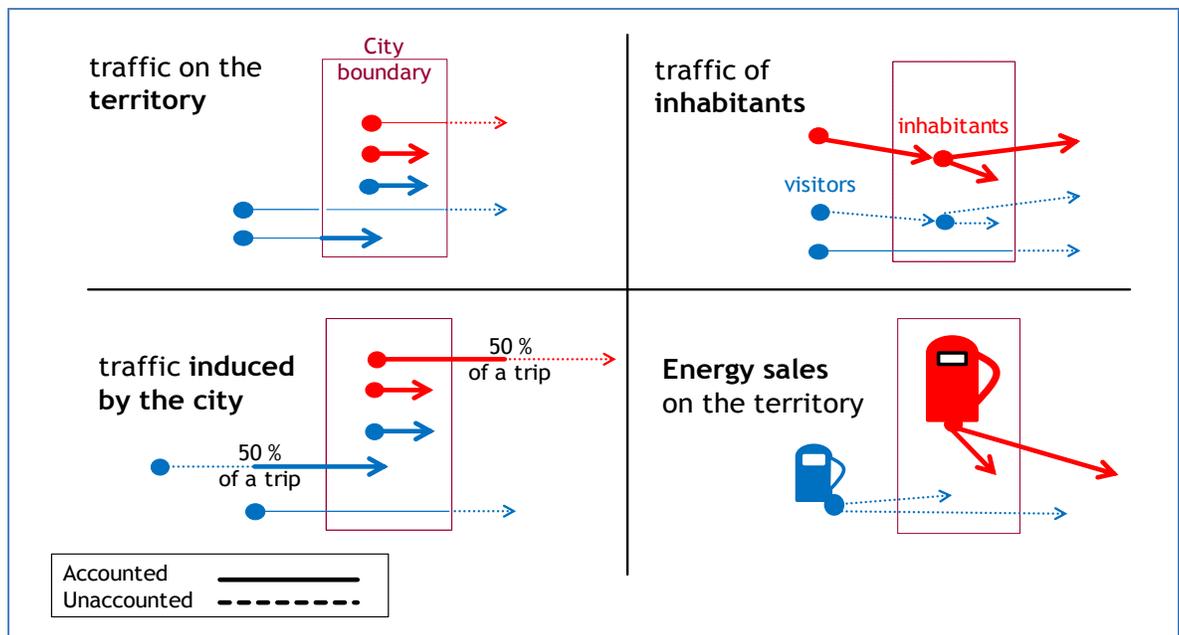
Figure 11: *Typical system boundaries of GHG balances for urban transport in Germany*

Source: IFEU Heidelberg 2012

3.2.2   Means of Transportation

The definition of transport activities considered in the GHG balance of a city includes also the selection and differentiation of means of transport. Transport activities in passenger and freight transport can first be differentiated by transport carrier and afterwards by several means of transportation with different properties (vehicle capacity, technical characteristics) as shown in

Table 8. This information is basic for the GHG emission calculations due to the different specific energy consumption and related GHG emissions of each means of transport (see chapter 1.2 & 1.3).

In GHG balances for urban transport, usually not all means of transport are considered due to their different relevance for local action. Esp. air traffic, inland navigation and rail freight transport are frequently omitted as they can only marginally be influenced by local measures. The relevance long-distance passenger transport (train, coach, car) depends largely on the system boundaries. For a territory balance, long-distance transport has only minor importance as the emission contribution of long-distance-trips on the city's territory is usually quite low. In contrast, long-distance trips can have higher importance for an inhabitants balance esp. if they are seen as a focus of city's climate protection program.

Table 8: *Transport carriers and means of transportation*

	Road	Rail	Water	Air
Passenger transport	Two-wheeler	Tram/light-rail	(passenger ship)	Air plane
	Passenger car	Regional train		
	Public bus	Long-distance passenger train		
	Coach			
Freight transport	Light duty truck	Freight rail transport	Inland navigation	Air plane
	Heavy-duty truck		(maritime navigation)	

3.2.3 Differentiation of Transport Activities by Origins and Causes

Transport activities of a city can be further differentiated in several ways in order to identify the origins of transport activities and the causes of trips. These differentiations can be very helpful for the identification of measure focuses and promising target groups. Important differentiations of transport activities are by trip distribution and trip purposes as illustrated in Figure 12.

The **trip distribution** describes the origin-destination relation of a trip with respect to the city.

- If a trip takes place entirely within the city limits, it is assigned to the **internal traffic**.
- **Origin traffic** starts in the city, but ends in another municipality.
- **Destination traffic** starts outside the city, but ends within the city limits.
- Trips that only cross the city's territory but neither start nor end in the city are referred to as **transit traffic**.

This differentiation is especially helpful to identify the share of GHG emissions from transport activities being completely or partially in the field of action for the city.

With the **trip purposes**, typical reasons for doing a trip are described, e.g. trip to work, shopping or leisure activities. This information can be used in a climate protection plan to develop target-group specific measures.

Considering all transport modes and further differentiations in the city's GHG emission balance would require very high data availability and cause high calculation efforts. Especially information on trip purposes is rarely available and, thus, not considered in the balances.
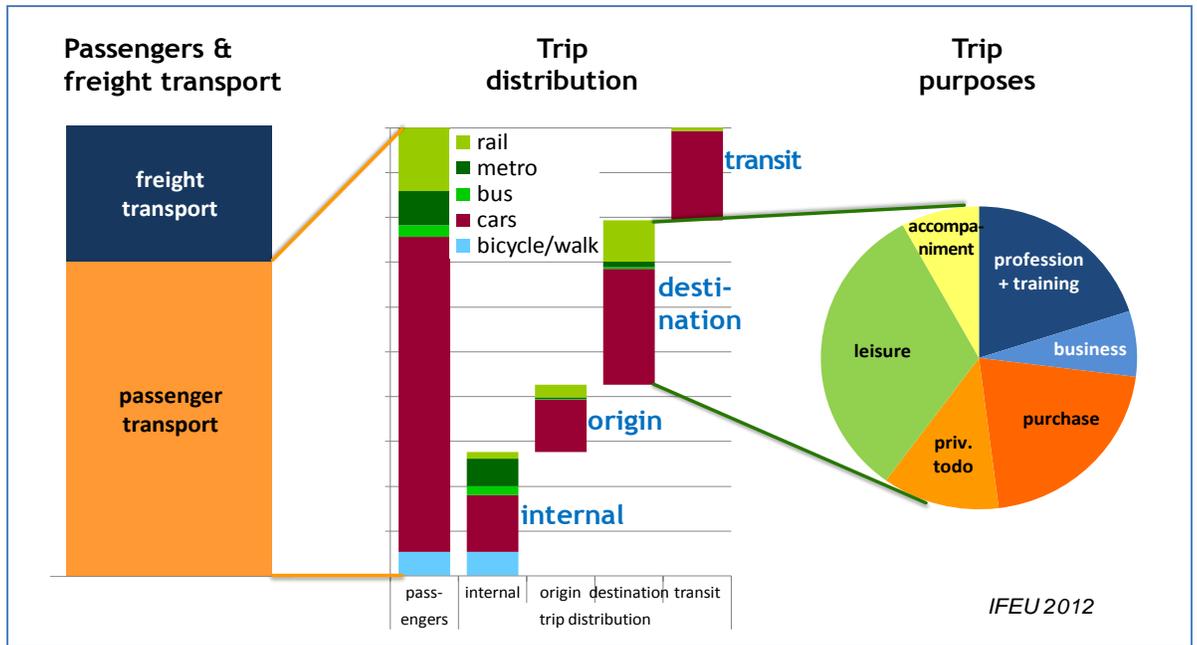
Figure 12: *Optional differentiations of transport activities attributed to a city (schematic)*

3.2.4   Data Sources for Transport Activities

Urban transport activities (mileages & transport performances) are highly city-specific depending on several influencing parameters such as:

- Number of inhabitants,
- Car ownership,
- Industrial settlements & number of employees in the city,
- City's function for surrounding municipalities,
- Transport infrastructure (e.g. cycle path network, public transport supply, parking space),
- Location of the city to national transport routes

E.g. solitary major cities in rural regions with high importance for surrounding municipalities (workplace, purchase, cultural and leisure activities etc.) can show considerable differences in amount and composition of local transport activities compared to cities of similar size, but located in urbanized agglomeration areas. **For this reason, determination and**

characterization of transport activities should not be done based on average values only (e.g. on national level), but include locally-adapted information where possible.

In German cities, several data sources are available that can be used for the determination of transport activities of a city. Primary data are collected mainly in traffic censuses and representative mobility surveys. These are subsequently joined in traffic models and projected to the considered area, e.g. the territory of a city. Additional information can be gathered from different statistical information e.g. about living and working places, freight transport volumes by regions of loading and unloading.

Typical city-specific traffic and mobility data in German cities are, e.g.:

- Mileage & transport performance data from municipal traffic models,

- Traffic censuses and driver surveys at access roads,

- Mileage data broken down from national and federal road traffic census data (e.g. annual VKT of all vehicle categories in each municipality of the federal state of Baden-Wuerttemberg provided by the federal statistical office)

- Mobility surveys for inhabitants (number and length of trips, modal split …): city-specific or from nation-wide surveys (e.g. [SrV 2008], [MiD 2008], micro-census),

- Operating data of public transport companies,

- Official statistics of commuting traffic

Major cities in Germany usually have own traffic models, capturing most road transport in the municipal area. Some of these models include additional information on public transport, on origin and destination of trips etc., which are further used in different ways in the cities. Besides, some cities use more information, e.g. about trip relations between the city and the surrounding region for their GHG balances.

Transport activity information used for the GHG emission calculations should reflect the actual situation of the city to the extent possible. Only this way the GHG balance is suitable for advanced objectives such as identification of measure focuses and estimation of city-specific emission reduction potentials (see chapter 3.1). However, in many cases, esp. in smaller cities, only limited information on local traffic is available. In this case, data gaps need to be filled with non-local parameters such as national average values (e.g. average VKT per vehicle type). Sometimes, average values are applied in GHG balances for cities for effort reasons, only, though local-specific information would be available. With increasing share of nonspecific information used in the emission calculations the validity of the GHG balance for the actual situation of the city decreases – and thus the suitability for advanced objectives of the balancing.

3.2.5   Pros and Cons of Different Methodological Approaches

The presented balancing methods consider different system boundaries, means of transport and differentiations of transport activities. In principle, all qualify for certain fields of application:

- The "**city-induced traffic**" principle most comprehensively covers the GHG emissions caused by the city and thus within its area of influence. The required balancing effort, however, is the highest, especially because for originating & destination traffic often no information is available on the corresponding share of the trips beyond the city limits.

- Main advantage of the "**territorial principle**" is the accordance with the political scope of a city. It is therefore also consistent with the balancing approaches in other sectors (which usually takes into account the energy consumption of stationary sources on the territory). Moreover, many large cities have traffic data available in the same scope from traffic planning models. However, in order the use the territorial principle for the analysis of measures and performance monitoring, a further differentiation is necessary, especially in order to determine origins and causes of traffic. Availability of respective data is often limited and can only be determined with considerable additional effort.

- The "**inhabitants principle**" focuses on the traffic of the city's inhabitants and thus on the target group which can be directly addressed by the city. Furthermore, the ascertainment of traffic and mobility data for the inhabitants is simpler than for non-inhabitants. In practice, however, often federal average data are used. This limits the complexity and effort of the balancing process, but neglects the local situation and thus limits the qualification for further balancing applications such as analysis of measures and monitoring of success of climate-protection activities.

As for the system boundaries, no definite recommendation can be given for the considered means of transport. The available data and the city's possible scope of action have to be considered:

- **Individual motor car traffic** and **urban public transport** have to be included in the balance. With greater integration of the city within its region, also regional transport modes should be included (especially **regional rail transport**).

- **Long distance passenger transport** should be included if they are on focus of measures. This is usually the case for the inhabitant principle.

- A differentiated consideration is necessary for **freight traffic**. The scope of action in German cities is usually limited to the urban and regional O&D freight traffic (especially delivery traffic), the potential influence is smaller than for passenger transport. City's influence it is generally limited for freight traffic with more distant origins and destinations. Since available data mostly do not allow for a further differentiation by origin of freight transport, it is in principle more appropriate to consider the entire road freight transport and include other means of transport only in specific cases (e.g. for transport

hubs in combined traffic). It can also be appropriate to entirely neglect freight transport in the balance and focus on passenger traffic which can be better influenced.

The discussion shows that methodological consistency and accordance of the used traffic activity data with the actual situation in the city are most important for the suitability of a balancing approach. A comparison of GHG balances for different years and between cities is only feasible if all balances have been conducted according to uniform methodologies.

