GIZ China | TRANSfer

Monitoring Greenhouse Gas Emissions of Transport Activities in Chinese Cities

A Step-by-Step Guide to Data Collection

Final Report

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany

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Monitoring Greenhouse Gas Emissions of Transport Activities in Chinese Cities

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The Project Context

The TRANSfer project is run by GIZ and funded by the International Climate Initiative of the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). Its objective is to support developing countries to develop and implement climate change mitigation strategies in the transport sector as „Nationally Appropriate Mitigation Actions" (NAMAs).

At country level, TRANSfer supports selected partner countries in developing and implementing NAMAs in the transport sector. The NAMAs supported by the project cover a broad variety of approaches in the partner countries Indonesia, the Philippines, South Africa, Peru and Colombia.

At international level and closely linked to the UNFCCC process, the project helps accelerate the learning process on transport NAMAs with knowledge exchange, trainings, facilitation of expert groups and documents with guidance and lessons learned.

In China, where transport accounts for almost one fifth of total carbon emissions, GIZ has been supporting Chinese institutions in developing sustainable low carbon transport systems on behalf of the German government for several years. In the context of TRANSfer, lessons learned on quantifying emission reductions of transport mitigation actions in China are summarised, edited and disseminated in China as well as shared internationally for replication.

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Glossary

CH_4	Methane
CO_2	Carbon dioxide
EFA	Emission factor
EV	Electric vehicle
GHG	Greenhouse gas
GPC	Global Protocol for Community-Scale GHG Emissions
LOS	Level of Service
MEP	Ministry of Environmental Protection
NEV	New Energy Vehicle (alternatively fuelled vehicle)
N_2O	Nitrogen dioxide
pkm	Passenger kilometres travelled
Segment	Segments are vehicle groups of the same size class and fuel type (e.g. for passenger cars: <1.4L or 1.4-2L or >2L for gasoline or diesel, respectively).
Subsegment	Subsegments are segments (vehicle groups of the same size class and fuel type), which are further split up according to their emission concept (e.g. China-1, -2, -3, -4 etc.)
tkm	Tonne kilometres travelled
ttw	Tank-to-wheel
VKT	Vehicle kilometres travelled

Scope and objective of this guide

Rapidly growing transport activities in urban areas are a big challenge for mitigating climate change. This paper provides a detailed approach for setting-up an emissions monitoring system for urban passenger transport in Chinese cities. The guide is intended to provide background information for a practical and **reliable approach to monitoring greenhouse gas** (GHG) emissions **in urban transport** considering local situations and data availability. In the context of this paper, the GHG emission monitoring system focuses on urban passenger transport - especially on buses, taxis and light duty passenger cars. In principle, however, the same approach is also applicable to freight transport. This guide does not describe a project monitoring approach, but an inventory approach. Instead of monitoring the emission reductions of a single project or policy, the system can monitor urban **transport emissions as a whole year-on-year**.

The ultimate aim is to enable transport planners and staff of environmental authorities in Chinese cities to generate a regular emissions inventory of the transport sector. This will allow them to understand, in a more specific way, which vehicles and activities are the main contributors to transport-related GHG emissions. Based on these analyses, key performance indicators of various transport activities such as average carbon intensity of transit kilometres, fuel economy of passenger car fleets, etc. can be derived.

This guide goes **beyond** calculations of overall fuel consumption in the transport sector, such as those promoted by G**lobal Protocol for Community-Scale Greenhouse Gas Emission Inventories** (WRI 2014). It introduces a calculation method for cities to carry out more detailed emission accounting based on transport activity that allows reporting emissions by modes, vehicle size, etc. The guide further explains different options to collect the necessary data – ranging from a basic to developed approach, depending on local capacities and resources. The methodology presented is in line with so called 'IPCC tier 3' methodologies (2006 IPCC Guidelines for National Greenhouse Gas Inventories).[1]

The guide is structured as follows:

- Chapter 1 introduces the GHG emission calculations methodology for transport and common data sources for determining transport activities and emission factors primarily of road transport. It also describes the basics of a GHG monitoring process.
- Chapter 2 represents the main part of the document and explains different options for methods and procedures to calculate transport activities. These include calculation procedures for the base year and periodic update years. Required basic data and data collection examples are provided as well as requirements for GHG emission factors.
- Chapter 3 outlines the possible scope and contents of GHG monitoring reports.
- This publication is the first version of the GHG monitoring guide and may be expanded to other countries in the context of the TRANSfer project.

The guide is part of a wider set of tools and publications by GIZ and its partners on emissions quantification and monitoring in the transport sector in Chinese cities. A key element in this toolbox is

[1] Three tiers are provided in IPCC. Tier 1 is the most aggregated method, in which emission factors only vary by fuel type, tier 2 is an intermediate approach still based on fuel consumption but differentiated by technology types and tier 3 is the most detailed approach, based on (travel) activity rather than fuel consumption. Tier 3 is the most demanding in terms of complexity and data requirements.

the China Road Transport Emission Model (CRTEM). This software package includes a Chinese version of the **European Handbook of Emission Factors for Road Transport** (HBEFA China). Its core benefit is the provision of detailed emission factors for road transport, which are adapted to Chinese driving conditions. Consequently, CRTEM is an important emission factor database that can be used for calculating greenhouse gas (GHG) emissions from urban transport in Chinese cities.

If you are interested in using the China Road Transport Emission Model and its emission factor database, please contact:

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1. Introduction to calculating and monitoring GHG emissions from transport

This chapter provides the background on how to calculate transport-related GHG emissions and how to start monitoring GHG emissions from transport activities.

Since cities and other monitoring regions can use different methods and delimitations to determine transport activities and related GHG emissions, **interpretation of monitoring results can vary considerably**! This chapter therefore also explains the main considerations for defining monitoring boundaries and common distinctions between them.

The availability of basic data and a city's monitoring objectives will determine how **monitoring boundaries** are set and which level of accuracy or detail is required. Section 1.3 in this chapter provides a general **overview of common data sources** supplying basic data for calculating transport activities and for GHG emission factors.

To keep calculations, examples and figures short and comparable we use abbreviations. All abbreviations are explained in the glossary.

1.1. Basics on calculating transport GHG emissions

The amount of GHG emissions caused by motorised transport depends on the extent of transport activities, the specific energy consumption of the means of transportation used and on the specific GHG emission intensity of the final energy carriers (see Figure 1).

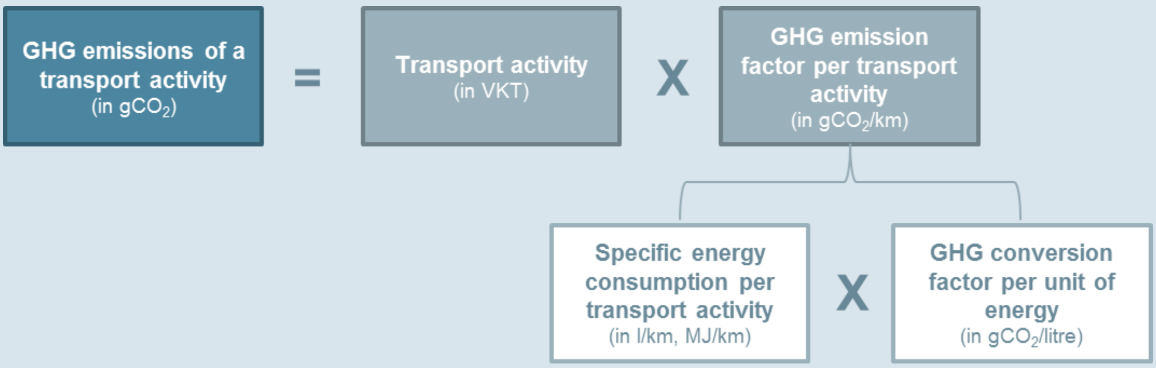


Figure 1: GHG emissions calculation function for motorised transport activities

Transport activity can refer to either the physical movement of vehicles (measured in vehicle kilometres travelled, VKT) or to the physical movement of passengers or goods from A to B (usually measured in passenger kilometres, pkm and tonne kilometres, tkm). The latter is usually referred to as **transport demand** and is a function of vehicle kilometres travelled and the respective load factors of the vehicles. In this guide, the focus of transport activity is on VKT as the "distance covered by a vehicle within a period of time".

The **specific GHG emissions** per transport activity (also called GHG emission factors) depend on the specific energy consumption per transport activity and the GHG conversion factors per unit of energy consumption.

The **specific energy consumption** depends on a range of influence factors: the means of transportation, its size and transportation capacity; technical characteristics like drive concept or vehicle age are relevant for the vehicle's energy efficiency; beyond that operation conditions - velocity, traffic flow, driving behaviour and load - affect the real energy demand.

GHG conversion factors per unit of energy depend on the final energy carrier used in the vehicle. Rail transport largely runs on electricity, whereas road traffic is currently almost entirely based on fossil fuels, despite an increase in electric mobility (see box below). When fossil fuels are used, most of the greenhouse gases are directly emitted during the fuel combustion in the vehicle (**tank-to-wheel**) whereas for electricity all emissions result from power production, not during vehicle use. These upstream emissions of energy supply result from the exploration of oil and gas, their transportation, as well as the refinery and electricity production processes (**well-to-tank)** (see Figure 2). The broader perspective on emissions considers both tank-to-wheel and well-to-tank emission and is consequently called well-to-wheel.