Figure 13 illustrates using the example of Frankfurt/Main how different balancing approaches can affect the total amount of calculated GHG emissions as well as the contribution of different means of transportation to the emissions. The example covers the consideration of upstream emissions, relevance of system boundaries and considered means of transportation as well as the importance of city-specific transport data compared to federal state averages.
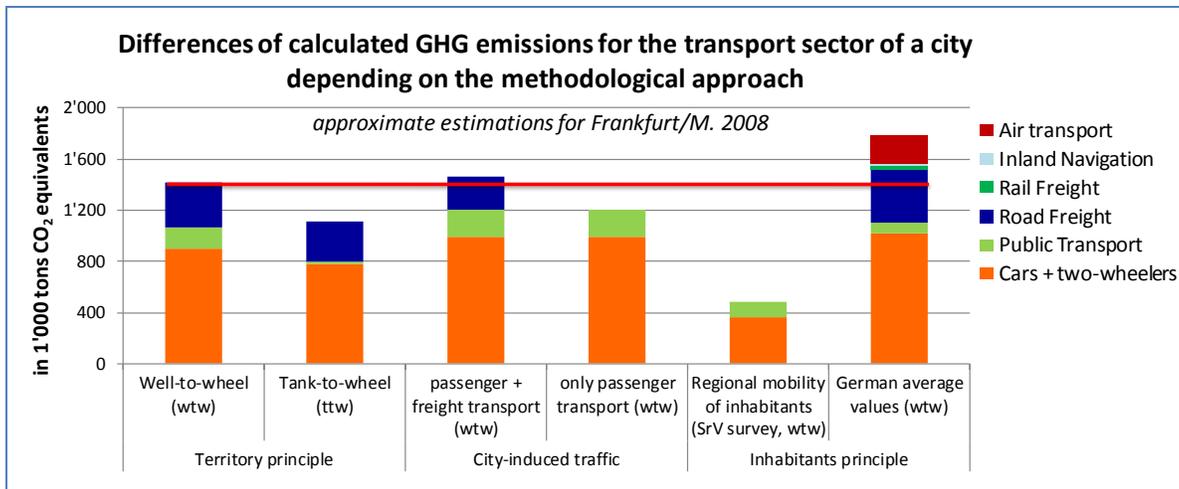
Figure 13: *Effects of different GHG balancing approaches on the calculated GHG emissions of a city using the example of Frankfurt am Main*

3.3 Emission Factors for GHG Balancing of City-related Transport Activities

Besides traffic volumes, the specific greenhouse gas emission factors are very important for the calculated transport emissions. More accurate information on vehicle characteristics, transportation and travel conditions can lead to a more realistic calculation of energy consumption and GHG emissions (see chapter 1.2 & 1.3).

To calculate the total emissions in a city, however, it is not feasible to determine individual energy consumption and emission factors for each single trip. Therefore emission calculations for a street situation of an urban area are based on average emission factors. Such factors represent average mileage shares of different vehicle layers with similar properties on the hand. On the other hand, these factors weight the specific energy consumption for different road types, speed limits and traffic situations.

In Germany it is common practice to use the average fleet composition of Germany for urban GHG balances and to apply average emission factors for urban, extra-urban and motorway conditions for each vehicle category. However, if adequate local-specific basic data are available, cities can also base their balance on regional fleet compositions and detailed traffic situations.

3.3.1 Harmonized Average GHG Emission Factors for Transport in Germany

Specific energy consumption and GHG emission factors for the transport sector are extensively harmonized in Germany. For **road transport**, specific energy consumption factors are available from the *"Handbook Emission Factors for Road Transport HBEFA"* [INFRAS 2010] resp. TREMOD, incl. German fleet compositions and distribution of traffic situations for several reference years (see chapter 2).

For **rail, water and air transport**, harmonized mean values for specific GHG emissions are used and documented in the *"Transport Emission Model TREMOD"* [IFEU 2010][6]. Furthermore, TREMOD provides specific GHG emission factors for all relevant energy carriers in transport incl. the **upstream GHG emissions** and other GHGs than CO_2.

3.3.2 Optional Local-specific Refinements of Road Transport Emission Calculations

In emission calculations for road transport, also regionalised fleet compositions and highly differentiated energy consumption and emission factors for all vehicle layers and individual traffic situations can be used from HBEFA. Municipal areas could therefore make very differentiated and localised emission calculations either in respect to the fleet composition or the local traffic flow. The required effort, however, is much higher compared to the use of average factors and mostly reasonable if e.g.

a. Very specific local conditions exist (regions with a strong automotive industry tend to have a younger vehicle fleet, rural areas an older vehicle fleet),
b. The balance is used for the evaluation of local measures which have a relevant impact on the specific energy consumption (e.g. improvements in traffic flow, reduction of vehicle age, alternative power trains).

For a **city specific fleet composition**, the statistical vehicle stock of inhabitants is available in the required differentiation for each municipality from the German 'Federal Motor Transport Authority' (KBA). However, this static fleet composition is not sufficient for emission calculations, but a dynamic fleet composition is required which regards the different yearly mileage per vehicle for different vehicle layers. E.g. newer cars have on average higher mileages per year than older cars in Germany, diesel cars are more driven than gasoline cars. On motorways, the share of diesel cars is higher than in urban traffic (Figure 14).

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[6] TREMOD is only directly available to selected organisations (s. chapter 2.3.2). A background report in German is publicly available at http://www.ifeu.de/tremod. Important TREMOD energy consumption & GHG emission factors are also made publicly available by different publications, e.g. DIFU guide "Climate protection in municipalities" [DIFU 2010].

Average yearly mileage of passenger cars in Germany depending on vehicle age

yearly kilometres per car

35000
30000
25000
20000
15000
10000
5000
0

Gasoline car
Diesel car

source: TREMOD

2010 2005 2000 1995 1990 1985 1980

first registration year

Shares of diesel and gasoline cars on the vehicle stock in Germany 2010 and on VKT

120%
100%
80%
60%
40%
20%
0%

Diesel
Gasoline

source: TREMOD

Vehicle Stock

motorway | other roads

VKT shares

Figure 14: *Relevance of vehicle age and engine type for the dynamic passenger car fleet composition in Germany*

One common method to obtain a dynamic fleet composition is converting the statistical vehicle fleet of the inhabitants into a dynamic fleet by applying average yearly mileage values per vehicle layer from TREMOD/HBEFA. In the best case, dynamic fleet compositions can be deducted from additional surveys. In Germany, these can be license plate surveys in which the license plates of all vehicles passing a defined measurement point are collected and digitally processed (by video analysis or manually) and then synchronized with additional information in the central vehicle register of KBA. Advantage of these license plate surveys is that the real dynamic fleet composition of the road transport in a city is captured, including not only vehicles of inhabitants but also of non-inhabitants. Such surveys, however, are very costly and, therefore, only done to a limited extent.

The use of **city-specific traffic situations** in the GHG balancing can be helpful if local measures are planned to improve the traffic flow. However, this is only possible with reasonable effort if corresponding traffic data are available, e.g. from a traffic model. These models usually distinguish street types and speed limits and sometimes also enable modelling of traffic flow (e.g. free, heavy, stop-and-go traffic). Applying such differentiated traffic data to the HBEFA emission factors for individual traffic situations (see Figure 15), additional cold start supplements have to be calculated, as they are not included in the detailed emission factors.

Area	Road type	Levels of service	30	40	50	60	70	80	90	100	110	120	130	>130
Rural	Motorway-Nat.	4 levels of service												
	Semi-Motorway	4 levels of service												
	TrunkRoad/Primary-Nat.	4 levels of service												
	Distributor/Secondary	4 levels of service												
	Distributor/Secondary(sinuous)	4 levels of service												
	Local/Collector	4 levels of service												
	Local/Collector(sinuous)	4 levels of service												
	Access-residential	4 levels of service												
Urban	Motorway-Nat.	4 levels of service												
	Motorway-City	4 levels of service												
	TrunkRoad/Primary-Nat.	4 levels of service												
	TrunkRoad/Primary-City	4 levels of service												
	Distributor/Secondary	4 levels of service												
	Local/Collector	4 levels of service												
	Access-residential	4 levels of service												

Figure 15: *Traffic situation scheme in HBEFA 3.1*

3.4   Calculation Tools for City-specific GHG Emission Inventories in Germany

In the recent years, several calculation tools have become available in Germany that can support cities in the modelling of local-specific GHG emissions of transport and other sectors. Furthermore, some emission calculation models from air pollution control and noise control can also be applied for the calculation of GHG emissions from transport. These tools have very different ranges of function and are addressed to different user groups. A short overview of selected calculation tools applicable for city-specific GHG emission inventories of transport in Germany is given in this chapter.

ECORegion

The internet tool **ECORegion** was especially designed for local authorities to calculate their energy and CO_2 inventories (developed by Ecospeed, Climate Alliance and B.&S.U.). It is distributed in three versions with different range of functions (see Figure 16   Figure 16). ECORegion enables the calculation GHG emissions resulting from stationary and transport energy consumption (in the pro and premium version also non-energetic emissions, e.g. from industrial processes). CO_2 emissions incl. upstream emissions can be calculated in all program versions, other greenhouse gases can only be considered in the pro and premium version.

Module	Smart	Pro	Premium
Energy	•	•	•
Final energy	•	•	•
LCA (Life Cycle Analysis, energetic)	•	•	•
energy autonomy	•	•	•
Climate correction (Heating grade days)		•	•
Emissionen	•	•	•
CO_2	•	•	•
All greenhouse gases according with IPCC		•	•
Business	•	•	•
By energy carriers	•	•	•
By sectors	•	•	•
By room heating, hot water, process		•	•
Majority consumer/emitter		•	•
Households	•	•	•
By energy carriers	•	•	•
By room heating, hot water, process energy		•	•
Traffic	•	•	•
By traffic types	•	•	•
By vehicle categories	•	•	•
Balancing methods IPCC and LCA	•	•	•
Non-energetic emissions according with Kyoto Protocol		•	•
Scenarios and measures simulation			•

Figure 16: *Range of functions of different versions of ECORegion*   Source: ECOSPEED

GHG balancing in ECORegion is a multi-step process. A first initial balance is calculated with federal average values, the only required user input for this are number of inhabitants and of employees. In the next steps, the calculation can be filled-up with further individual data and, thus, be adapted to the local situation of the city.

For the transport sector, one further option is to enter local vehicle stocks: the calculation method changes from federal average values per inhabitant to average values per vehicle type. However, also local traffic demand data can be used for the calculations. Transport performance (pass.km, ton-km) are required for passenger transport, freight rail transport and inland navigation. VKT (veh.km) are required for road freight transport. No rules are given whether the traffic demand data should refer to the city's territory, inhabitants or to other system boundaries.

For all other calculation parameters such as fleet composition (only energy carrier), specific energy consumption and CO_2 emission factors, default values are preset for all calculation years. However, all these parameters can also be changed individually by the user.

As a result of the different levels of city-specific adaption of calculations and as no detailed rules are set for the entry of local information, calculated GHG emissions can vary strongly for the same city. Hence, comparisons of different GHG balances done with ECORegion are only admissible, if the application of identical methodology is ensured.

BICO2 Balancing Tool

BICO2 is an Excel-based GHG balancing tool developed by IFEU Heidelberg and used for GHG balances of cities and regions. It covers GHG emissions resulting from stationary and transport energy consumption and considers upstream emissions as well as CO_2 equivalents incl. CH_4 and N_2O. All sectors are balanced using the territory principle.

Objective of the BICO2 development is to provide cities with an easy-to-handle calculation tool for annual GHG balancing. The tool shall be usable by the city's authorities autonomously and be updatable regularly with locally available data. For that, BICO2 is adapted to the individual data situation in each city.

In the transport sector, usually complete road transport on city's territory as well as public transport (bus, tram, metro and short-distance train) is considered in the balance. However, further means of transportation can be considered on demand. Applied emission factors come from TREMOD.

Road transport calculations are usually differentiated by road categories (urban, rural, motorway) but not by detailed traffic situations. Further differentiations of emission calculations, esp. by trip distribution, are done depending on the data situation in the city.

Beside individual BICO2 solutions for several cities throughout Germany, a special version of BICO2 was developed for the municipalities in the German federal state of Baden-Wuerttemberg. This „BICO2-BW" is based on the annual VKT data for road transport being available each year and for each municipality by the Statistical Office of Baden-Wuerttemberg. Only transport information on public transport have to be gathered independently by the municipalities, e.g. from local public transport operators, timetables and railway guides.

HBEFA Integration Into the Transportation Planning Software VISUM

PTV's VISUM, a traffic model software widely used for traffic planning in German cities can been amended by a HBEFA module, enabling the calculation of tailpipe emissions from the road traffic, covered in the traffic module. Focus is to enable users of VISUM to calculate greenhouse gas and air pollutant emissions as a simple post-processing step of the traffic demand modelling. This way, traffic planners shall get a tool helping them to evaluate traffic situations from an environmental perspective and to make road transport more environmentally friendly.

Due to the use of HBEFA, emission calculations are limited to road traffic and calculate only tailpipe emissions during vehicle use. However, emission calculations are done with high spatial resolution (corresponding to the traffic modelling) and reflect individual traffic situations depending on street type, speed limit and traffic volumes in each street (see Figure 17). The system boundaries of the calculations are identical to the traffic model.
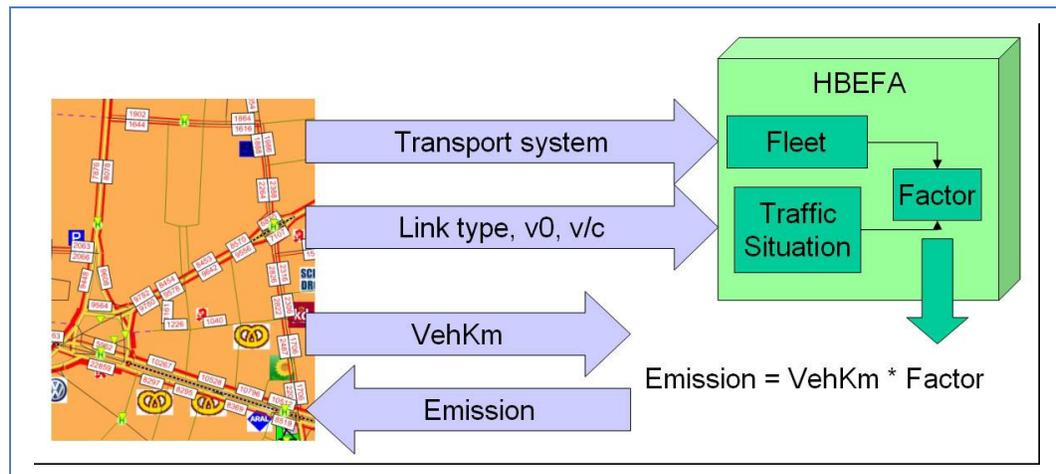

Figure 17: *Data flow between VISUM and HBEFA*   Source: PTV 2010

IMMIS^em Module of Program System IMMIS

IMMIS^{em/luft/lärm} is a modular GIS-integrated program system developed by IVU Umwelt to evaluate traffic induced air and noise pollution. It is applied by local, regional and federal authorities as well as consulting companies, esp. in air pollution and noise control planning.

The modul IMMIS^em calculates tailpipe emissions of air pollutants and greenhouse gases from road transport at street level for subsequent dispersion modelling. It can be applied for single streets as well as for entire cities. In consequence, the system boundaries of the calculations are identical to the traffic data coming e.g. from municipal traffic planning.

Emission calculations in IMMIS^em are based on detailed emission factors from HBEFA and consider the detailed traffic situations in each street depending on street type, speed limit and level of service. Also cold start supplements are calculated.
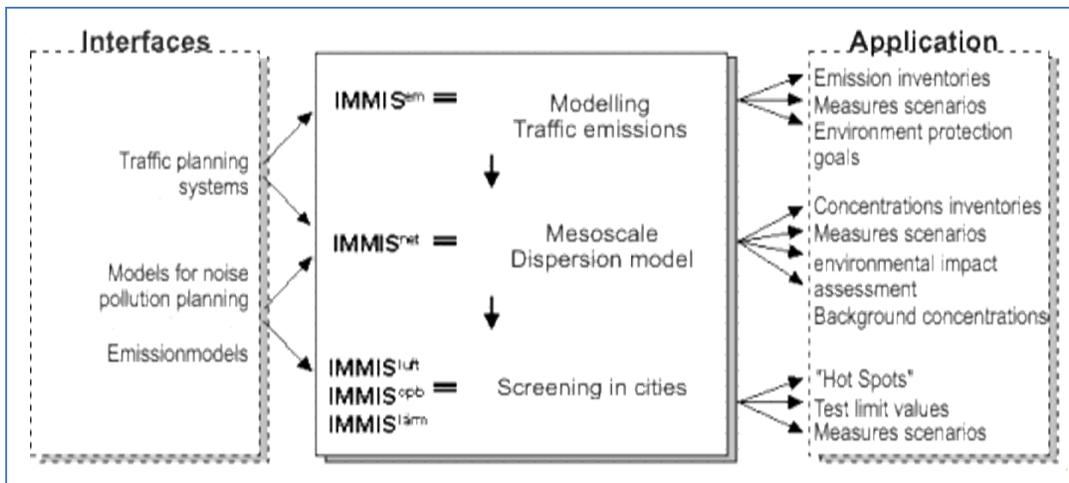
Figure 18: *Modular GIS-integrated program system IMMIS*   Source: IVU Umwelt

Comparison of the Calculation Tools

The briefly presented calculation tools are characterized and compared in more detail in Table 9. The main differences between the tools are due to their different objectives.

ECORegion und BICO2, both are GHG balancing tools, transport is one of several considered sectors. Transport activity data is mostly demanded as aggregated totals (VKT, pass.km, ton.km) which are linked to the average emission factors implemented in the tool. Direct as well as upstream emissions are calculated irrespective of their point of origin (since this is irrelevant for the global climate impact). These tools can be quickly mastered also by users with little training as no detailed transport knowledge is required as long as respective transport data are available from other sources in the required format.

Weaknesses of ECORegion are the multi-level calculation process and the lack of guidelines for the implemented traffic data and thus changing system boundaries of the balances. In practice this leads to GHG balances which are often not directly comparable (see also chapter 3.2.5).

HBEFA-in-VISUM and IMMIS[em] have a focus on the street by street ascertainment of air pollutant emissions from road traffic. They are closely connected to the availability of differentiated traffic data from traffic surveys or models and part of software packages for a) traffic modelling or b) subsequent analyses of air quality. These tools also allow for a street by street calculation of GHG emissions taking into account variable local traffic situations, but are limited to direct emissions during vehicle use. The complexity and level of detail require more technical knowledge of traffic and emission modelling.

Both tool groups are, thus, not directly comparable in terms of functionality for municipal GHG balancing and have advantages and disadvantages for such balances. An optimal scope of functions could be realized with a combination of both tool types, combining the advantage of differentiated road traffic calculations in road emission tools with the advantage in respect to upstream emissions and other means of transportation of GHG balancing tools.

Table 9: *Overview of selected calculation tools for transport-related GHG emissions of cities*

	ECORegion	BICO2	HBEFA-in-VISUM	IMMIS [em]
Purpose(s) and model applications	GHG balances for cities, incl. all sectors of final energy consumption. + Non-energetic emissions (only pro+premium version)	GHG balances for cities incl. all sectors of final energy consumption	Calculation of direct airborne emissions from road transport within the transport planning software VISUM	Air quality plans: Calculation of direct airboren emissions from road transport at street level for dispersion modelling.
Tool structure	Stand-alone tool. Three versions with different range of functions	Stand-alone tool	Add-on module for the transport planning software VISUM	Module of the program system IMMIS
Developer	ECOSPEED AG	IFEU	PTV	IVU Umwelt GmbH
Availability	Distributed by ECOSPEED AG, order by registration	Not publicly available. Available for KEA (Energy Agency of the state of Baden-Wuerttemberg) for municipalities in the German federal state Baden-Wuerttemberg Internal usage by IFEU for other municipalities in Germany	Distributed by PTV	Distributed by IVU Umwelt GmbH
Time period for calculations	1990-2030	2000-2030	1995-2030	1995-2030
Transport modes	all transport modes	road transport + public transport, other transport modes optional	road transport	road transport
System boundaries	Undefined. Depending on calculation step and input data	Territory	Streets covered in the traffic model	Streets covered in the traffic input data
Emission factor data bases	TREMOD, DIW, others	HBEFA 3.1, TREMOD	HBEFA 3.1	HBEFA 3.1
Road transport: Traffic situations - level of detail	Average traffic situation mix for a) short-distance traffic b) long-distance traffic	Average traffic situation mix by road category (motorway, rural, urban)	Detailed traffic situations incl. Road type, speed limit and level of service	Detailed traffic situations incl. Road type, speed limit and level of service
Road transport: Cold start consideration	Yes. Included in the average emission factors.	Yes. Included in average urban emission factors	Yes. Separated cold start model.	Yes. Separated cold start model.
Road transport: Regional fleet compositions	No	No	No	No. (consideration of typical effects of low-emission zone on fleet compositions possible)
Differentiation of trip distribution	No	Depending on differentiation of traffic input data.	Depending on differentiation of traffic input data.	Depending on differentiation of traffic input data.
Differentiation of trip purposes	No	No	Depending on differentiation in the traffic model	Depending on differentiation in the traffic model
Traffic data entry	manual entry, import from MS Excel	manual entry	data transfer from VISUM	manual entry, import from VISUM (IMMIS expansion module)
Processing of traffic data	No	No	Differentiation of traffic composition (i.e. shares of cars, light-duty trucks etc.) if only a smaller number of vehicle types (e.g. cars/trucks) are distinguished in the traffic model	Differentiation of traffic composition (i.e. shares of cars, light-duty trucks etc.) if only a smaller number of vehicle types (e.g. cars/trucks) are distinguished in the traffic model
Greenhouse gases	CO_2 (all versions), other GHGs (only pro+premium version)	CO_2, CH_4, N_2O	CO_2, CH_4, N_2O	CO_2, CH_4, N_2O
Upstream emissions	Yes ("LCA methodology")	Yes	No	No

4 GHG Balancing Practice for Transport in Major German Cities and London

Based on the elaboration on GHG balancing methodologies in chapter 3, recent inventories from selected major German cities have been analysed. In the present chapter, the methodological approaches of each city are summarized and compared. Advantages and disadvantages regarding their suitability to meet the objectives of GHG balancing are discussed.

As complementary European example for GHG balancing for the transport sector in metropolitan areas, the London Energy and Greenhouse Gas Inventory (LEGGI) 2008 for Greater London (the 32 London boroughs and the City of London), has been analysed.

4.1 Description of Selected German Cities

In the selection of cities, illustrating GHG balancing good-practice in Germany and to work out specific advantages of individual approaches, several criteria have been considered:

- GHG balances meeting good-practice for different criteria identified in chapter 3.

- Detailed description of methodology and data sources in the studies and, where necessary, additional information from the institutions having realized the GHG balance

- Inventories conducted by different institutions in order to avoid misleading conclusions about GHG balancing practice in Germany coming from several inventories with same methodology from only one single institution.

Figure 19 presents the eight major German cities considered in the analysis and their locations in Germany. In order to meet the objective of providing helpful information from German inventories for a GHG modelling of the megacity Beijing, primarily cities of more than 500'000 inhabitants have been considered in the analysis. Among the eight cities, Cologne and Munich are exceeding one million inhabitants. Also the cities of Frankfurt/Main, Bremen and Leipzig have more than 500'000 inhabitants. In the case of Hannover, the GHG balance represents not only the city of Hannover (about 526'000 inhabitants), but the whole urban agglomeration "Region Hannover" with more than 1.1 million inhabitants. All selected cities are characterized by a high population density. According to a German classification, the cities considered are categorized as being nucleated towns within agglomeration areas [BBSR 2010].
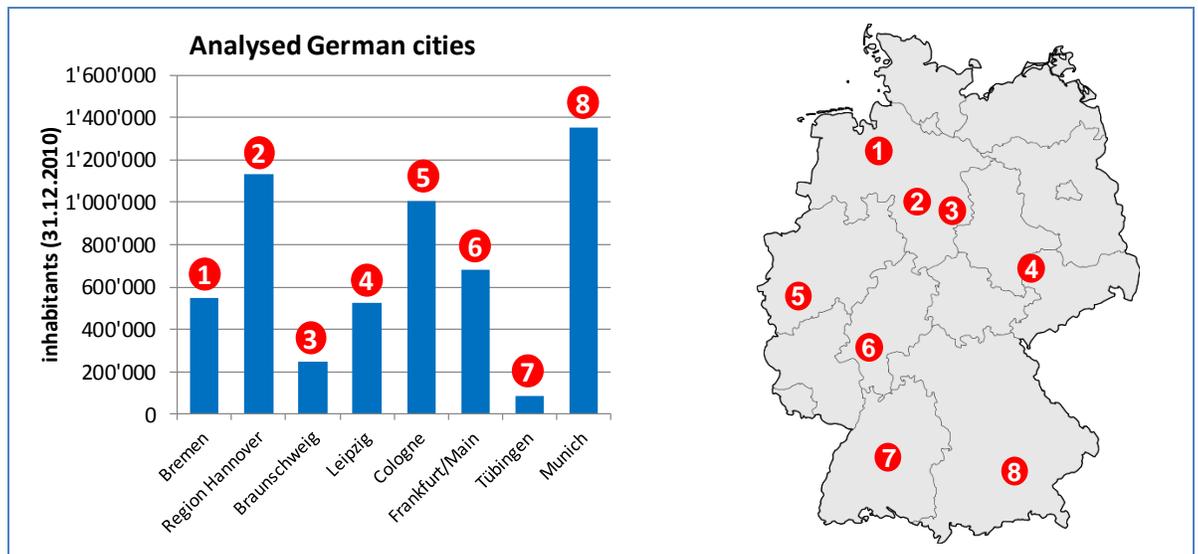
Figure 19: *Selected major German cities*

Some general parameters describing each city and the GHG balances have been collected in Table 10. Apart from the number of inhabitants of each city, main parameters are **title and kind of the report** (e.g. independent GHG balancing report or climate action plan) and **responsibilities for the GHG balancing** –the commissioner (usually the municipal environmental office) as well as the authoring institution (generally consulting engineers or scientific bureaus with environmental or transport planning background).

Table 10: *Overview of general parameters for the analysed German cities and Greater London*

	Bremen	Region Hannover	Braunschweig	Leipzig	Cologne	Frankfurt /Main	Tübingen	Munich	Greater London
Inhabitants (31.12.2010)	547,340	1,132,130	248,867	522,883	1,007,119	679,664	88,358	1,353,186	7825200 (July 2010)
Report information									
Report title	Klimaschutz-konzept Bremen - Berechnung der verkehrs-bedingten CO_2-Emissionen	GIS-basierte Erstellung einer CO2–Bilanz der Quellgruppe Verkehr für die Region Hannover	Energie- und Treibhausgas-Bilanzen Braunschweig 1990 bis 2008	Integriertes Energie- und Klimaschutz-konzept für die Stadt Leipzig	Klimaschutz-konzept für die Stadt Köln – Teilbereich Verkehr	Energiever-brauch und Treibhaus-gasemissionen des Verkehrs im Stadtgebiet Frankfurt /Main	Mobilität 2030 Tübingen. Abschlussbericht der Pilotphase im Projekt „Nachhaltiger Stadtverkehr Tübingen"	CO_2-Monitoring 1990 – 2008	London Energy and Greenhouse Gas Inventory (LEGGI) 2008 Methodology Manual
Kind of publication	GHG balancing and scenarios report	GHG balancing report	GHG balancing report	Energy and climate action plan	Climate action plan	GHG balancing report	Climate action plan	GHG balancing report	GHG balancing report
Considered sectors	transport sector	transport sector	transport & stationary sectors	transport & stationary sectors	transport sector	transport & stationary sectors	transport sector	transport & stationary sectors	transport & stationary sectors
GHG balance year	2005	2005	2008	2008	2006	2008	2008	2008	2008
Year of publication	2008	2008	2010	2011	2011	2010 (internal report)	2010	2011	2010
Responsibilities for the GHG Balancing									
Commissioner	Senator für Umwelt, Bau, Verkehr und Europa der Freien Hanse-stadt Bremen, Referat 51	Region Hannover	Stadt Braunschweig	Stadt Leipzig, Amt für Umweltschutz	Umwelt- und Verbraucher-schutzamt der Stadt Köln	Stadt Frankfurt am Main	Universitätsstadt Tübingen	Stadtrats-beschluss vom 09.10.1996, Auftrag an die Stadt-verwaltung	Greater London Authority (GLA)
Authoring institution	IVV Engineering Group GmbH & Co. KG, Aachen	GEO-NET Umweltconsulting GmbH, Hannover	GEO-NET Umweltconsulting GmbH, Hannover	IVAS - Ingenieurbüro für Verkehrsanlagen und -systeme, Dresden	Wuppertal Institute for Climate, Environment and Energy, Wuppertal	ifeu – Institute for Energy- and Environmental Research Heidelberg GmbH	imove - Institute for mobility and transport, University of Kaiserslautern	Referat für Gesundheit und Umwelt der Stadt München	AEA, London

4.2   Comparison of the Analysed GHG Balances

The GHG balances of the selected eight German cities and of Greater London were analysed following the explanations on methodology and data sources in chapter 3. All descriptions to the balances have been determined from the corresponding reports and in some cases complemented by personal communication with the authors. A detailed citation of references is not done as this would affect the readability of this text due to the scattered information within the reports.