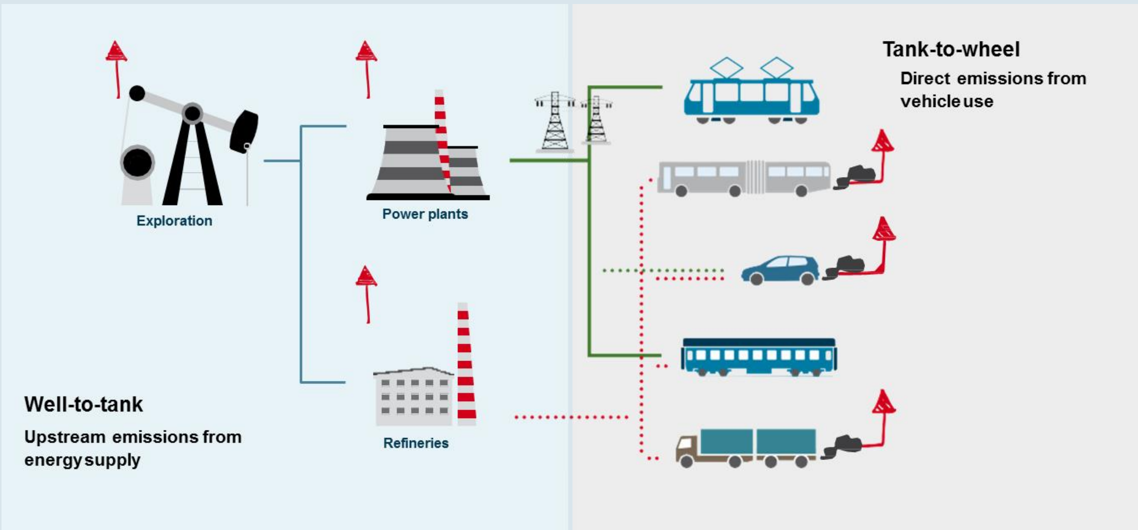


Figure 2: Well-to-tank and tank-to-wheel emissions (Source: adapted from Ifeu, 2012)

GHGs emitted by transport mainly consist of carbon dioxide (CO_2) besides small amounts of methane (CH_4) and nitrous oxide (N_2O). In order to compare the warming effects of different GHGs, the global warming potential (GWP) is used. GWP relates the amount of heat trapped in the atmosphere by a particular 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 (for a time horizon of 100 years) of carbon dioxide, methane and nitrous oxide: [IPCC 2007]

CO_2	CH_4	N_2O
1	25	298

Electrically powered mobility in Chinese cities

In the future, a substantial increase in alternative energy carriers is expected in road transport. The option mostly discussed in public and politics is electrically powered mobility. Can electric vehicles diminish GHG emissions significantly? Which conditions are fostering electrically powered mobility, which are obstructive? What are the technical challenges countries have to match in the near future to make electric vehicles economically competitive?

With electricity, there are no direct emissions at the local level. All GHG emissions result from the upstream energy supply. The mitigation potential of electric mobility therefore depends on the primary energy carrier mix used to produce electricity. A joint study by GIZ and Tsinghua University found that based on the expected development of the electricity mix in China substantial CO_2 mitigation effects might occur from 2020 onwards, but not before.

China is one of the major actors who promote electrically powered vehicles, including inter alia purchase subsidies. Sales of electric vehicles (EVs) has quadrupled in 2014 with 83,900 electric vehicles sold, compared with the previous year. By 2020, 200,000 city buses and 100,000 taxis shall be pure EVs, and the share of New Energy Vehicles (NEVs) in public transport and city logistic shall be over 30%. The support policies for electric vehicles have been extended and the existing subsidy and incentive measures have been complemented and updated. The government will continue to provide financial incentives for the demonstration and application of NEV. The purchase subsidies will however be reduced by 5 to 10% per year in the future.

In January 2014, the responsible Chinese authorities issued new evaluation criteria for the financial support to electric vehicles (new: range on pure EV mode; former: battery capacity).

In addition, China has exempted EVs from the number plates authorization auction (Shanghai) and the lottery draw for new registrations (Beijing).

The expansion of the charging infrastructure is financially supported. In November 2014, the Chinese government issued new regulations to subsidize the development of charging facilities for electric vehicles. This means that the central government will directly transfer subsidies to the respective city governments proportional to the number of electric vehicles registered in the municipality.

In addition, mandatory guidelines for increasing the share of electric vehicles in public fleets were published.

Depending on the characteristics of the transport activity, specific GHG emission factors (GHG EFA in gCO_2e) are required per vehicle kilometre travelled. Calculating GHG emissions based on transport activities is called a **bottom-up approach**.

Another way to calculate GHG emissions of transport is based on statistical data on the final energy consumption of one or several means of transportation (e.g. total fuel consumption or fuel sales) – called **top-down approach**. It is often applied for monitoring total transport-related GHG emissions at the national level or of confined vehicle fleets, such as of public transport operators or logistics companies.

Figure 3 illustrates the difference in the calculation formula of the energy consumption-based top-down and the activity-based bottom-up approach.

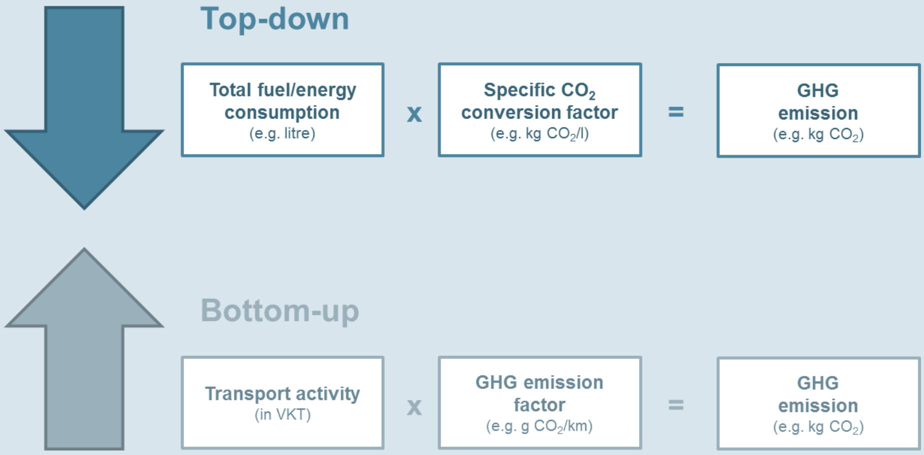


Figure 3: Calculation formula for top-down vs. bottom-up approach (Source: INFRAS, 2015)

The top-down approach essentially skips over the activity data. The advantage of this approach is that calculated GHG emissions directly refer to the fuel consumption from statistics so that the data collection effort is small. On the downside, fuel consumption statistics are seldom available on city level and, more important, provide only very limited information on where the fuel is consumed or by whom. The main problem is that territorial and sectoral boundaries may be inaccurate since fuel sold within a city can be consumed outside or vice versa. It is also possible that the fuel sold is used by off-road machinery e.g. in the construction sector or by other consumers outside the road transport sector. The interpretation of transport emissions for a city calculated based on fuel consumption statistics must therefore be done with care. Moreover, since no information on transport activities is gathered, the top-down approach is in most cases not suited to evaluate emission reductions related to specific policies or measures. However, for public transport operators that exclusively provide services on specific lines in the city territory it is a practical and useful approach.

1.2. Assessment Boundaries

Monitoring GHG emissions can have different objectives: (1) Reporting GHG emissions developments over time, (2) defining the relevance of transport for the total GHG emissions in the city or (3) understanding which activities contribute most emissions in the current situation to support decision-making. Another objective can be (4) controlling the success of mitigation projects or programmes and monitoring goal achievement. Different objectives of emissions monitoring go along with different requirements to the methodology. Especially monitoring the success of a specific mitigation action such as modal shift measures or fleet efficiency improvements requires a higher level of detail in transport data (e.g. locally specific occupancy rates by mode or a locally specific differentiation of the vehicle fleet composition) than only reporting total GHG emission developments over time. The intended use of the results in turn determines the method used and data requirements for appropriate monitoring. This guidance focuses on annual emission inventories for cities; it does not aim to provide an approach to evaluate the effect of a specific mitigation action.

Monitoring boundaries refer to the scope of the monitoring. This includes the transport activities and modes, the geographic scope, the GHG emissions covered as well as the temporal scope. The boundaries frame the monitoring process and define which aspects are being monitored and which are not. Before starting data collection, adequate monitoring boundaries have to be defined. These primarily depend on the objectives, but also on data availability. For instance, if cities are interested in congestion reduction effects on transport emissions, detailed data on local driving situations are required; but if decision-makers are more interested in a comparison of the overall emission developments of different transport modes the use of averaged traffic situations is possible.

The availability of adequate data is a decisive factor when choosing a feasible monitoring method and defining monitoring boundaries. Boundaries have to be determined very thoroughly - they are crucial to make monitoring results comprehensible and comparable.

All starts with the primary decision about which emission sources are to be considered and which GHG emission factors are needed respectively. This includes the following questions:

- Which transport activities are covered? What is the adequate geographic coverage for these activities (city, municipality, suburb, etc.)?
- Which means of transportation are included?
- Which type of emission factors is applied for each emission source?
- What is the time period or intervals to be covered (years, hours, months, etc.)?

1.2.1. Transport activities covered and geographic scope

Transport activities can be attributed to a **monitoring** area with different **approaches**. This has consequences for the informative value and the further use of the monitoring results. The typical system boundaries for monitoring are explained in the following.