A special focus in this chapter is given to the presentation of transport data sources available in the cities. For this purpose, additional information has been gathered from the authoring institutions and from the cities' authorities.

4.2.1   Objectives of the GHG Balances

The analysed reports can be distinguished by

   a. GHG balances as part of energy and climate action plans
   b. Independent GHG balancing reports.

Objectives of the GHG balances as stated in the reports correspond largely with those already explained in chapter 3.1:

- **Description of past GHG emission developments** (ex-post) and **monitoring of future developments**. Key preconditions named in the reports are consistent, comparable methodologies to past balances as well as easy-to-update databases in future years [Leipzig 2011, Cologne 2011]. Also **comparisons with other cities** are targeted [Cologne 2011].

- **Identification of climate-relevant scopes**: First compared to other sectors [Braunschweig 2010], second to set priorities and estimate reduction potentials within the transport sector [Cologne 2011]. In this way, the GHG balance is seen as **starting point for future CO$_2$ reduction programs**.

- For the **setting of city-specific emission reduction targets** [Braunschweig 2010], the balances should be suitable to **estimate future effects of measures in the individual field of action of each city** [Leipzig 2011]. Future periodic updates of the GHG balances should enable the **evaluation of realised measures** [Braunschweig 2010].

In some reports, no statements are made regarding the objectives of the GHG balances. However, this is only the case for GHG balancing reports without integration into action plans.

In Germany, municipal climate action plans can be government-funded by BMU. In the funding guidelines, GHG balances are explicitly demanded for all considered sectors as part of such a climate action plan. So this is another important reason for preparing a GHG balance for the transport sector in German cities. For the GHG balances that have been analysed in this report this guideline concerns the cities of Tübingen, Leipzig and Köln.

The objectives as stated in the London Energy and Greenhouse Gas Inventory LEGGI are similar to those in German reports. LEGGI is used for "assessing the spatial distributions and relative significance of the various fuel/energy consumption sources and sectors and greenhouse gases emissions to **reach informed opinions when formulating, monitoring and evaluating energy policies and preparing energy and climate change reports**."

Table 11 gives an overview of the reasons for preparing GHG balances as stated in the report of each city.

Table 11: *Reasons for preparing GHG balances for the transport sector stated in the reports of the analysed cities*

Bremen	No explanations in the report. However, the GHG balance is used in the report as basis to calculate CO_2 emission reductions in future scenarios with additional measures.
Braun-schweig	With the GHG balance, most relevant sectors (transport & stationary sectors) shall be identified as basis for the determination of measure focuses and to derive target-oriented activities of the city's authorities: ■ Starting point for future CO_2 mitigation programs in Braunschweig. ■ Basis for local emission reduction targets and to develop strategies in priority fields of action. ■ Periodic update of the GHG balance in future in order to evaluate implemented measures and for the control of success of climate protection activities. Methodology and data bases have been chosen in a way to enable easy and consistent updating in future years.
Leipzig	Basis for appropriate evaluation of GHG emission reduction potentials in the transport sector for measures in city's fields of action. ■ Trends and Monitoring: comparability of GHG balances for different years in order to identify emission trends in future ■ Analysis of measures: GHG balance is expedient for the development of measures and to forecast related emission-reducing effects in scenarios within the scope of Leipzig's energy and climate protection plan. The authors emphasise the consideration of city's direct field of responsibility as an important boundary condition for the GHG balance.
Cologne	Easy-updatable GHG balance for ■ Description of status-quo of the city and benchmark with other cities ■ Basis for the identification of sections with particular need for action or substantial reduction potentials ■ Identifying fields of action for the city's authorities and to estimate the effects of (political) measures. Basis for the development of measure recommendations
Tübingen	No explanations in the report. However, the balancing results are directly applied for estimating emission reduction potentials of proposed measures.
Munich	Annual CO_2 emission monitoring for the city of Munich according to the title of the report. No further explanations in the report.
London	The LEGGI is used for assessing the spatial distributions and relative significance of the various fuel/energy consumption sources and sectors and greenhouse gases emissions to reach informed opinions when formulating, monitoring and evaluating energy policies and preparing energy and climate change reports. The LEGGI plays a major role in the development and implementation of the Mayor's Climate Change Mitigation and Energy Strategy (CCMES).

4.2.2   Characterization of Transport Activities

In this section, the methodological approaches in the analysed GHG balances regarding system boundaries and differentiations of transport activities are summarized. Explanations to transport

data sources, which together with the balancing objectives are relevant for the methodological decisions, are not given in this chapter as the transport data sources available in the cities are presented in more detail in chapter 4.2.5.2.

System Boundaries

With the exception of Tübingen the emission calculations have been done according to territorial principle, i.e. emissions of transport within the city area are balanced. Tübingen balanced the "city-induced" transport activities including internal traffic as well as originating and destination traffic (with complete trip distances), but no transit traffic.

In the cases of Leipzig, Cologne and Munich beside the territorial balances further balances using differing system boundaries were calculated and explained:

- Leipzig compares the territorial balance with an inhabitants balance, applying mainly national average values. This is done because of the required comparison to balances of former years done with this methodology. Apart from that aspect, the authors rate the done inhabitants balance as not useful. Due to the use of national average values it cannot be used to estimate specific effects from measures elaborated for the city and controlling the success of climate protection measures in future years will not be possible.

- Next to the territorial balance, Cologne has an inhabitants balance generated with ECORegion. The inhabitant balance bases upon the vehicle stock in Cologne and the national average VKT per vehicle type. The authors indicate that there might be differences between national average data and the situation in Cologne. Nevertheless this inhabitant balance is intended for future GHG monitoring due the easy up-dating. Questions concerning the covering of effects of local measures in the future are not discussed.

- Munich applies ECORegion generating a mixture of territorial and inhabitants balance. Some transport data are extracted from the regular CO_2 monitoring according to the territorial principle. All missing transport modes are completed by national average values provided in ECORegion.

Means of Transportation

- The analysed GHG balances differ considerably concerning the coverage of means of transport (see Table 12). **Passenger cars** and **public buses** are always included within the balances. Likewise, **road freight transport** is considered in seven of the eight German cities and London. Only Tübingen focuses exclusively on passenger transport.

- The accounting for **rail transport** varies. Some cities consider light rail (tram, metro), regional and long-distance trains as well as freight rail transport. Other cities, however, consider light rail and regional trains only. Sometimes whole rail transport is displayed as total sum, only. In some balances, no rail transport is considered at all. London accounts only for diesel trains. Over ground electric trains and London Underground trains plus

stationary combustion in the rail sector are excluded from the transport sector (but accounted for in the Industrial & Commercial Electricity sector).

■ **Inland navigation** is accounted for in some of the cities with navigable river (systems), but not in all. Using ECORegion, cities automatically get a GHG amount ascribed referring to national average values, independent whether the city has navigable rivers or not.

■ Six out of the eight German cities have an airport. Greater London area has several airports (Heathrow and smaller ones). In three of the balances, GHG emissions of **air transport** during the LTO cycle (Landing-Take-off-Cycle) are considered. In one balance all outgoing flights are included (based on kerosene sales). Again, Using ECORegion, cities automatically get a GHG amount ascribed referring to national average values.

In conclusion, with motorized individual transport and public transport those means of transportation in the direct scope of action by local authorities in Germany are considered in each balance. Looking at means of transportation that can be controlled less by the cities, i.e. regional rail traffic and trucks, the consideration in the GHG balances already varies. The largest discrepancies can be observed concerning means of transportation that are almost unrelated to the city-induced transport.

Table 12: *Means of transport in the GHG balances of analysed German cities and Greater London*

	Private transport (cars)	Public bus	Road freight	Tram & Metro	Regional train	Long-distance train	Rail freight	Inland naviga-tion	Air traffic
Bremen	Yes	Yes	Yes	Yes	No	No	No	No	No
Region Hannover	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]	Yes[1]	Yes	Yes[3]
Braunschweig	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]	Yes[1]	Yes	No
Leipzig	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes[3]
Cologne	Yes[2]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes[4]
Frankfurt /Main	Yes[2]	Yes	Yes	Yes	Yes	No	No	No	No
Tübingen	Yes	Yes	No	n.a.	No	No	No	No	No
Munich I (selfmade)	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Munich II (ECORegion)	Yes	Yes	Yes	Yes	Yes	Yes[5]	Yes[5]	Yes[5]	Yes[5]
London	Yes	Yes	Yes	No[6]	Yes[7]	Yes[7]	Yes[7]	Yes	Yes[3]

[1] rail transport not differentiated by type of train
[2] incl. two-wheelers
[3] LTO cycle
[4] outgoing flights
[5] German average values per inhabitant
[6] accounted for in the Industrial & Commercial Electricity sector
[7] only diesel trains. Electric trains are accounted for in the Industrial & Commercial Electricity sector

Origins and Causes of Transport Activities

A differentiation regarding trip distributions between internal, originating and destination traffic is the fundament of the balance done for Tübingen. Even more, simplified estimations have been done in this city determining transport relations between distinct city-districts. This was used as base for developing measures with certain spatial reference or with focus on certain subsets of the traffic activities. Furthermore, in the estimates of emission reduction potentials some rough assumptions on trip purposes have been considered.

Differentiations regarding trip distribution have been done also for some of the cities with territorial balance:

- Bremen makes a differentiation of trip distribution when modelling the traffic demand in order to calculate VKT and to display the potential effects of measures. As well in Leipzig, estimates of the GHG reduction potentials are done based on a differentiation of transport activities by trip distribution. Both cities use these differentiations only in the internal calculations, but do not differentiate the GHG balancing results in the report.

- In Cologne as well as Frankfurt/Main, GHG balancing results are differentiated by trip distribution. The balance of Cologne additionally includes rough estimates concerning the distribution of trips between inhabitants and non-inhabitants (in-commuters, visitors).

No differentiations by trip distribution were done in the GHG balances of Munich, Braunschweig and the Region Hannover. The Region Hannover, covering next to the city of Hannover another 20 municipalities, splits up transport and emissions for each municipality, however without any information about traffic relations between the municipalities.

The LEGGI study area is geographically divided for reporting and analytical purposes into three sub-areas covering different boroughs of the Greater London area: Central, Inner and Outer Greater London areas – and furthermore in 1-km² grid (see   Figure 20).
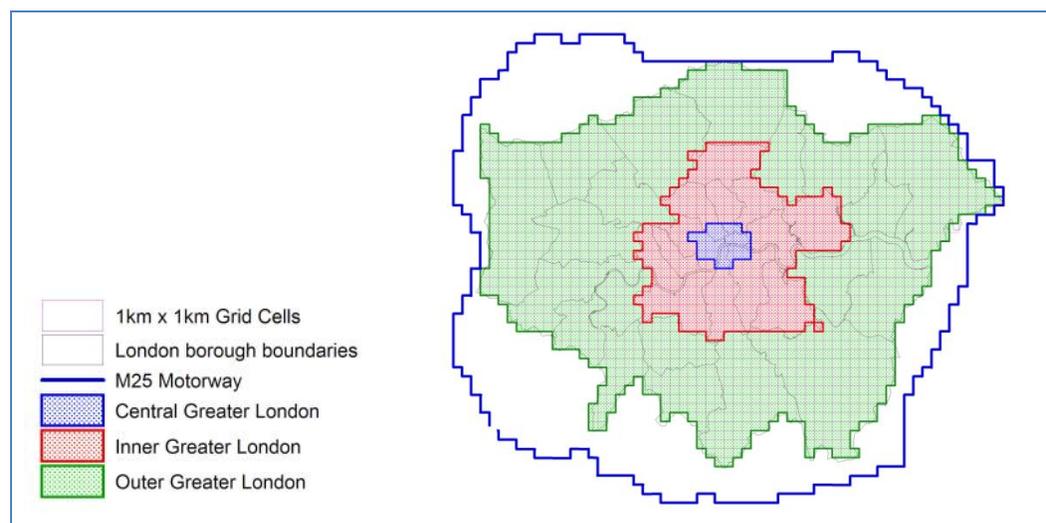

Figure 20: *London Energy and Greenhouse Gas Inventory (LEGGI) 2008 area [London 2010]*

4.2.3 Considered GHG Emissions and Emission Factor Databases

Consideration of Upstream Emissions and Other GHGs than CO$_2$

Though complete well-to-wheel emissions should be considered in a GHG balance for covering all relevant GHG emissions from transport activities (see chapter 1.3), the inclusion of **upstream GHG emissions** is handled differently in some cities (see Table 13). In Bremen and Cologne, only tram and regional train transport are calculated with upstream emissions but not road transport. The GHG inventory for London attributes only tailpipe emissions to the transport sector. Emissions from electric trains are covered by the inventory but accounted for in the Industrial and Commercial Electricity sector.

CO$_2$ equivalents: All GHG inventories are based upon the accounting of carbon dioxide emissions. Emissions of methane (CH$_4$) and nitrous oxides (N$_2$O) are only considered in the GHG balances of Frankfurt/M. Leipzig, Region Hannover, Braunschweig and Greater London.

Table 13: *Consideration of upstream emissions and further greenhouse gases in the GHG balances of the analysed cities*

	Bremen	Region Hannover	Braun-schweig	Leipzig	Cologne	Frankfurt /Main	Tübingen	Munich	Greater London
Upstream emissions	Only tram	Yes	Yes	Yes	Only tram & electric regional trains	Yes	Yes	Yes	No
CO$_2$ equivalents	No	Yes	Yes	Yes	No	Yes	No	No	Yes

Emission Factor Databases

In Germany, specific energy consumption and GHG emission factors for the transport sector are extensively harmonized as already explained in chapter 3.3. Consequently, the HBEFA emission factor database is applied for road transport in 7 of 8 analysed German cities – directly or via applied calculation models and tools (e.g. TREMOD, MOBILEV). Only for Cologne, a deviant data source has been used (see Table 14).

In contrast, energy consumption data for public transport and rail transport have been provided for most cities directly from public transport operators. Hence, these data are more city-specific than German average values. For the other cities, TREMOD data were applied (direct application or via data provided by the Federal Environmental Agency of Germany UBA).

Inland navigation and air transport are handled very differently in the balances, ranging from direct fuel consumption values to rough estimates (see Table 14).

German average upstream emission factors are provided for all transport modes and energy carriers in TREMOD (see chapter 2.3.2). However, most cities did not apply TREMOD, but emission factor databases without upstream emissions (HBEFA, energy consumption data from public transport operators). Most of these cities refer to GEMIS, a recognized LCA database in

Germany, for upstream emissions. For urban tram and metro transport, also GHG emission factors for the local electricity mix of the city are applied.

Emission factor databases in the London Energy and Greenhouse Gas Inventory are completely different to those applied in the German cities. They come from different sources such as the UK Department for Transport (DfT), London Atmospheric Emissions Inventory (LAEI) and single scientific publications. No further analysis of these data bases and no comparison to the emission factor data bases in the analysed German cities were possible in this study.

Table 14: *Emission factor databases in the analysed German cities*

	Bremen	Region Hannover	Braun- schweig	Leipzig	Cologne	Frankfurt /Main	Tübingen	Munich
Fuel consumption and direct GHG emission factors								
Road	MOBILEV[1] (HBEFA2.1)	HBEFA	HBEFA	HBEFA	[WWF 2009]	TREMOD	HBEFA in VISUM	HBEFA
Public transport	PT operator	PT operator	PT operator	PT operator	PT operator	TREMOD	PT operator	PT operator
Rail	-	German railways	German railways	UBA[2]	TREMOD	TREMOD	-	German railways
Inland navigation	-	UBA[2]	UBA[2]	-	LANUV[3]	-	-	-
Air transport	-	conclusions by analogy	-	LfULG[3]	Airport Köln-Bonn	-	-	-
Energy carrier related GHG emission factors								
Fuels	-	GEMIS	GEMIS	UBA[2]	-	TREMOD	n.s.	GEMIS
Electricity (tram/metro)	Local electricity mix	GEMIS	Local electricity mix	UBA[2]	Local electricity mix	TREMOD	-	Local electricity mix
Electricity (railways)	-	German Railways	German Railways	UBA[2]	TREMOD	TREMOD	-	German Railways

[1] MOBILEV is a road transport emission calculation tool and part of the UBA tool set CITAIR for air quality modelling & measure evaluation. MOBILEV is based on the older HBEFA 2.1 version and not up-to-date anymore.
[2] UBA (German Federal Environmental Agency) uses TREMOD for all transport emissions calculation and reporting.
[3] Environmental agency of the federal state

4.2.4   Local-specific Refinements of Road Transport Emission Calculations

In order to further improve the GHG balances regarding road transport and to adapt it to the specific local situation of the city, it is possible to apply the highly differentiated emission factors provided by HBEFA. These emission factors allow for making very differentiated and localised emission calculations either in respect to the fleet composition or the local traffic flow. The required effort, however, is much higher compared to the use of average factors. Therefore, these refinements are only possible if adequate local-specific basic data for vehicle fleet compositions and traffic flow characteristics (on street level) are available.

There is no local adaption of the ***fleet composition*** of the road transport in any of the analysed German cities. The average German fleet composition from TREMOD/HBEFA was used in all cities.

A different situation can be found in the emission calculations looking at the accounting for individual ***traffic flow characteristics*** in the cities. In most of the cities, road traffic data were drawn from local traffic models (see next chapter). For some cities, these traffic models provided much differentiated distributions regarding types of streets and traffic flow that were used in the GHG balances for refining the emission calculations instead of using average emission factors (see Table 15). However, detailed emission factors from HBEFA for specific traffic situations do not consider cold start supplements, but this has to be calculated separately in this case. That is why in some cases, the GHG balances do not consider cold start emissions. Effects of omitting cold start supplements on the calculated emission levels are shown in Figure 5 (chapter 1.2).

In the GHG inventory for **Greater London**, both individual fleet compositions for central, inner and outer London as well as "hourly and daily flow profiles for thousands of road links" have been applied in the energy consumption and greenhouse gas emissions calculations. All these information were adopted from the detailed LAEI 2008 road transport datasets and, thus, from existing detailed investigations on air pollutant emissions in Greater London. Methodology aspects and specific information are also explained in some detail in the report [London 2010, pp. 15-28].

Table 15: *Local-specific refinements of road transport emission calculations in the GHG balances of the analysed cities*

	Bremen	Region Hannover	Braun-schweig	Leipzig	Cologne	Frankfurt /Main	Tübingen	Munich	Greater London
Local fleet composition	No	No	No	No	No	No	No	No	Yes
Traffic flow characteristics	Yes	Yes	Yes	Not specified	No	No	Yes	Not specified	Yes
Cold start	Not specified	No	Yes	Yes	Yes	Yes	Yes	Not specified	Yes

4.2.5   Traffic Data Sources in the Analysed German Cities

The availability of adequate city-specific traffic data is a fundamental precondition for the preparation of GHG balances that are suitable for the different balancing objectives. For this reason, traffic data availability for GHG balancing in the analysed German cities was taken into particular consideration.

As first part of this section, an overview on the traffic data used in the GHG balances will be given. Certainly, actual data availability in most of the analysed cities goes beyond that information used in the balances. Therefore, an additional survey regarding data availability with focus on road traffic modelling was done of the authors of the GHG balancing reports resp. the

cities' authorities. In the second part of this section, the results of this survey are presented and resulting additional options for coverage and differentiation of transport activities in a GHG balance are discussed.

4.2.5.1 Traffic Data Used for the GHG Balances of the Analysed German Cities

In general traffic data sources used in the analysed GHG balances are similar (see Table 13):

- For **_road transport_**, data taken from local traffic models were used in all cities, with the exception of Cologne. In Bremen and Leipzig the traffic models were applied directly in the balancing. In other cases, data were provided in an aggregated form by the municipal bureaus or transferred from other model applications, e.g. from traffic development planning (Tübingen) or from air pollutant inventories (London). In Cologne, data are taken from the local emission cadastre, which is administrated and provided by the Environmental Agency of North Rhine-Westphalia to each municipality of the federal state.

- Concerning **_public transport_** and **_rail transport_** data were predominantly provided by local public transport operators or taken from publications (e.g. environmental reports). In some cases also local timetables were analysed. In Bremen, data for tram traffic were adopted from a specific tram model for the city.

- As far as **_inland navigation_** and **_air transport_** are considered in the GHG balances, statistical data were taken from public authorities respectively airport operators.

Throughout the balances city-specific data sources were applied covering the local transport activities in the cities quite well. Differences between the balances mainly concern road transport data sources. Indeed, largely traffic models of the cities serve as data sources. However, traffic data were drawn from the models in different ways and used for the characterisation of the road transport within the balances (see chapter 4.2.2 & 4.2.4).

Partly this can be explained by the different professional backgrounds of the institutions being in charge of the balancing (see Table 10). In some cities (like Bremen and Leipzig) the balances were elaborated by traffic modelling and planning experts, who are experienced in working with traffic models. Yet, in most of the cities the authors being responsible for the balancing have their working focus on environmental consulting and are, therefore, more dependent on the provision of already well-structured traffic data.

Table 16: *Used traffic data in the GHG balances of the analysed cities*

	Road transport	Public transport (bus, tram, metro)	Rail transport	Inland navigation	Air transport
Bremen	Usage of the traffic model. Further estimates for residential roads not in the model	Bus: road traffic model, tram: specific tram traffic model by PT operator	-	-	-
Region Hannover	Data from the traffic model provided by the city, basic data differentiated by cars and trucks	Public transport operator	German Rail (DB): not further used as also direct energy consumption was provided	Federal Waterways and Shipping Directorate	Statistics of departures & arrivals at the local airport
Braun-schweig	Data from the traffic model provided by the city. Additional estimates for smaller residential roads	Public transport operator			-
Leipzig	Usage of the traffic model	No. Direct energy consumption data provided by PT operator	Local timetables & railway guides	-	No. Emission data directly provided by LfULG[1]
Cologne	Data from emission cadastre (LANUV[1]) + own estimates for trip distribution	Environmental report of public transport operator	Local timetables & railway guides UBA study[3] for freight trains	Local authorities	Statistics of number of boarding and alighting passengers
Frankfurt /Main	Data from the traffic model for main roads differentiated by cars, LCV & trucks, by road types & trip distribution. Provided by the city.	Public transport operator	Public transport operator	-	-
Tübingen	Data from a traffic model from recent urban traffic planning processes	No. Direct energy consumption data provided by PT operator	-	-	-
Munich	Data from the traffic model + estimates for residential roads not in the model	Public transport operator	German railways	-	-
London	Road Transport datasets from London Atmospheric Emissions Inventory (LAEI) 2008	Bus: LAEI 2008, Metro: not accounted for	Data bases for London (TRATIM, ACTRAFF)	No new data. Transfer of analyses from LAEI 2006	Heathrow Emissions Inventory 2002. Activity data from smaller airports

[1] Environmental agency of the federal state

4.2.5.2   Survey on Traffic Data Availability in German Cities

Some of the analysed GHG balances (like Bremen, Leipzig and Tübingen) show the applied local traffic models enable characterisations of (road) traffic in the GHG balances in very detail. In this way, the balancing ambitious application fields, especially for the definition and evaluation of customized city-specific measures.

Often the traffic models of the other cities as well allow more detailed characterisations of local traffic activities than it has been done in the analysed balances. This is the result of an additional internet research and supplemental survey of the authors of the GHG balances resp. cities' authorities.

The results of the additional analysis about in the cities available traffic models are summarized in Table 13. The following findings are notably:

- Most of the traffic models of the analysed cities consider not only road traffic but also tram and/or metro as well as rail transport. In the travel demand modelling (trip generation & distribution, mode choice) that is upstream of the trip routing in the transport infrastructure network also bicycle and pedestrian traffic are included frequently. Therewith, these models are usually capable of analysing shifting effects from passenger cars to more environmentally friendly transport modes.

- All models differentiate the road network into various types of roads, process speed limits as well as in some cases street capacities. Additionally, in some of the models the diurnal variation of traffic amounts can be modelled. These models offer a good basis for refined GHG emission calculations considering specific road traffic flow characteristics in the city.

- Differentiating origins and causes of transport activities is a basic element of the transport demand modelling. Likewise data about transport relations between different urban areas (e.g. city districts) are captured. However, this degree of differentiation gets often lost when aggregating the data for the traffic routing in the road network. Thus, the traffic models in general provide a good basis for the differentiation of GHG balances in terms of origins and causes of traffic. This information enables the identification of relevant measure focuses and analyses of GHG reduction potentials for target-oriented measures. However, in most cases considerable additional effort is necessary to extract this information from the traffic models.

- Diverse primary data on local traffic activities are applied the traffic modelling of a city, as already introduced in chapter 3.2.4. Fundamental data sources are continuous as well as complementary demand-driven traffic counts at important roads in the city area and at arterial roads. Furthermore mobility surveys of inhabitants and additional inquiries regarding O&D traffic also including non-inhabitants (e.g. driver surveys at arterial roads).

- Due to the processing of data from past years it is possible to display former trends. The ability of most traffic models of making future calculations is helpful for the estimation of trend as well as calculation of scenarios of measures and for the definition of emissions reduction targets.

The analysis shows that the considered traffic models in general provide a good data basis for city-specific GHG balances with a high degree of differentiation regarding traffic distribution (origins and causes) as well as regarding emission relevant traffic flow characteristics.

GHG balances based on these model capabilities are well suited for important application fields of the GHG balancing of cities – especially for the identification of relevant action fields, the estimation of reduction potentials as well as calculation of scenarios for future years.

Traffic models are primarily applied for traffic planning and therefore in most cases updated regularly regarding changes in the transport network as well as traffic volumes. Hence, they can provide also a good basis to monitor future GHG-emissions.

In some cases cities already take the benefits from these potentials of local traffic models when preparing GHG-balances. However, the additional effort, that has to be brought up in order to analyse data from traffic models regarding certain questions not being in the focus of the models, can be seen as a main barrier. That is why the existing potential of using traffic models in the GHG balancing so far is not used very often.