In the **territorial approach** all transport activities of a means of transportation in the territory are covered. The territory can be defined as the whole area of a city or only the city-governed districts. The territorial approach is the most suitable approach for urban transport inventories because it covers all activities in the territory independent of who travels (see Figure 5) and relates most closely to the sphere of influence of city authorities. In addition, it best facilitates delimitating transport emissions from one city to another. Further differentiations within the territorial approach – e.g. if a trip takes place fully inside the city or crosses city boundaries – further strengthen the understanding of why vehicles are being used and help to identify suitable policy interventions. Sometimes, however, data availability does not allow following the ideal level of differentiation and a compromise has to be found between the ideal approach and the available resources for data collection. This may mean following a second-best approach (see chapter 2 for identifying feasible approaches to GHG monitoring).

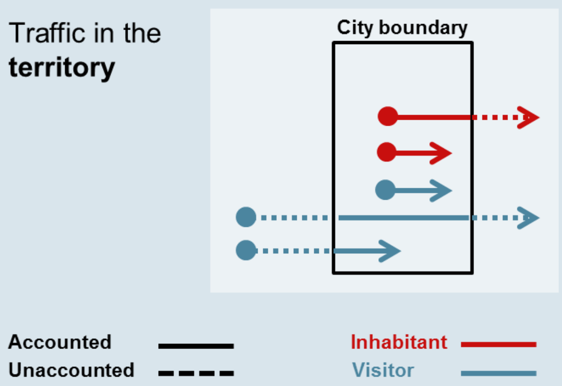


Figure 4: Territorial system boundary (Source: IFEU, 2012)

This guide recommends using a territorial approach whenever possible (see also box below). To better understand why, the most common alternative approaches are also briefly introduced.

A different system boundary is followed in the **inhabitants' approach**, which covers all the traffic of inhabitants, regardless of where the traffic occurs (see Figure 6). Consequently, the inhabitants approach has no fixed territorial boundary and ignores all information on traffic from outsiders, such as commuters who do not live within the city boundary. This means that possible GHG emission reductions in commuting by external traffic are not included in the monitoring; on the other hand emissions related to inter-city travel by inhabitants, which can hardly be influenced by city governments, are included and increase a city's GHG emissions inventory when an inhabitants approach is used.

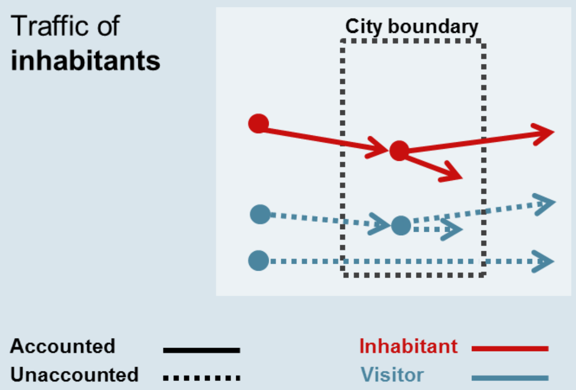


Figure 5: Inhabitant-based system boundary (Source: IFEU, 2012)

An entirely different approach is the above-mentioned **top-down approach**, which bases the system boundary on **energy sales** in a city. As already mentioned above, this approach provides no information on the actual transport activities related to the monitoring area and is subject to significant uncertainties regarding where the fuel is finally burnt. Its value for transport policy making is consequently very limited, but fuel sales data can be used to triangulate bottom-up calculations.

1.2.2. Means of transportation

The definition of transport activities includes the selection and differentiation of the various means of transportation. Passenger and freight transport can first be differentiated by transport carrier and then by several modes with different properties as shown in Figure 6. The choice of means of transportation is the basis for the GHG emission calculations according to the specific energy consumption and related GHG emissions of each means.

Ideally, all transport modes are covered for a full transport GHG emission inventory of a city, but in reality data may not be readily available to calculate emissions from all modes. Setting priorities based on the relevance of the means of transportation for the local monitoring objective may be necessary (see Figure 6 below). Usually, local and regional passenger transport causes the largest share of transport emissions in the city territory, making it a first priority. This is followed by light and heavy duty trucks. However, depending on the monitoring objectives priorities can be different.

	Road	Rail	Water	Air
Passenger transport	Motorcycles	Tram/light-rail		
	Passenger cars	Subway		
	Public bus	Regional train		
	Coach	Long-distance passenger train	(passenger ship)	Aviation
Freight transport	Light duty truck	Freight rail transport	Inland navigation	Aviation
	Heavy-duty truck		(maritime navigation)	

Priority 1

Priority 2

Priority 3

Figure 6: Motorised means of transportation (priorities are only exemplary) (Source: IFEU 2014)

Recently, the number of electric bicycles has been growing rapidly. Since their energy consumption and GHG emissions are low compared to passenger cars, they are often not considered in emission calculations. In the future, as their transport share increases further, it might become necessary to include electric bicycles in urban GHG monitoring, even if their specific energy consumption and emissions are low.

1.2.3. GHG emission factors

Two fundamental decisions on the GHG emissions covered have to be made: 1) CO_2 vs. CO_2 equivalents and 2) the emission origins - direct emissions from vehicle use only (tank-to-wheel) vs. direct and upstream emissions (well-to-wheel).

Considering upstream (well-to-tank) emissions and CH_4 and N_2O contributions to total GHG emissions is particularly relevant, where measures include a change to electricity or alternative fuels (e.g. biofuels) and therefore a significant change in the GHG impacts of the final energy supply. It is also important to consider upstream emissions when comparing different transport modes running on fuels produced from different primary energy sources.

A **best-practice approach** for GHG emission monitoring is to consider all well-to-wheel CO_2 equivalent emissions. This presents the most complete picture of transport related emissions and emission reductions. All relevant impacts resulting from shifts between fossil-fuel-driven vehicles and alternative drive concepts can then be considered. Where the monitoring covers only fossil fuel-driven vehicles, the use of tank-to-wheel CO_2 emissions is sufficient to start with. If electricity-driven means of transportation are included, the use of well-to-wheel emission factors is required. Figure 7 highlights the importance of considering well-to-tank emissions when assessing electric vehicles.

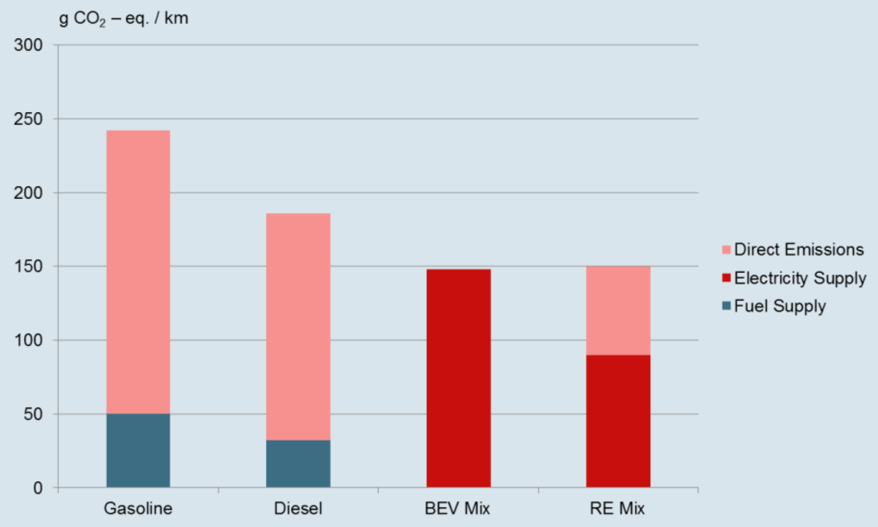


Figure 7: Well-to-wheel emissions of different vehicles 2010 (Source: IFEU 2011)

At the vehicle level, the specific energy consumption per kilometre travelled depends on technical parameters and operating conditions. In road transport, considerable differences in energy consumption and related GHG emission factors per kilometre are mainly caused by:

- Different vehicle characteristics, such as engine type, engine capacity, vehicle age and to a lesser extent the emission concept (the emission standards China 1-5 correspond to the European vehicle emission standards Euro 1-6). As emission standards are phased in over time, data on emission concepts can be used as proxy indicator for vehicle age.
- Different traffic characteristics, especially speed, traffic quality and road gradients, depending primarily on transport infrastructure and traffic volumes, but also on other conditions such as traffic lights, weather conditions etc.

Figure 8 on the left shows how specific emissions decline with stricter emission standards (as indicator for vehicle age) across all size classes and how emissions rise with engine size. On the right, emission factors are presented for different road types by level of Service (LOS), showing very high emissions per km for congested roads (LOS 4 and 5) for all road types.

Emission factors range from very disaggregated factors, e.g. specific emission factors for each passenger car subsegment differentiated by vehicle size and age, to averaged emission factors, e.g. only one average emission factor for all buses. Where average emission factors are used, these should ideally be derived from detailed factors, which are aggregated based on average fleet compositions and average driving situations (see chapter 1.3.2 for more details on data sources for emission factors).