Table 17: *Overview of selected traffic model characteristics*

Parameter		Coverage in the traffic models
Means of transportation	Road transport differentiation	Range from ■ total VKT + hdv share to ■ differentiation cars, delivery vans, trucks, buses
	Tram+metro systems	Mainly covered.
	Rail transport	Mainly covered.
	Walking and cycling	Often part of transport demand modelling, but without routing in the road network
Road types and traffic flow	Differentiation of road types	Varies. E.g. ■ administrative: motorway, federal highway, state road, district road, urban road ■ functional classification: motorway, trunk roads, collecting, access and residential roads
	Information on speed limits	Yes. In some models incl. Average speed for freeflow conditions
	Differentiation of traffic situations	Varies. E.g. ■ only DTV (daily traffic values) per road link ■ morning & afternoon rush-hours, rest of the day ■ diurnal variation curves
Origins and causes of traffic	Trip distributions (internal, origin, destination and transit traffic)	Relevant part of the transport demand modelling in the traffic models. In some models differentiation by inhabitants and non-inhabitants in the demand modelling, but without routing in the road network
	Traffic relations between different city districts	Yes. E.g. transport links between different geographic cells in the model. However, differentiation only possible with resonable additional effort
	Trip purposes	Generally included in the models. However differentiation requires special analyses with reasonable additional effort
Primary data used in the traffic modelling	Permanent traffic counting	Yes.
	Particular traffic counting	Yes, demand-driven
	Cordon counts, driver surveys	Yes. In some cities regularly, in others demand-driven (e.g. before/after
	Mobility surveys of inhabitants	Yes. E.g. SrV, MiD, individual household surveys.
	Public transport primary data	Line network and time tables. In some models also network observation and evaluation.
Time period	Past years	Only in some models. Only selected years, no annual data.
	Prognoses/scenarios for future years	Generally, yes. Ranging from 2020 to 2030.
Sources: Internet research, surveys of authors of GHG balances and cities' authorities of the German cities Bremen, Braunschweig, Region Hannover, Leipzig, Cologne, Frankfurt/Main, Tübingen, Munich.		

4.3   Summary of the Analysis

The GHG balances of the analysed cities largely base upon the balancing methods and main data sources as introduced in chapter 3, however, differ significantly in the specifications.

Coverage and Differentiation of Transport Activities

Important basic requirements regarding essential application fields of GHG balances such as monitoring of emissions trends and the identification of main action fields within the transport sector are fulfilled by each of the analysed balances. By the definition of system boundaries and the usage of local specific traffic data all transport activities concerning the cities are considered in the balance. Means of transportation that belong closely to the field of action of German cities are covered by the balances to a great extent, as well. Only in Tübingen, the climate action plan focuses completely on passenger transport and, therefore, freight transport is omitted also in the GHG balance. Required traffic data can be obtained with moderate effort from local traffic models or, such as the case of Cologne and London, from other investigations related to air-quality in the cities.

For further characterisations of traffic activities, several balances conduct differentiations of the origins of traffic into internal, originating/destination and transit traffic. This is an important support in order to determine measure focuses and to estimate city-specific emission reduction potentials. Yet, this differentiation usually requires increased effort, as in most cases these details can be extracted from the used traffic models only with additional analyses (see chapter 4.2.5). Persons resp. institutions being responsible for the GHG balancing need considerable own skills concerning traffic modelling or depend on support by local traffic planning authorities.

An even more detailed differentiation regarding trip purposes has been carried out only in Tübingen (not in the GHG balance, but in the subsequent potential analysis). Actually, such a differentiation would be possible in most other cities, too, based on the respective traffic models. However, this requires considerable additional work that has not been afforded in the present balances.

Some of the analysed cities have further distinctive features for the characterisation of transport activities that are helpful regarding application fields of the GHG-balances:

- In Tübingen, traffic relations between different urban areas were investigated. Even though these estimations are only rough due to the extra effort and the direct availability of the model for the analyses, they offer additional options for the analysis and potential estimates of measures focusing on the city or individual parts of the city.

- In Cologne, simplified assumptions concerning the share of in-commuters and visitors on the traffic of the city were made, supporting the evaluation of the relevance and potential of specific measures for these target groups. This was done by using public available statistical data and, thus, avoiding detailed traffic modelling.

- In Bremen and Leipzig, the traffic models were applied directly for balancing and analysing emission reduction potentials. Herewith interactions between different means of transportation could be displayed in the model and a depiction of the effects on the whole transport system to be expected by city-specific measures could be realised.

The traffic models of most of the cities are not limited to a present calculation year, but allow for calculating scenarios of the future, too. Therewith, traffic models can be important instruments in order to estimate possible effects of single measures as well as packages of measures for the future and to define emission reduction targets on this basis.

Refinements of Road Transport Emission Calculations

Local adaptations of fleet compositions have not been applied in any of the analysed German GHG balances. Usually, this is not necessary as possible actions of municipal authorities towards more efficient resp. low-carbon vehicles are limited. In the GHG balance of Greater London, area-specific fleet compositions have been applied in the calculations. However, these were adopted from the London Atmospheric Emission Inventory (LAEI) dealing with air quality where specific fleet compositions have higher relevance than for greenhouse gases.

In some cities, further refinements of the emission calculations were realised for road transport by processing data about street types and traffic flow characteristics that are provided by traffic models. Such refinement of emission calculations might be done in case that adequate information about traffic situations is directly available from traffic models or can be determined with reasonable effort, e.g. in calculation tools such as HBEFA-in-VISUM or IMMIS^{em} (see chapter 3.4). This can be helpful additional information for the evaluation of local measures which are aimed at improvements in traffic flow. However, this has to be seen as second-tier in Germany compared to other optional traffic characterizations as reduction potentials in this field are supposed to be low compared to measures leading to the avoidance of traffic or shifting to environmentally-friendly transport modes.

Emission Factor Databases and Completeness of Covered GHG Emissions

The analysis of the GHG-balances of German cities clearly shows that the in Germany widely harmonized databases for specific energy consumptions and GHG emissions in motorized transport are applied to a large extent within the balances. Exceptions mainly occur where locally determined energy consumption data are available, e.g. from public transport operators, covering the city-specific situation more individual than the national database.

In four out of eight German cities, emissions from transport were calculated as explained in chapter 1.3, i.e. including upstream emissions of the energy supply chain and emissions from CO_2, CH_4 and N_2O (CO_2 equivalents). Two more GHG balances considered upstream emissions as well, yet omitted CH_4 and N_2O emissions. As 99 % of the GHG emissions (CO_2 equ.) from the transport sector are due to CO_2, this deviation can be tolerated. In the future, however, with increasing shares of alternative final energy carriers (electricity with different

primary energy carriers, biofuels) other GHG may gain more significance in the transport sector and therefore should be considered in the balances. This can be done with little effort.

In two cities (Bremen and Cologne), only tailpipe emissions were calculated for fossil-fuelled vehicles (esp. road transport). In contrast, emissions for tram traffic and electric trains were calculated for the upstream energy supply. Even though the large part of GHG emissions caused by the transport sector of these cities is covered, this approach is not consistent and prevents objective comparisons of GHG emissions from different means of transportation in these cities.

In London, only direct tailpipe emissions from final energy consumption are assigned to the transport sector. GHG emissions caused by electric trains are accounted for in the energy sector where they occur, but not in the transport sector. Indeed, this is consistent with IPCC guidelines that only account for direct emissions. However, this procedure is not appropriate for a causer and measure-orientated GHG-emission balancing. On the level of local balances it is therefore seen to be rather unsuitable.

4.4 The Process of GHG Balancing for Transport in Cities – Case Study Frankfurt/Main

In this section, the balancing of transport-related GHG emissions is illustrated extensively for the case study of Frankfurt/M., including detailed information on input data, processing steps and presentation of the results. This shall facilitate the understanding of the balancing process for transport-related GHG emissions in major cities in Germany.

The GHG balance for the transport sector and the stationary sectors in Frankfurt/M. for the year 2009 was commissioned by the municipal energy department ("Energiereferat") and developed from ifeu – Institute for Energy and Environmental Research Heidelberg.

In the transport sector, final energy consumption and GHG emissions have been calculated based on the territory principle, i.e. covering those transport activities within the city's boundary. All vehicle categories in road transport and in local/regional public transport have been considered in the balance. Emissions were calculated "bottom-up" by multiplication of transport activities (VKT, pass.km) with corresponding energy consumption and GHG emission factors. The applied well-to-wheel GHG emission factors from the German national emission inventory model TREMOD included CO_2, CH_4 and N_2O in CO_2 equivalents.

Road Transport

The principal data base for road transport activities in Frankfurt/M. is the "Verkehrsdatenbasis Rhein-Main VDRM", a comprehensive traffic model covering not only the territory of Frankfurt, but also large parts of the surrounding region incl. several other cities >100.000 inhabitants. For the GHG balancing of Frankfurt/M., **VKT values per weekday (mo-fr)** differentiated by vehicle category, road types and trip distribution (see Figure 21) were provided by the municipal mobility and traffic planning office.
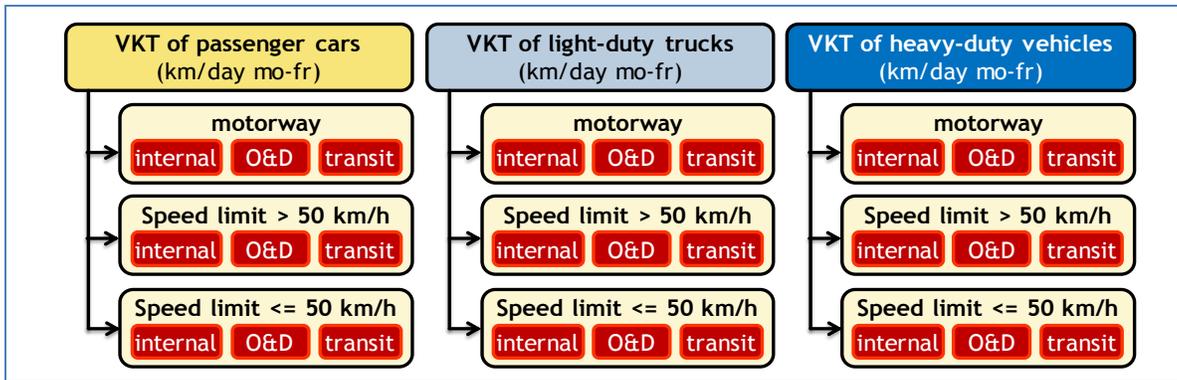
Figure 21: *Road traffic data structure provided from the VDRM traffic model for Frankfurt/Main*

In order to apply the provided VKT data in the emission calculations, some further adaptations were necessary before:

1. VKT per weekday (mo-fr) were converted to annual VKT considering simplified estimates of daily VKT changes on weekends per vehicle category and road type (Figure 22).

Figure 22: *Conversion of VKT per weekday (mo-fr) to annual VKT*

2. Heavy-duty vehicles in the VDRM traffic model include heavy-duty trucks as well as bus traffic. For separate consideration of both vehicle categories in the GHG balance, annual operation mileages of public buses in Frankfurt/M. were obtained from annual statistics of the public transport operator. These values were subtracted from the VKT of heavy-duty vehicles and in this way VKT of heavy-duty trucks determined (Figure 23).
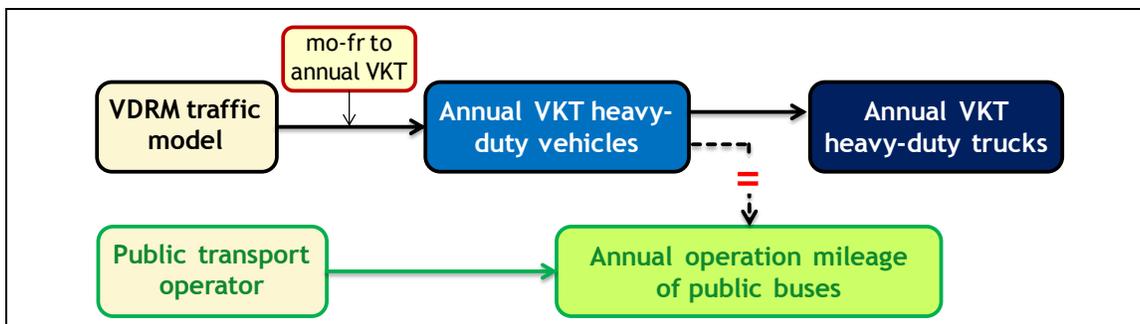
Figure 23: *Determination of annual VKT values for heavy-duty trucks*

3. Motorcycles are not covered in the VDRM traffic model. In order to consider them in the GHG balance, average VKT shares on total road traffic were estimated based on national average values for different road types.

In the result, prepared annual VKT were on hand for the emission calculations for all vehicle categories differentiated by road types and by trip distributions.

As next step, *energy consumption and GHG emission factors* (CO_2 equ., WTW) for the balancing year 2009 were determined from TREMOD in the same differentiations as the annual VKT values. These national average emission factors include weighted vehicle fleet compositions (motor type, size classes…) for different road categories (motorway, others) and, besides, average shares of different traffic flow characteristics (free flow, Stop+Go…) for each road type.

Now, the GHG emissions of road transport on the territory of the city of Frankfurt/M. in the year 2009 could be calculated by **multiplication of VKT with the emission factors**.

Figure 24 summarizes the GHG emissions calculation process for road transport. As can be seen in the depicted calculation process, VKT differentiation by trip distribution was firstly omitted in the emission calculations (as origin and destination of a trip have no direct influence on the emission behaviour). Instead, calculated emissions were separated afterwards into internal, O&D and transit traffic according to their VKT shares per road type and, finally, also total shares of different traffic origins in the GHG balance were determined.

Vehicle category	Road type	VKT		GHG EFA		GHG emissions	VKT share			GHG emissions (1'000 tons CO2 equ.)		
		million veh.km		g CO2 equ. / veh.km		1'000 tons CO2 equ.	internal	O&D	transit	internal	O&D	transit
motor-cycles	motorway	17	x	132	=	2.3	7%	56%	38%	0.2	1.3	0.9
	speed limit > 50 km/h	27	x	110	=	2.9	20%	69%	12%	0.6	2.0	0.3
	speed limit ≤ 50 km/h	35	x	106	=	3.7	47%	51%	2%	1.8	1.9	0.1
	Total				Σ	**8.9**				**2.5**	**5.2**	**1.3**
passenger cars	motorway	2,294	x	221	=	508.1	7%	56%	38%	34.1	283.1	190.9
	speed limit > 50 km/h	800	x	165	=	131.6	20%	69%	12%	26.0	90.4	15.2
	speed limit ≤ 50 km/h	990	x	242	=	239.7	47%	51%	2%	113.7	122.4	3.6
	Total				Σ	**879.4**				**173.7**	**495.9**	**209.7**
light-duty trucks	motorway	128	x	356	=	45.4	5%	42%	53%	2.4	19.1	23.9
	speed limit > 50 km/h	26	x	236	=	6.2	32%	52%	17%	2.0	3.2	1.0
	speed limit ≤ 50 km/h	29	x	284	=	8.3	41%	56%	3%	3.4	4.6	0.3
	Total				Σ	**59.9**				**7.8**	**26.9**	**25.2**
heavy-duty trucks	motorway	234	x	817	=	191.0	4%	29%	67%	7.2	56.2	127.6
	speed limit > 50 km/h	46	x	710	=	32.4	20%	64%	15%	6.6	20.9	4.9
	speed limit ≤ 50 km/h	50	x	849	=	42.4	29%	69%	3%	12.1	29.2	1.1
	Total				Σ	**265.8**				**25.9**	**106.2**	**133.7**
public bus	motorway	-	x	854	=	-						
	speed limit >50 km/h	1	x	879	=	1.1						
	speed limit ≤ 50 km/h	16	x	1,167	=	18.1						
	Total				Σ	**19.2**						

Figure 24: *GHG emission calculation process for road transport in Frankfurt/Main*

Passenger Rail Traffic (Tram, Metro and Regional Trains)

The public transport system in Frankfurt/M. consists of several transport modes. Besides public buses (see road transport), these are the city's **tram** and **metro system** and **regional trains** connecting the city and the neighbouring region. Operating data of all public transport modes are regularly documented in the annual reports of the local public transport association in Frankfurt/M. traffiQ.

For the tram & metro system, the traffiQ annual reports provide the offered transport services (seat-km) as well as effectively provided passenger kilometres. These values could directly be adopted for the GHG emission calculations.

For regional trains, only operation mileage in train kilometres is available in the reports. However, energy consumption and GHG emissions in rail traffic depend highly on the size of the trains and, thus, on their transport capacity. A train with four wagons needs about twice as much driving energy than a train with two wagons. For this reason, enhanced information on the trains and their seat capacity as well as occupancy rates were gathered from the regional public transport association RMV. Based in this information, annual seat-kilometres and passenger-kilometres were calculated also for regional train traffic. Additionally, the apportionment between electric and diesel traction was estimated with information obtained from RMV.

Now, the GHG emissions of passenger rail transport on the territory of the city of Frankfurt/M. in the year 2009 were calculated by **multiplication of seat-km with corresponding emission factors** from TREMOD. Figure 25 summarizes the GHG emissions calculation process for rail transport.

		Offered transport services			Transport		GHG EFA	GHG emissions
		million train-km	seats per train	million seat-km	occu-pancy rate	million pass.km	g CO2 equ. / seat-km	1'000 tons CO2 equ.
Tram & metro	electric			4,243		**650**	x 14.8 =	**62.9**
Regional train	all	8.1	x 480 =	3,888	x 31% =	1,205		
			x (electric/diesel split)					
	electric		94.4%	3,670		**1,138**	x 19.7 =	**72.4**
	diesel		5.6%	218		**68**	x 22.4 =	**4.9**
							Total passenger rail Σ	**140.2**

Figure 25: *GHG emission calculation process for rail transport in Frankfurt/M.*

Presentation of Results of the GHG Balance

The GHG balancing results can be visualized in different ways and therewith provide different interpretations for climate protection activities in the transport sector.

Figure 26 shows in the upper part the GHG balance for Frankfurt/M. in the highest degree of differentiation as possible with the traffic activity data applied in the emission calculations. Already on this basis, main contributors to the whole GHG emissions of the transport sector can be identified. Nevertheless, this presentation of results is rather confusing and, therefore, seen to be of limited value for subsequent application fields. Hence, certain aggregations of the GHG balancing results are recommendable for their further use in climate action planning, esp. for road transport, as exemplarily shown in the lower part of Figure 26.

On the left, road transport emissions are differentiated by trip distribution. This is helpful to identify main reasons of high traffic-related GHG emissions and to define important measure focuses and estimate measure-specific emission reduction potentials. In the case of Frankfurt/M., it can be seen that measures should focus primarily on origin & destination passenger traffic, which causes more than one third of all transport-related GHG emissions.

On the right, road transport emissions are differentiated by road types. This can be helpful in order to identify the GHG emission share in the direct scope of municipal action and to estimate possible effects of traffic management measures (speed limits, traffic flow improvements…). E.g. in Germany, city's authorities have no responsibility for traffic regulations on motorways. In Frankfurt/M., 54% of the transport-related GHG emissions result from motorway traffic and, thus, cannot be addressed with traffic management measures of the city.
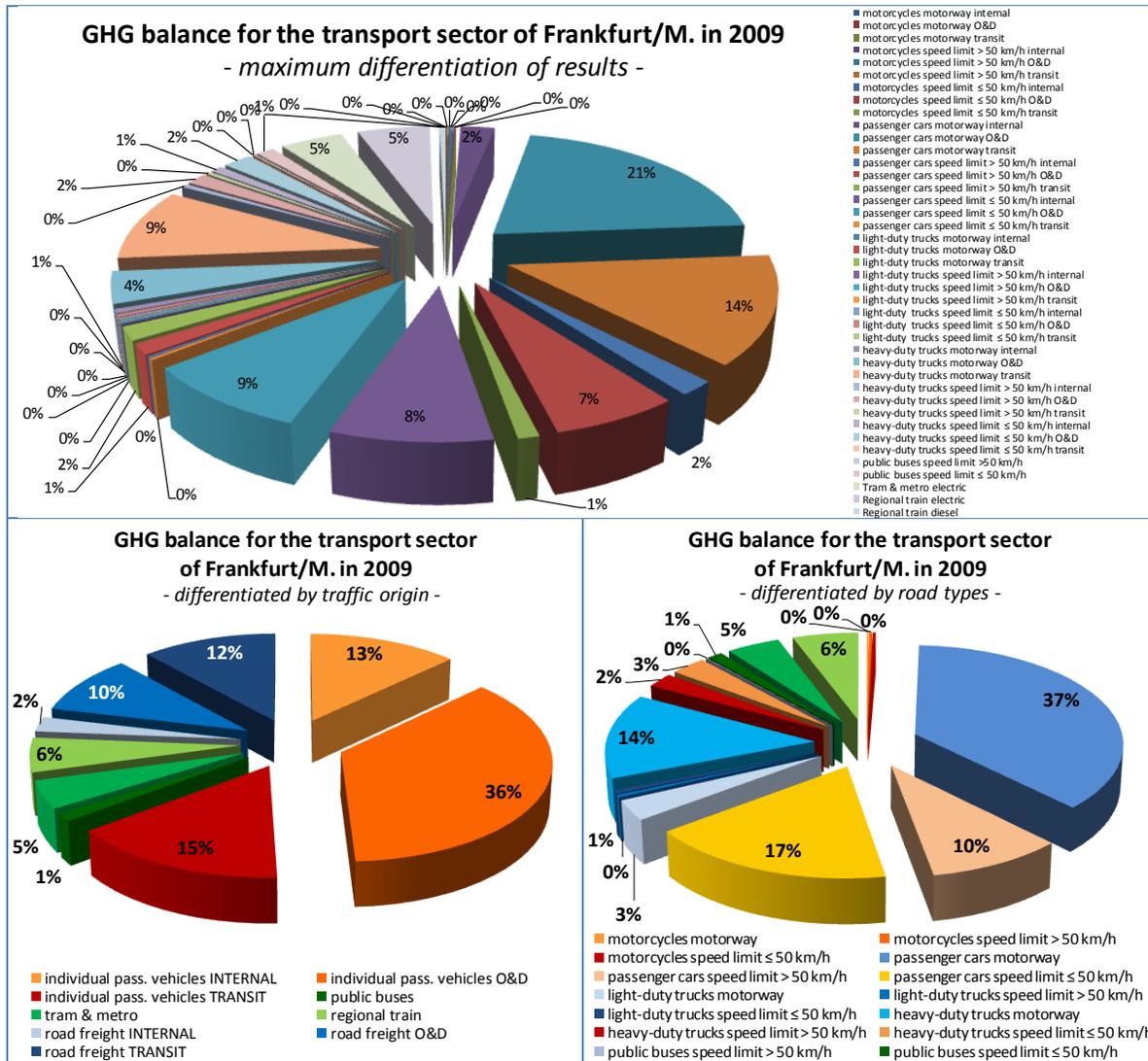
Figure 26: *GHG balancing results for the transport sector in Frankfurt/M.*

In other cities, GHG balances for the transport can enable deviating presentations of results depending on the particular differentiations of input data and emission calculations. These can be e.g. emission contributions from traffic relations between different city districts or the shares of different trip purposes (work, shopping, leisure) in the GHG balance – helping to identify main causes of high transport-related GHG emissions, to define measure focuses and to estimate measure-specific GHG emission reduction potentials.

5 Recommendations for Balancing GHG Emissions from Transport in Beijing

Based on the analyses of GHG Balances for transport in German Cities first good-practice recommendations for the developing of a GHG emission inventory and the monitoring GHG emissions of the transport sector in Beijing are given.

In order to apply experiences from German cities to the specific situation of the megacity Beijing, known differences of the transport sector between Germany and China as well as information on the data situation in Beijing have been considered based on information provided by the GIZ, previous IFEU research on transport-related emissions in China [IFEU 2008] and general information to the transport in China.

The recommendations for GHG balancing of the transport sector in the megacity of Beijing are mainly guided by the structure in chapter 3 and 4. They can be seen as a step-by-step strategy how a GHG balance for the transport sector of Beijing could be elaborated.

5.1 Characterization of Transport Activities for the GHG Balance of Beijing

The first step to draw a GHG balance for the transport sector of Beijing is to decide what transport activities concerning the city of Beijing have to be covered by balance, i.e. the definition of system boundaries and considered means of transportation. Following this, necessary, helpful and possible differentiations of the transport activities have to be discussed. All these decisions depend on the planned applications of the balancing results, but at same time on the availability of required transport data (i.e. VKT resp. Pass. or ton-km) or options for their determination with reasonable additional effort.

The recommendations for the characterization of transport activities in the GHG balance of Beijing are explained step-by-step and at the end illustrated in   Figure 27.

Step 1: System Boundaries

The authors consider a **_territory balance_** according to the delimitations of the existing Beijing traffic model to be the most appropriate choice as this will probably enable the most complete coverage of transport activities concerning Beijing with reasonable effort.

1. Step system boundaries

A city-induced traffic balance would require considerably higher efforts as traffic relations between Beijing and surrounding municipalities (or even to more distant cities) would have to be estimated separately. Moreover, it can be assumed due to the size of the agglomeration that origin-destination traffic to other cities is of minor importance compared to internal traffic in Beijing. Also an inhabitants' balance, which captures the traffic of Beijing's population in and outside Beijing appears to be more

Transport on the territory

unsuitable regarding climate protection action fields of the city as well as regarding data availability for the mobility of the inhabitants.

Step 2: Means of Transportation

The selection of means of transportation to be included in the GHG balance must be based on their relevance for the GHG emissions, the potential scope for action of Beijing's authorities and on data availability.

In any case, **passenger car** traffic must be included in the balance. **Taxis** should be covered as single vehicle category, due to their particular importance. In addition, **motorcycles** (esp. electric scooters) should be considered if possible. Though they are currently not covered by Beijing's traffic model, they present a significant part of motorized individual transport in Beijing and are energy-efficient alternatives to car traffic – thus, important for the development of modal-shift measures and the estimation of related GHG mitigation potentials.

Furthermore, public transport by **bus** and **subway** needs to be covered by the GHG balance. It makes a significant contribution to passenger transport and its performance is crucial for potential shifts of car traffic to more climate-friendly transport modes. Depending on the defined system boundaries (which districts are covered) also the inclusion of the Beijing **Suburban Railway** can be important that connects urban Beijing with outlying districts and counties beyond the reach of the city's Beijing Subway network. Though currently only the first line is operating, the planned network expansion sets the course for future potentials of modal-shift from individual transport modes to public transport.

2. Step
means of transportation

Passenger transport
cars | taxis
scooters
public bus
subway
(suburban rail)

Freight transport
trucks

Road freight transport with trucks should be considered in the GHG balance of Beijing, as well, despite lower potentials regarding traffic reduction or modal-shift. As trucks are not covered in the traffic model of Beijing at this time, approximate calculations of related GHG emissions based on average VKT would be conceivable. For compatibility with the territorial balance in passenger transport, VKT values for mainly urban trips should be estimated without major share of long-distance trips.

The long-distance traffic (high speed trains, air planes) is similar to German cities dispensable in the GHG balance for Beijing because these means of transportation have only a small share of the traffic on the territory. The same applies to freight trains.
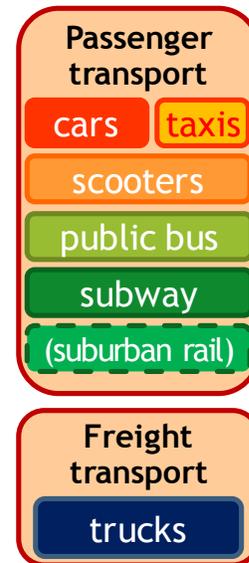
Step 3: Trip Distributions in Beijing

Differentiating the transport activities is a very important step in the GHG balance in order to assess the causes of transport-related GHG emissions, esp. to identify main contributors, to focus GHG mitigation measures and to analyse emission reduction potentials for target-oriented measures.

The information about the shares of internal trips and origin-destination traffic to neighbouring municipalities helps to identify the main causes of GHG emissions from transport in German cities. However, for Beijing it can be assumed due to the size of the agglomeration that origin-destination traffic to other cities is of minor importance compared to internal traffic and this differentiation is not that important.