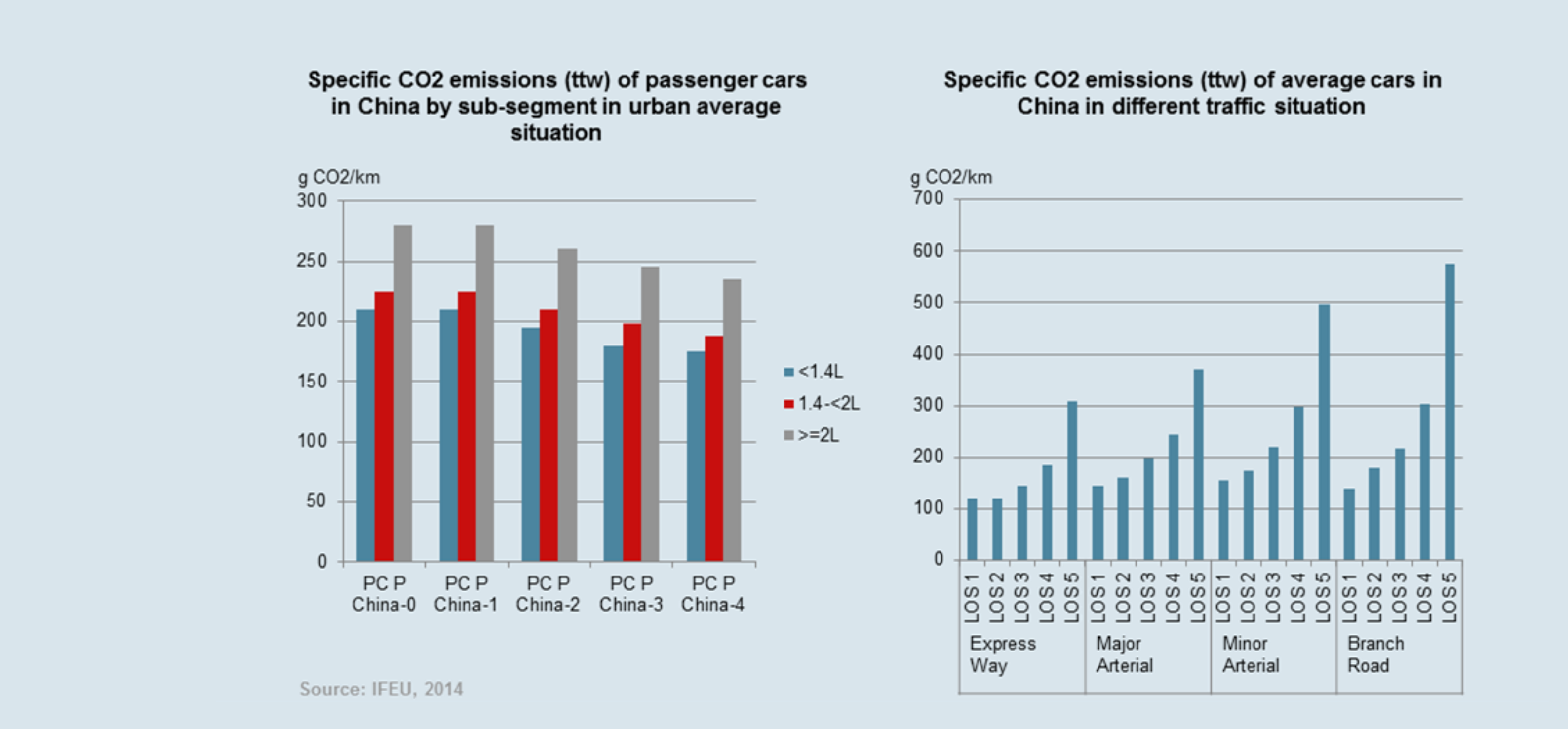


Figure 8: Examples for the variation of CO_2 emission factors (tank-to-wheel) in road transport (Source: INFRAS 2014)

1.3. Data sources for GHG monitoring

Which common data sources in the transport sector can provide basic data for calculating transport activities and GHG emission factors? The following overview of data sources can help institutions in charge of GHG monitoring to examine the availability of transport-related data from locally available data sources and to assess which of the institution's own data collections could provide additional data. More specific data needs and possible data sources for different GHG calculation methods as recommended in this guide will be given in the respective sections of Chapter 2.

1.3.1. Overview of common data sources for transport activities

Transport activities are highly dependent on local circumstances, such as number of inhabitants, car ownership, transport infrastructure, location of a city in regard to national transport routes, industrial settlements and number of employees in a city. For example, travel patterns in singular cities that attract people from surrounding more rural municipalities through workplace, shops, culture and leisure facilities considerably differ from cities of similar size located in urbanised agglomeration areas (clusters). For this reason, transport activities for the monitoring area should be determined primarily based on locally specific information, average values should only be used where no local data is available.

Table 3 provides a comprehensive overview of common data sources for the determination of transport activities in cities and their differentiation by emission-relevant vehicle and traffic characteristics. Currently in China, different departments collect the statistical data. Since no official data sharing or communication mechanism exists, cities seldom have a reliable database on the whole transport system. Most detailed information is not publicly accessible. The data, which can be openly accessed from public sources are mostly macro data not suited for emissions quantification. More details on transport data availability and ownership in China are summarised in the report "Data Availability for Measuring and Reporting Transport-related Greenhouse Gas Emissions in Chinese Cities" prepared by Institute of Comprehensive Transportation, NDRC and GIZ.

The following information are given for each data source in the table:

Means of transport: A few data sources can be specific for a single means of transport; the majority provides data for several transport modes.

Kind of activity data: Data sources can provide transport activity data (VKT, pkm) directly. They may also provide basic parameters for the subsequent calculations of specific transport activities (e.g. number of cars and average annual VKT per car).

System boundaries: Even if transport activity data is available, system boundaries may not match. Since it is not appropriate to combine data referring to different system boundaries, in this cases correction factors may be required.

Fleet composition: In road traffic, differentiation of transport activities by vehicle characteristics (engine size, vehicle age) should be considered. Also in rail transport a differentiation by traction (electric, diesel) is useful. This provides information for further differentiating transport activities in the future.

Traffic situation: In road transport, locally specific situations (road types, level of service - LOS) should be considered if adequate data are available. The definition of levels of service based on congestion levels, road types and ranges of average speed in km/h in China are summarised in Table 2 below (for more information on LOS, please refer to the technical paper "Modelling Energy Consumption and GHG Emissions of Road Transport in China" (Sun et al., 2014).

Table 2: Characteristics of Levels of Service (LOS) in China; based on average speed per road type

Level of service (LOS)	LOS 1: Free flow	LOS 2: Heavy traffic	LOS 3: Saturated traffic	LOS 4: Stop-and-go	LOS 5: Heavy stop-and-go
Congestion level	Unimpeded	Basically unimpeded	Mild congested	Moderate congested	Severe congested
Expressway	>55 km/h	>40-55 km/h	>30-40 km/h	>20-30 km/h	≤20 km/h
Major arterial	>40 km/h	>30-40 km/h	>20-30 km/h	>15-20 km/h	≤15 km/h
Minor arterial	>35 km/h	>25-35 km/h	>15-25 km/h	>10-15 km/h	≤10 km/h
Branch	>35 km/h	>25-35 km/h	>15-25 km/h	>10-15 km/h	≤10 km/h

Table 3: Table Data sources for transport activities in cities

Data source	Means of transportation	Kind of activity data	System boundaries	Fleet composition	Traffic situation
Trip survey (in households or companies)	- Passenger cars - Motorcycles - Taxi - Buses - Subway - Regional train	Per person: - Pkm* ** For cars differentiated into driver, co-driver, with chauffeur*	Inhabitants	Optional (depending on configuration of the survey)	No
Vehicle registration statistics	- Passenger cars - Taxis - Trucks - Motorcycles (no e-bikes)	Vehicle stock by technical characteristics	Inhabitants (= owners of registered vehicles)	Yes, but only for stock, not for VKT	No
Vehicle activity survey	- Passenger cars - Taxis - Motorcycles - Trucks	Per vehicle: - VKT or - number of trips and distances	Inhabitants (= owners of the vehicles)	Optional: Depending on configuration of the survey	No (only if survey includes → Floating car data)
Main inspection data	- Passenger cars - Taxis - Trucks	Per car: - VKT from odometer	Inhabitants (= owners of the vehicles)	Yes.	No
Taxameter information	- Taxis	Per taxi: - VKT or - number of trips & trip distances	Territorial: cruising radius of local taxi fleet (territory might differ to geographical boundaries of the city	Optional: only if analysed taxis are representative for whole taxi fleet	No
Floating car data (GPS)	- Passenger cars - Taxis - Buses - (Trucks)	Per vehicle: - VKT for single vehicle in analysed time period. Extrapolation to total VKT only if analysed vehicles and time period are representative for fleet	Inhabitants (= owners of the vehicles)	Optional: only if analysed vehicles are representative for whole fleet	Yes: Conversion to HBEFA traffic situations is only possible with linkage to GIS data of the road network.
Traffic counting with on-road sensors	- Passenger cars - Taxis - Buses - Motorcycles - Trucks	Traffic volumes in the analysed road section	Territorial: No stand-alone data source, but for calibrating traffic model and estimating VKT development	No	Optional: Some road sensors provide information on vehicle speed

Data source	Means of transportation	Kind of activity data	System boundaries	Fleet composition	Traffic situation
Video monitoring on selected road sections	- Passenger cars - Taxis - Buses - Motorcycles - Trucks	Traffic volumes in the analysed road section	Territorial: No stand-alone data source for territorial VKT of a city, but for calibrating traffic model and updating VKT data	Optional: Licence plate survey and matching with vehicle registration statistics	No
Public transport companies	- Bus - Subway - Regional train	For the whole public transport network or for different routes: - Final energy consumption - VKT - Pass.km, - Transport capacity, - Load factors	Territorial: public transport network might differ to geographical boundaries of the city	Optional: - Bus per engine type (and size) - Train per traction	No
Public transport network plans	- Bus - Subway - Regional train	Length of each public transport route	Territorial: public transport network might differ to geographical boundaries of the city	No	No
Public transport timetables	- Bus - Subway - Regional train	Service frequency of each public transport route (e.g. number of buses per day)	Territorial: public transport network might differ to geographical boundaries of the city	No	No
IC cards	- Bus - Subway	- Number of passenger trips - Pkm (only subway)	Territorial: public transport network might differ to geographical boundaries of the city	No	No
Car hailing Apps	- Taxi	- Number of passenger trips - Pkm	Territorial: public transport network might differ to geographical boundaries of the city	No	No
Travel demand model (depending on year of calibration)	- Passenger cars (incl. private and non- private car) - Taxis - Buses - Trucks	Per road section: - Road length - Traffic volumes - VKT	Territorial: territory covered by the model might differ to geographical boundaries of the city	No	By road type. Shares of LOS can be derived from some models with further data (e.g. traffic counts).

1.3.2. Data sources for emission factors for road transport

Specific tank-to-wheel emission factors for all road vehicle categories[2] are available in 'The Handbook of Emission Factors for Road Transport HBEFA' (INFRAS, 2010). This emission factor database was originally developed for Europe and has been adapted to Chinese cities and driving situations and can now also be used in China.

HBEFA provides GHG emission factors on different levels of detail:

- Aggregated GHG emission factors per vehicle category for average fleet compositions and average traffic situations. They are applicable if only the sum of transport activities is known.
- Detailed GHG emission factors for different vehicle subsegments and traffic situations. They are applicable if the city-specific differentiation of transport activities by fleet composition and/or traffic situations is known.

The following two figures illustrate the differentiation levels of emission factors in HBEFA for different fleet compositions (Figure 9) and different traffic situations (Figure 10).

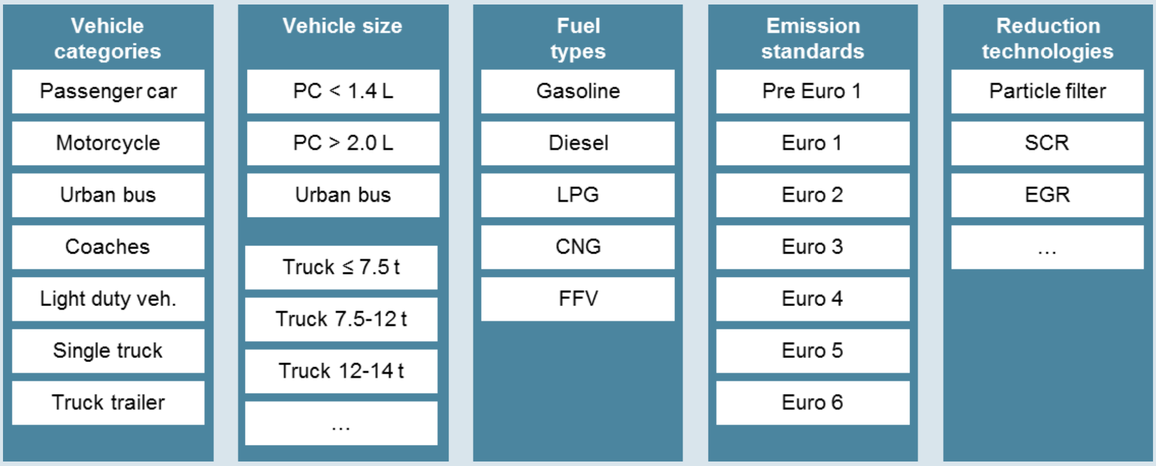


Figure 9: Differentiation of fleet compositions in HBEFA (Source: INFRAS 2013)

The differentiation by traffic situations (also called level of service (LOS) for HBEFA China was adjusted to reflect Chinese traffic characteristics and is in line with the five congestion levels used in China.

The HBEFA expert version already provides a Microsoft Access based integrated emission calculation model linked to the HBEFA database. This enables the calculation of tank-to-wheel GHG emissions by entering local fleet compositions and transport activity data (VKT). Both fleet and transport activity data can be provided either detailed (e.g. output files of travel demand models) or in more aggregated form. The Chinese version of the HBEFA expert version, the China Road

[2] No officially approved GHG emission factors are available for public transport in China, especially for rail systems. As a consequence, adequate GHG emission factors from public rail transport need to be determined separately if these means of transportation have to be considered in the inventory. They can be based on energy consumption statistics from public transport operators and statistics of the applicable primary energy carriers and their specific GHG emissions from electricity supplies in China.

Transport Emission Model (CRTEM/HBEFA-China), allows Chinese cities to track data on tank-to-wheel emissions and calculate the emission impacts of transport scenarios. The model facilitates a reliable estimation of energy consumption and carbon emissions of urban road transport. Equipped with China-specific default values, the model is flexible enough to be used by cities with and without travel demand models. If projections of traffic activity are available, the CRTEM/HBEFA-China can also be used to calculate future emission scenarios.

Adopting HBEFA to local conditions – The case in China

In the context of the Sino-German project Transport Demand Management in Chinese Cities, GIZ adapted 'The Handbook of Emission Factors for Road Transport (HBEFA)' to China and initiated the development of the China Road Transport Emission Model (CRTEM/HBEFA-China). The prime objective of the model is to estimate road traffic emissions with high temporal and spatial resolution, to be used as a tool to assess the impact of urban transport policy on emission reductions. Equipped with China-specific default values, the model is flexible enough to be used by cities with and without travel demand models. Where travel demand models are available, the CRTEM can also be easily used to calculate future emission scenarios.

HBEFA/CRTEM provides emission factors i.e. the specific emission in g/km for passenger cars, light duty vehicles, heavy duty vehicles, buses and motorcycles. A special feature is that these emission factors are available for a range of different traffic situations. This enables transport planners to quantify the impact according to available and common categories of traffic data. For each vehicle category, emission factors are given for different road types (with different speed limits) and 5 traffic situations (free flow, heavy traffic, saturated traffic, stop-and-go and heavy stop-and-go). Each traffic situation is characterised by a typical driving pattern, which is a series of data points representing the speed of a vehicle versus time.

HBEFA was adapted to the context of Chinese situations through the development of local driving cycles representing specific traffic situations. Emission characteristics of vehicles in Chinese cities have also been considered. To identify typical traffic situations in China, more than 2,000 hours of GPS data were collected in Beijing and Shenzhen during 2012 and 2013. GPS transmitters were applied to record real road vehicle movements once per second (1 Hz) and were temporarily stored in the memory of the devices. The GPS devices were installed in 20 taxis and private passenger cars. They collected information on geographic coordinates, speed and acceleration for each second over the course of one week in both Beijing and Shenzhen.

Figure 11 shows the CO_2 emissions of a standardised passenger car (production year 2002; engine capacity 1.4 - 2.0 l) for the Chinese traffic situations identified. The emission factor for heavy stop-and-go traffic is 2.6 to 3.2 times higher compared to free flow situations. The highest emissions with 621 gCO_2/km is caused by the traffic situation 'Branches: Heavy stop-and-go traffic'; but normal stop-and-go traffic already generates high specific CO_2 emissions. The values between 196 and 327 gCO_2/km are 55% to 89% higher than emission values for free flowing traffic. For further information please refer to the following publications:

- Modelling GHG Emissions of Road Transport in China on GIZ's CRTEM/HBEFA-China Model (Sun et. al., 2014)
- Balancing GHG emissions from the transport sector of cities (IFEU, 2012)

Level of service	LOS 1: free flow	LOS 2: heavy traffic	LOS 3: saturated traffic	LOS 4: stop and go	LOS 5: heavy stop and go
Congestion level	Unimpeded	Basically unimpeded	Mid congestion	Moderate congestion	Severe congestion
Unit	Km/h	Km/h	Km/h	Km/h	Km/h
Highway / Expressway	>55	40-55	30-40	20-30	<20
Major arterial	>44	30-40	20-30	15-20	<15
Minor arterial	>35	25-35	15-25	10-15	<10
Branch	>35	25-35	15-25	10-15	<10

Figure 10: Differentiation of traffic situations in HBEFA for Chinese cities (Source: INFRAS 2014)

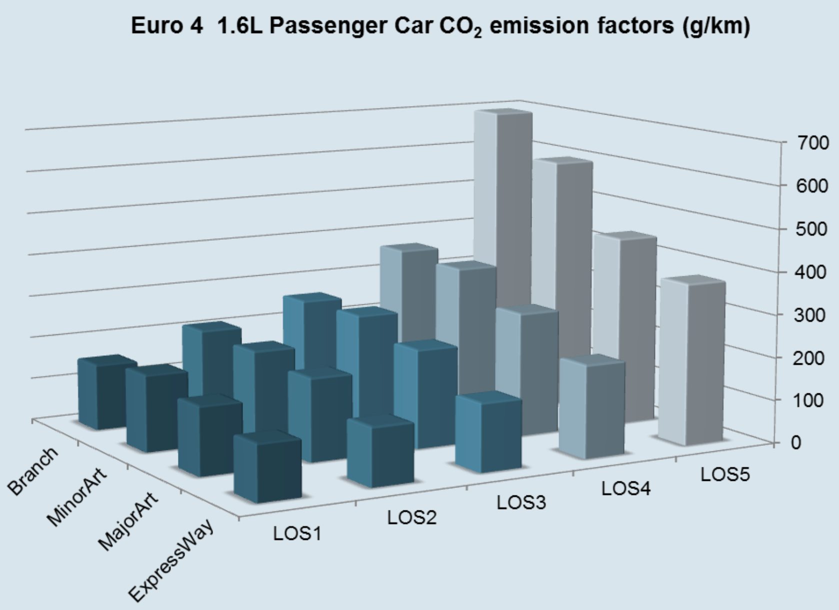


Figure 11: CO_2 emission factors for a typical Euro 4 1.6 litre passenger car in China under different road types and levels of service (Source: HBEFA China, INFRAS 2014)

Since HBEFA China is currently focused on tank-to-wheel emissions of road transport, if GHG monitoring also includes rail services, adequate GHG emission factors from public rail transport must be determined separately. They can be based on energy consumption statistics from public transport operators and statistics of the applicable primary energy carriers and their specific GHG emissions from electricity supplies in China. To ensure consistency and allow comparison between modes, well-to-tank emissions of conventional fuels also have to be taken into account (e.g. through national default values for upstream emissions per litre fuel).