In contrast, for Beijing a spatial differentiation of traffic within the balance area is seen an important step. In this way it can be determined in the balance, which trip relations contribute a major part to the GHG emissions of traffic in Beijing and, thus, should be on the focus of measures. Traffic differentiation in the GHG balance should for one thing distinguish traffic within individual districts (or towns), for the other thing major traffic flows between different districts or towns.

Differentiating transport activities by trip relations in the GHG balance may be associated with relevant additional effort. This information is included in the demand modelling in Beijing's traffic model, however it might have been aggregated in the routing of trips in the road network (trip assignment). Nevertheless, in the opinion of the authors this differentiation is crucial and should be aspired despite the possibly higher effort – at least via simplified estimates such as done in the German city Tübingen (see chapter 4.2.2).

This trip differentiation is mainly recommended for passenger transport as here the best opportunities exist for reducing traffic or shifting it to climate-friendly transport modes. Moreover, freight transport is not covered in the traffic model of Beijing; hence, the effort for such differentiations in the GHG balance would be even higher.

Based on the activity model for trip generation as part of the Beijing traffic model, further determinations on the shares of different trip purposes (work, shopping, business etc.) on total passenger transport, per means of transportation or even for the individual trip relations might be also possible with additional effort – and thus, refine the GHG balance and enable the development and evaluation of customized GHG mitigation measures.

VKT Differentiation in Road Traffic by Road Types (Step 4) and Traffic Flow (Step 5)

The emission level of transport activities is highly affected by the traffic flows, i.e. vehicle speeds and driving dynamics. This is covered in GHG emission calculations in Germany at different
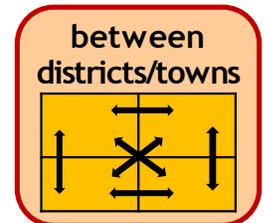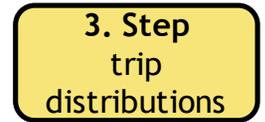
levels of detail. E.g. in rail transport, usually average energy consumption values are used for each transport mode (tram, subway, short-distance, long-distance train) differentiated by propulsion types (electric, diesel).

In road transport, the use of average factors for different road types (e.g. motorway, extra-urban, urban) is common practice. Beyond that, further refinements of emission calculations are possible under consideration of road type, driving speeds and traffic flow characteristics (e.g. Stop+Go shares) if a corresponding differentiation of traffic activities (VKT) is present.

For Beijing, a differentiation of road transport emission calculations **by road types** according to the differentiations in the traffic model seems to be most appropriate in the opinion of the authors.

Further differentiations **by traffic flow characteristics** (driving speeds, level of service) could also be helpful for the situation in Beijing if measures are planned to significantly improve the traffic flow and this shall be covered in the GHG balance. For that reason, it could optionally be examined during the elaboration of the GHG balance if the required refinement of VKT values can be achieved from the traffic model with reasonable effort.

The recommended step-by-step processing for capturing and differentiation of transport activities for the GHG balance of Beijing is shown summarized in Figure 27.
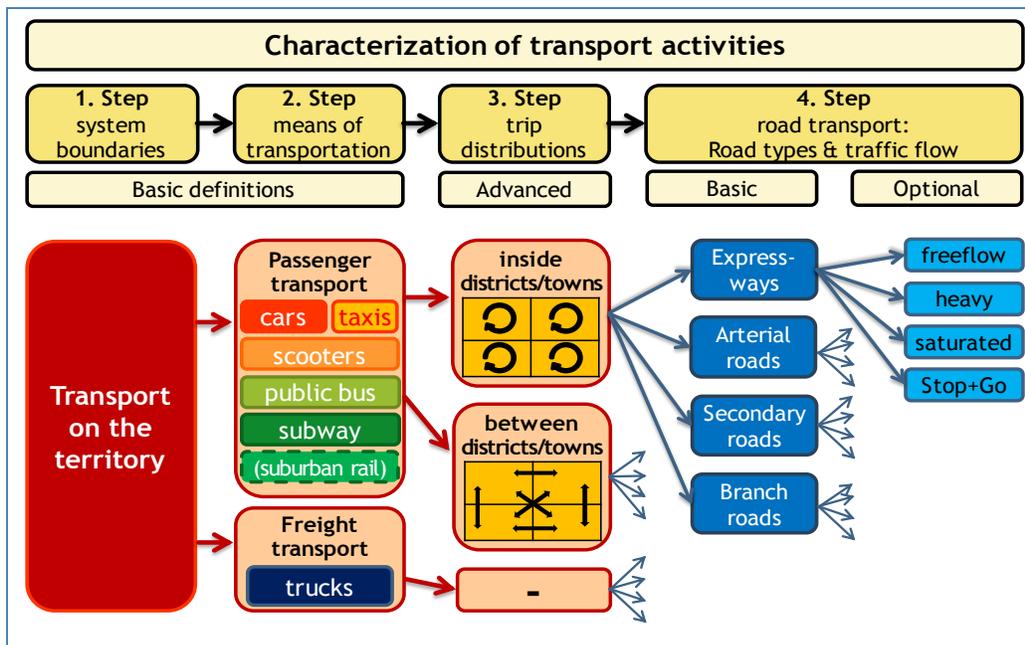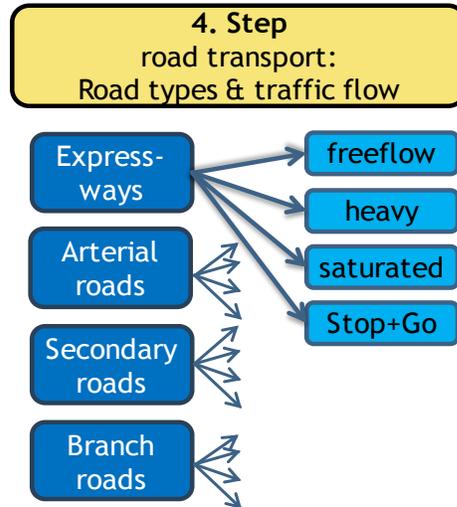
Figure 27: *Recommendations for the characterization of transport activities of Beijing*

5.2   Recommendations for Emission Factor Databases

The importance of adequate energy consumption and GHG emission factors for emission calculations of motorized transport is discussed in detail in chapter 1. Furthermore, the second chapter presents emission factor databases and inventory models for Germany and gives a short comparative overview on emission factor databases and models in other European countries and USA. Based in this information, first recommendations can be given for the GHG balancing of transport activities for Beijing.

In order to provide appropriate emission factors for a GHG balance of the transport sector in Beijing, existing information for the situation in Beijing resp. PR China should be reviewed first. In the last years, emission calculations for air pollutants as well as greenhouse gases from motorized transport in China and in Chinese cities (incl. Beijing) have been undertaken in several studies, e.g.:

- [IFEU 2008]: Transport in China: Energy Consumption and Emissions of Different Transport Modes,

- [Oliver 2009]: In-use Vehicle Emissions in China: Beijing Study,

- [Huo 2011] Modeling vehicle emissions in different types of Chinese cities: Importance of vehicle fleet and local features,

- [Wang 2011]: CO_2 and pollutant emissions from passenger cars in China.

These studies apply different emission factor databases (e.g. TREMOD in [IFEU 2008], IVE model in [Oliver 2009], [Huo 2011] or Copert IV in [Wang 2011]) and adapt them to the situation of transport in PR China. Primarily road transport is on focus of the studies; however, in some cases also other means of transportation are considered (e.g. [IFEU 2008]).

Main adaptations of road emission factor databases in the exemplarily cited studies concern deviating **fleet compositions** as well as specific **traffic flow characteristics** (e.g. average speeds on different road types) in Chinese cities. We recommend for a GHG balance of the transport sector in Beijing focus on these two aspects, as well. In addition, upstream emissions from final energy supply are shortly addressed.

Fleet Compositions in Road Transport

Passenger car models sold in China are regarding their fuel consumption characteristics generally comparable to cars that are sold in the U.S. or Europe. Therefore, the fuel consumption and emission behaviour of motorized road vehicles in China can be mapped with a European emission factor database like HBEFA.

However, vehicle fleet compositions in China differ strongly from those in Germany or other European countries: The average age of passenger cars in China is lower, they have different vehicle and engine size distributions and there are significantly less diesel cars in China [IFEU

2008]. Furthermore, it can be assumed that average VKT per car in China differ to those in Germany due to deviant usage pattern in both countries.

In consequence, for applying European emission factor databases like HBEFA in China the derivation of specific Chinese fleet compositions is required, considering different vehicle stock characteristics and usage patterns. In the best case, specific fleet compositions can be drawn for the specific situation in Beijing. As far as such information cannot be determined from existing studies, additional investigations (e.g. licence plate surveys) are required.

Also for the other vehicle categories (e.g. trucks), individual fleet compositions for Beijing must be derived to apply HBEFA emission factors. Where applicable, additional China-specific vehicle layers might have to be introduced if they are not defined in HBEFA but have relevant traffic shares in Beijing (e.g. electric scooters or rural vehicles).

Emission Factor Differentiation by Traffic Flow Characteristics

HBEFA provides fuel consumption and emission factors for a variety of traffic situations (defined by different road types, speed limits and levels of service, see Figure 15) with different average speeds and driving dynamics. Furthermore, average emission factors are provided for different road types (motorway, extra-urban, urban), based on weighted traffic shares of single traffic situations. These weighted mixes of traffic situations for individual road types cannot be adopted from Germany or other European countries for China.

However, the individual HBEFA traffic situations should be applicable also on road traffic in China. Beyond that, it should be examined if existing HBEFA traffic situations already cover the whole range of specific traffic conditions in Chinese cities or if additional traffic situations have to be derived, e.g. for strong Stop & Go traffic. Therefore, at this point additional analyses are required to derive adequate average emission factors for the road traffic in Beijing. These should be harmonized with the road types as differentiated in Beijing's traffic model and usable for the GHG balance of Beijing.
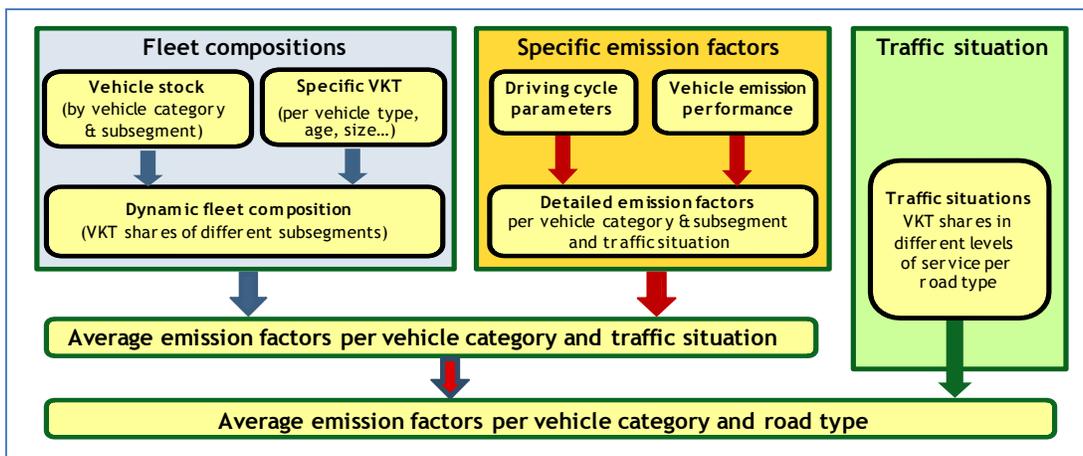
Figure 28: *Recommendations for the derivation of road transport emission factors for Beijing*

Energy Consumption Factors for Public Transport

HBEFA provides emission factors only for road transport. For all other means of transportation that should be included in the GHG balance of Beijing, therefore, additional energy consumption resp. emission data sources are required. This mainly relates to electric subway and trolley buses and possibly diesel-powered suburban railways.

If no measured energy consumption data are available from public transport operators average consumption factors have to be determined from other information sources. Options for a direct adoption of factors from other countries have to be examined under consideration of vehicle technical characteristics as well as vehicle use information. For example, investigations in [IFEU 2008] for metro systems in China revealed lower energy consumption per seat-km (higher train capacity due to more standing room) and even more per passenger-km (higher average occupancy of the trains) compared to Germany.

Well-to-wheel GHG Emissions

GHG balances of the transport sector should also for Beijing consider not only tailpipe emissions of major greenhouse gases (CO_2, CH_4 und N_2O), but also upstream emissions of final energy supply. Only this way, greenhouse effects of the transport in Beijing are covered comprehensively.

Upstream emission factors for fossil-fuelled vehicles can directly be adopted for transport in China from available/several international publications. However for electricity, China-specific GHG emission factors are needed as they depend on the mix of primary energy carriers in the electricity production. CO_2 emission factors and efficiency of electricity supply in China have been estimated e.g. in [IFEU 2008] for the years 2005 and 2020. However, they should be available for other reference years from further information sources.

5.3   Summary

For the elaboration of a comprehensive GHG balance for the transport sector in Beijing two working fields have to be distinguished:

1. Coverage and differentiation of transport activities with focus on the planned applications of the balancing results, but at same time on the availability of required transport data
2. Provision of adequate GHG emission factors for the specific situation in Beijing.

For both working fields, first recommendations have been developed in this chapter considering practical experiences from Germany as well as aspects of the specific situation in Beijing.

For the characterization of transport activities for the GHG balance, the traffic model of the city provides a good database for capturing and differentiating transport activities in the emission calculations in a way needed for ambitious applications of the balancing results such as identifying main causes of GHG emissions and deriving promising measures.

In order to provide adequate GHG emission factors, the authors see further need for adjustment. Emission factor databases from Europe could be an appropriate basis; however, important adaptions on the specific situation in Beijing, esp. regarding fleet compositions and traffic situations are required. Work in this field has already been started in the TDM project. Therefore, it can be assumed that comprehensive basic data will be available also for emission factors in the near future enabling comprehensive and good-practice GHG emission balancing for the transport sector in Beijing.

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