2. Developing a feasible GHG monitoring approach

Local data sources, availability of emission factors, clear objectives and boundaries – as shown in chapter 1, these are all important components for a reliable monitoring approach of greenhouse gases from transport. At the same time it is beyond dispute, that no universal monitoring approach exists that is suitable for every city or matching all specific conditions. The first step to design an appropriate monitoring approach is always to identify your status quo. This can be done along the following considerations:

- Are detailed emission factors available?

  The level of differentiation of emission factors available greatly influences the feasibility of detailed monitoring approaches. If only average localised emission factors are available, there is no need to collect activity data at a high level of differentiation for emission calculations (for other reasons it might still be desirable). If detailed emission factors are not readily available, the subsequent question is whether emission factors are reliable and necessary to achieve useful monitoring results. If no local or at least country specific emission factors are available at all, this greatly affects the accuracy of emissions calculations. For China, the Handbook for Emission Factors (HBEFA) can be used in all Chinese cities. It provides differentiated emission factors per vehicle type and traffic situation, as well as aggregated values for average fleet composition and typical mix of traffic situations.

- Which travel activity and fleet composition data can be collected within a feasible time and at acceptable expenditure?

  The effort put into data collection is always a compromise between accuracy und feasibility. Feasibility obviously depends on locally available resources and expertise. In general, one should always strive for the highest accuracy possible, but as a rule of thumb the effort put into data collection should match the expected size of emissions contribution.

- Do you already have experience with emission monitoring?

  Locally available expertise may influence the choice of a suitable emissions monitoring approach. However, it is common practice for cities to outsource the emissions calculations to specialised institutions. Nonetheless the more expertise is locally available the easier it is to make informed decisions. Capacity development may be necessary to support building up solid local transport emission inventories.

GHG monitoring is no singular effort but a continuous process that can be improved over time; it can be complex and requires technical and personnel resources. Nonetheless, in the end, competence and experience achieved over the process will ensure sustainable results and practical knowledge about your city's GHG emissions and their main sources.

In this chapter approaches to determining the main parameters for GHG monitoring are explained in detail. Different monitoring objectives require different levels of accuracy, different results and a different scope of underlying transport activities. This implies different requirements for data and for local data sources. Unfortunately, data availability and the capacity for handling data collection are often limited. As a consequence, simplified calculations are sometimes done, even though a highly differentiated GHG monitoring would be advantageous.

In order to cope with different requirements and capacities, this guide recommends a methodology with three alternatives (see also Figure 12):

1. **The 'basic approach'** enables an initial start on GHG monitoring when data availability and knowledge about GHG relevance of transport activities are still limited. Calculations are mainly based on non-local default values and can result in inventories based on inhabitants rather than the territory.
2. **The 'advanced approach'** should be adequate for most cities. Calculations are done with locally specific parameters and for the territory with reasonable accuracy and level of detail.
3. **The 'developed approach'** has high requirements for data availability, but in turn provides a high accuracy of monitoring results and meaningfulness for demanding monitoring objectives.

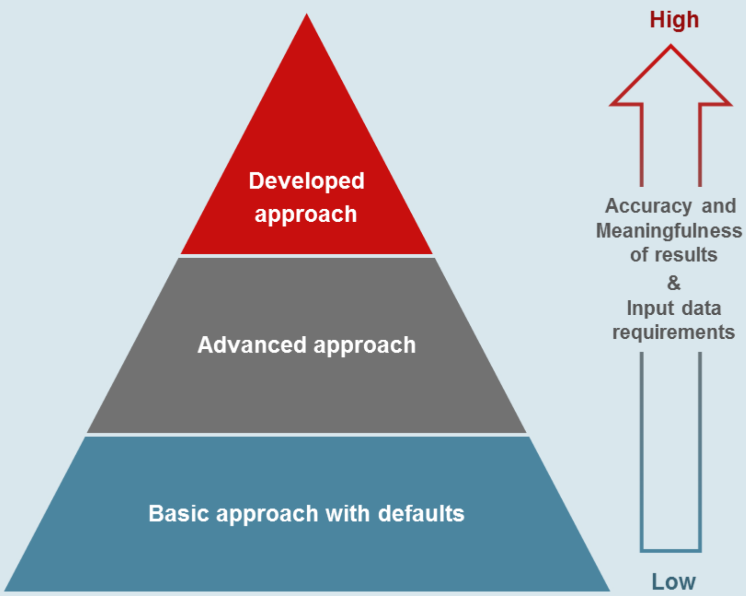


Figure 12: General methodological approach for determining transport activities for GHG monitoring

In many cases it is necessary to make a decision on whether monitoring will be based on limited data and default values making the results less accurate or whether additional data can be collected (e.g. to become more accurate or meet requirements for selected boundaries), causing more efforts and costs but resulting in much better information.

It is also possible to combine the above three approaches for different parameters, using the more detailed approaches e.g. for modes for which more data is available or the high share of emissions warrants larger efforts for data collection.

All options will, in most cases, require cooperation with official authorities and institutions or with specialized organisations for certain topics (e.g. vehicle activity surveys or traffic counting). Which data sources exist and are adequate for the data requirements and which organisations should be involved in data provision can vary considerably between cities. Improving data availability is a continuous task in the GHG monitoring process. Once additional data sources are available or new data is collected through surveys, the calculation methodology can be improved.

In some cases changing data sources will lead to changing monitoring boundaries, e.g. improvement form annual total vehicle mileage data to territorial data of road transport activities or changing from tank-to-wheel to well-to-wheel emission factors. In these cases, statistics and emission reports must make these methodological changes explicit. If possible, recalculating former years should be considered to make data comparable over time, but this will only be feasible in few cases.

Overview of data requirements for annual monitoring

The following graph summarises the basic data categories for annual monitoring of road transport-related GHG emissions (in dark blue), using the CRTEM/HBEFA China expert version. Data to assess rail transport-related emissions has to be collected in addition to that. Ideally, data in dark orange should be city-specific, but as fall-back default values are included in the model. The pictures on the right represent the different modules of the emission model.

All data can be collected at different levels of detail with different approaches as explained in the following sections in the main text.

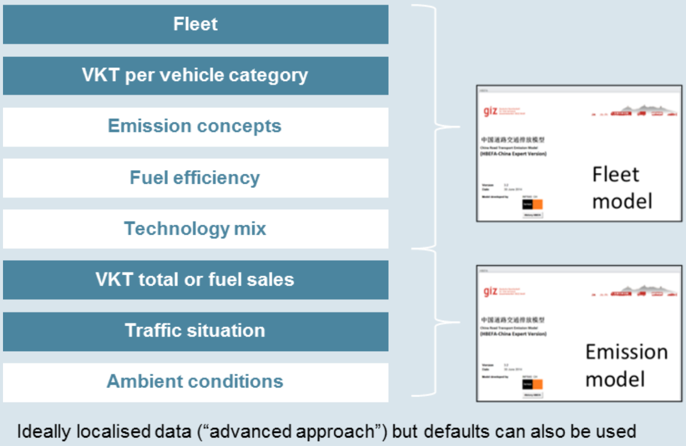


Figure 13: Input data for emission calculation in HBEFA (Source: INFRAS 2014)

The following sections explain the three different calculation approaches for road transport activities and fleet composition, respectively; public rail transport is dealt with in a separate chapter. The explanations include general characteristics and calculation procedures for the base year and for monitoring updates in future years, complemented by required data and possible data sources.

2.1. Calculating road transport activities

GHG monitoring of road transport usually covers several vehicle classes - particularly passenger cars, light and heavy duty trucks. It can also include taxis, buses, motorcycles and electric bicycles. Appropriate calculation approaches have to be identified individually for each vehicle class covered in the monitoring. There is no need to choose the same approach for all classes, where more data is available, a more advanced approach can be applied.

Figure 14 defines the characteristics of the three approaches to calculating urban road transport activities.

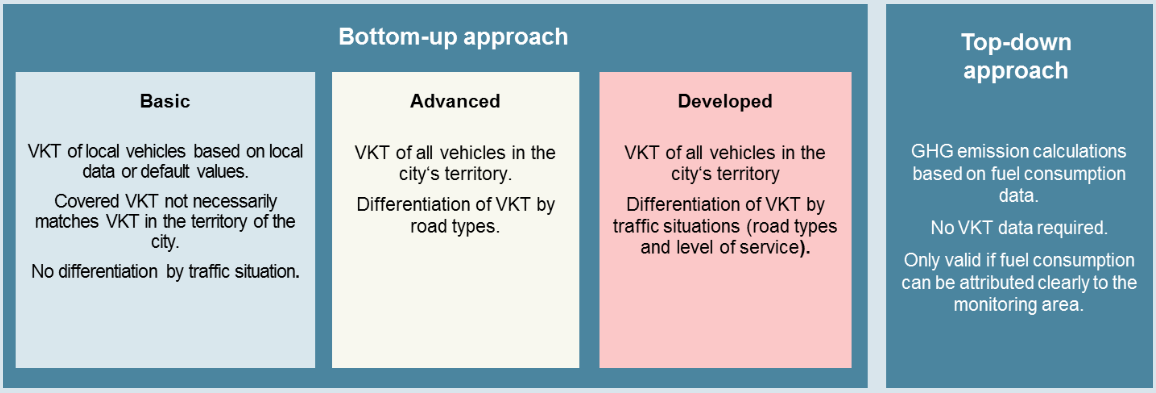


Figure 14: Definition of calculation approaches for road transport activities

In the **basic approach** the calculation of road transport activity in the monitoring area is based on vehicles kilometres travelled (VKT) from registered vehicles. The VKT is calculated by multiplying the number of vehicles by average values of vehicle activity (average annual mileage per vehicle) based on city-specific surveys or on default values. Aggregated average GHG emission factors without differentiation of traffic situations are applied.

Alternatively, VKT can be calculated based on mobility data of the inhabitants in an area. In this case, the VKT is calculated by multiplying the number of inhabitants by inhabitant mobility (number of trips and average trip lengths divided by the load factor) based on city-specific surveys or on default values and then multiplied with aggregated average GHG emission factors.

The calculation result does not necessarily correspond to the recommended territorial approach. For large monitoring areas, the VKT of inhabitants is roughly comparable to the VKT in the territory (most trips take place within city boundaries). However, for smaller territories, the VKT of inhabitants differs from those in the territory, mainly due to a significant contribution from external visitors or due to travel activity of the inhabitants outside of the monitoring area (e.g. commuting to a larger city nearby).

In the **advanced approach** the calculation of the VKT of a vehicle category within the boundaries of the monitoring area is differentiated by road types, but not by level of service (LOS). For the GHG calculations aggregated emission factors per road type are applied, which include default shares of LOS.

Using the **developed approach** the total VKT is differentiated by road types (expressways, major and minor arterial roads, branch roads) and by level of service within each road type (free-flow, heavy, saturated, stop-and-go, heavy stop-and-go). By the developed approach the highest city-specific differentiation of total VKT by traffic situations is achieved.

In mountainous regions medium road gradients should be estimated for all road types in approach B and C.

Top-down calculation: If the total fuel consumption of a vehicle category is known, GHG emissions can be calculated directly based on these fuel consumption data and no VKT calculation is required. A top-down approach is only valid if the fuel consumption can be attributed clearly to the monitoring area, e.g. if a bus company only runs in the monitoring territory and has data on the total fuel consumption of its bus fleet. Following this approach, however, does not render any information on transport activities, which may be helpful for comparing different transport modes and analysing mitigation measures.

2.1.1. Road transport activities by basic approach

The annual VKT for the city (vehicle-km/year) is calculated based on the activity of registered vehicles (Figure 15), using vehicle inspection data or VKT surveys.

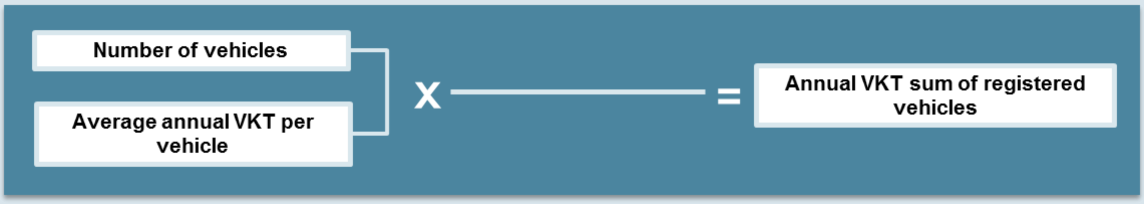


Figure 15: Calculation function for road transport activities in the basic approach (Source: IFEU 2014)

As mentioned before, the basic approach renders VKT data according to the vehicles of inhabitants; it therefore does not necessarily match the territorial boundary of the city (illustrated in Figure 16).

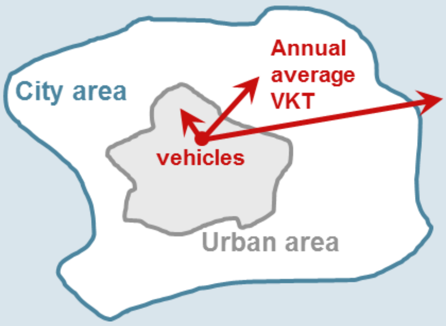


Figure 16: System boundary of VKT calculation in the basic approach (Source: INFRAS, 2015)

Basic approach – updates in future monitoring years

In future monitoring years, transport activities will be calculated using the same data sources and calculations as for the base year.

City-specific data (number of vehicles) have to be determined for each update year.

City-specific surveys on vehicle activity are ideally repeated every year. In order to reduce updating efforts, full surveys are often only repeated every five years. A complementary survey with a small sampling size can indicate if there are unexpected short-term changes in mobility behaviour, which should be taken into account. Activity data is always gathered from the most recent available year.

If default data (e.g. national average values) for vehicle activity are applied instead of city-specific data sets, it is also necessary to make sure that most recent data is used in update years, including yearly changes in the number of vehicles.

2.1.2. Road transport activities by advanced approach

The advanced approach is more attached to the actual city's road network than the basic approach. At first it should be verified that the analysed road network matches the geographical boundaries of the designated monitoring area (e.g. city districts). This way, the advanced approach renders VKT data in the city territory (illustrated in Figure 17).

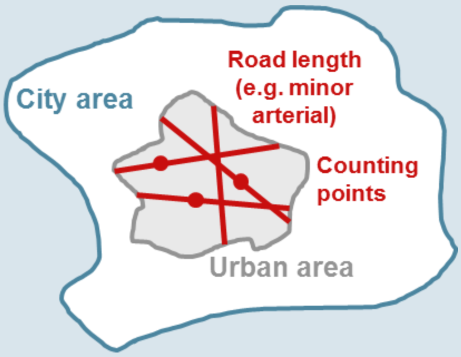


Figure 17: System boundary of VKT calculation in the advanced approach (Source: INFRAS, 2015)

The VKT within the territory is then calculated based on local traffic data gathered through traffic counts (Figure 18).

If **traffic counts** are used to determine VKT, counting needs to be done on several road sections of each road type. The number of traffic counting stations depends on the size of the monitoring area. Furthermore, traffic counting needs to be done individually for each vehicle category (car, truck, motorbike) since traffic shares and daily variations of different vehicle categories (passenger cars, trucks, etc.) are road-specific.

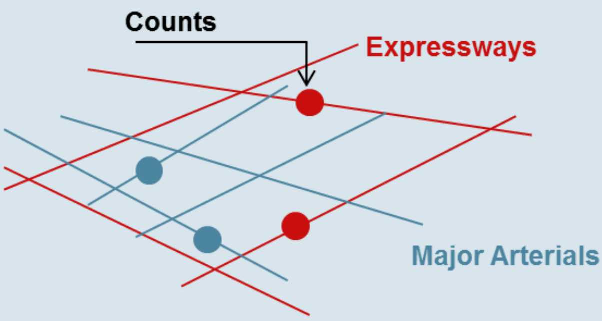


Figure 18: Traffic counts on different road types (Source: INFRAS 2015)

In order to get comprehensive estimates for the daily number of vehicles, traffic counts should cover a 24-hour period or at least different time spans during a weekday (peak-hours, off-peak, night hours) and, if possible, traffic changes on weekends (or e.g. related to seasons). The counted daily average number of cars is then multiplied with the road length of each respective road type to calculate total VKT per road type (see Figure 19).

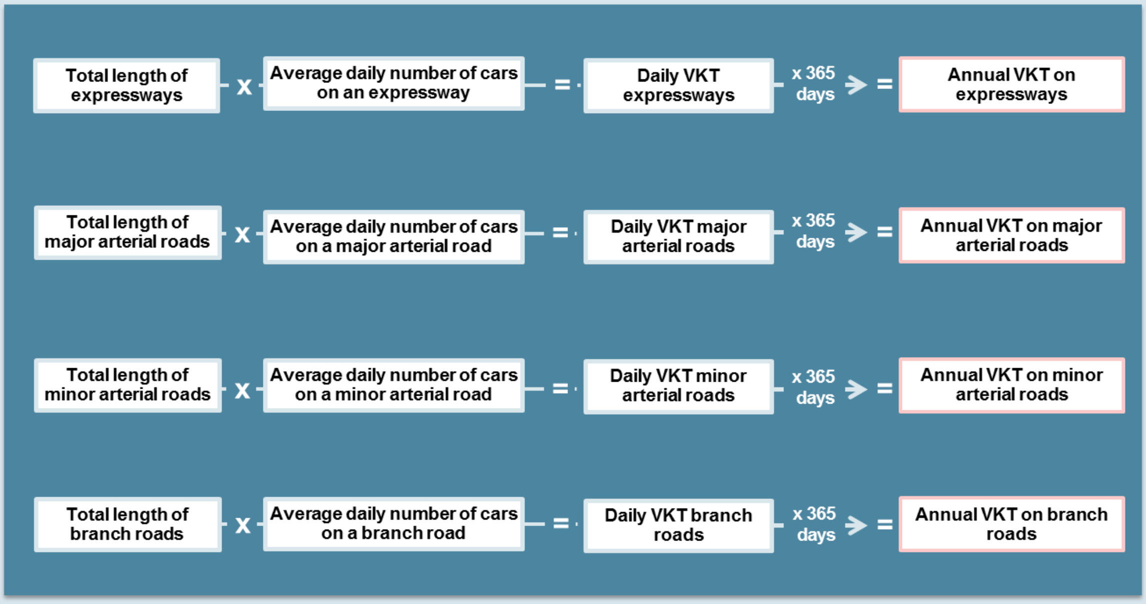


Figure 19: Calculating road transport activities in the advanced approach based on traffic counts (Source: IFEU 2014)

Alternatively to traffic counts, local traffic data can be provided by a travel demand model. Post-processing of traffic data from a travel demand model may needs the following calculations.

From peak-hour traffic to average daily traffic: Many travel demand models only provide the number of cars for the peak hour per road link. The so-called K factor (design hour factor) indicates the ratio between peak hour and the average daily traffic and can be used for calculating daily traffic volumes based on peak-hour values. The K factor value varies between roads and should ideally be determined individually for different road types (e.g. with 24 hour traffic counting). If this is not possible, a default value of 10% (i.e. peak-hour-traffic makes up 10% of daily traffic) may be used as a first approximation.

From daily VKT to annual VKT: Most travel demand models provide data for weekdays. Multiplying the daily VKT of weekdays by 365 days doesn't cover deviating traffic amounts on weekends. But this simplified procedure can be reasonable in situations where no detailed information on VKT changes on weekends is available. If information about traffic on weekends is available, a more refined calculation of the annual VKT is recommended:

$$Annual\,VKT = 365 * \frac{[5x\,VKT_{mo-fr}] + [1x\,VKT_{sa}] + [1x\,VKT_{su}]}{7}$$

Seasonal variations of the daily VKT during the year could also be considered for calculating the annual VKT, if appropriate information is available.

Advanced approach – updates in future monitoring years

If the extensive traffic counting approach cannot be updated regularly, VKT developments can be calculated with relative (percentage) developments against the base year using simple indicators. Such indicators might be available for each road type (e.g. by traffic counting on a selected minor number of road sections) or applied only to the overall traffic development (e.g. by raising the number of registered cars).

Fewer traffic counting sites can be used after the base year in order to reduce the amount of work, but should still cover each road type adequately. To calculate relative developments, traffic counting data from the monitoring year have to be compared with the base year data for the same site and time period. A simple method for rough estimates of traffic changes is to compare relative developments of the total number of registered cars. However, this only provides estimates on total traffic development - not on individual developments per road type.

If a regularly updated travel demand model is used, transport activities in future monitoring years can be calculated by directly implementing the current data. Usually, however, travel demand models are only updated every few years, not on an annual basis. Where travel demand models exist, data from the model can be used each time the model is updated, e.g. every five years, but not for annual monitoring – data from the travel demand model can then also be used to triangulate emission calculations based on traffic counts.

2.1.3. Road transport activities by developed approach

In the developed approach the VKT in a territory is calculated with a high degree of accuracy based on traffic situations: The developed approach considers road types as well as the level of service. VKT per road type is determined as in the advanced approach described above. The LOS shares depend on the city, its traffic activity and its traffic management but also on the specific time of day, month and season. The percentage shares of different LOS within each road type are determined using floating car data (see Table 4).

Updating the LOS share in future monitoring years requires the same data sources and calculations as for the base year.

Table 4: Data sources for VKT and LOS shares per road type in the developed approach

Data sources	Basic data
Floating car survey OR	Vehicle speed of cars for different hours of the day for each road section
Taxi GPS data and GIS model of the road network	GPS data on location and speed of taxis over the day Mapping of GPS data to the road network and attribution of road types to the vehicle speed data
Data source for daily traffic variations (e.g. 24 h traffic counting)	Variation of traffic volumes over the day for each road type

To determine percentage LOS shares you have to determine the LOS of each hour (comparison of the average speed of floating cars, namely GPS taxis, for each road type with predefined LOS speed ranges e.g. form HBEFA), followed by determining the LOS shares of total VKT, i.e. summarise VKT shares of all hours with the same LOS (see Figure 20).

In order to correctly convey the hourly road-specific LOS classification to the daily VKT, a 24-hour traffic distribution is required for each vehicle category. This data can be obtained, for example, from 24-hour traffic counts. Alternatively, default daily traffic variation curves can be used if available (e.g. from official road construction guidelines).

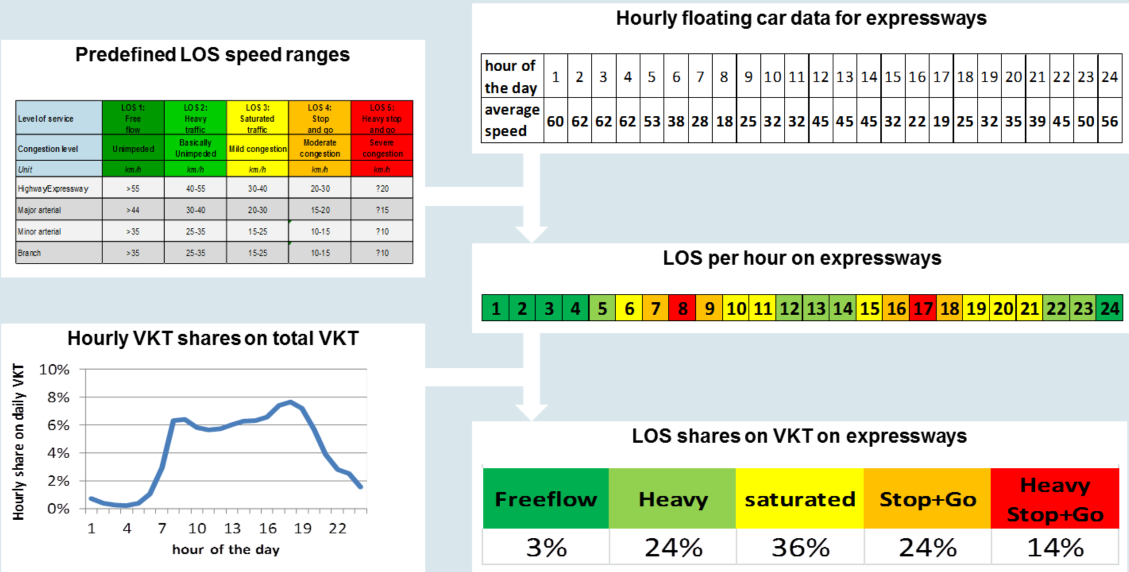


Figure 20: Example for determining LOS shares of road transport activities in the "developed approach" (Source: IFEU 2014)

Similar to the advanced approach, the developed approach, too, can make use of a travel demand model, which provides VKT differentiated by road type and by LOS. In this case, the model results can be directly transferred into a GHG calculation model (e.g. CRTEM/HBEFA China expert version). However, for monitoring years the same limitation applies that travel demand models are typically only updated every five years and can therefore only be used for monitoring in their update year. In these years, travel demand models provide an excellent source for data validation of the developed approach based on traffic counts and floating car data.

2.1.4. Top-down approach for public bus activities

GHG emissions can be calculated directly based on fuel consumption of a vehicle category. In this case no VKT calculation is required. This approach can be reasonable in particular for public transport activities if energy consumption statistics of public transport operators are available. However, a top-down approach is only robust if the fuel consumption e.g. of public buses can be clearly attributed to the monitoring area.

Since no information on VKT is gathered with this approach additional bottom-up analyses of transport activities is necessary if comparisons of specific GHG emissions or analyses of mitigation potentials is required, e.g. of a modal-shift from passenger cars to public buses.

Based on fuel consumption, only CO_2 emissions can be calculated accurately. For other greenhouse gases and air pollutants additional information on the fleet composition (vehicle size, emission concepts) are required. When using HBEFA, currently only direct tailpipe CO_2 emissions (tank-to-wheel) are calculated; information on well-to-wheel emissions is not yet included in the database.

Data requirements for the top-down calculation of public bus emissions are the total annual fuel consumption by fuel type, if available differentiated by bus route in the monitoring area. The data source is local transport authorities or bus companies. The fuel consumption data (e.g. in litres of fuel, Mega-Joules, etc.) is then directly entered into a calculation tool (e.g. HBEFA) to render the total GHG emissions or GHG emission per route.

The top-down approach can also be used to enhance the reliability of bottom-up calculations by comparing the results. Ideally, results should be very similar for the two approaches. If the two approaches deviate significantly from one another, the data used in both calculations should be carefully scrutinised to identify possible mistakes. Note that when comparing results, possible deviations in system boundaries between the two approaches and other effects, such as fuels bought within the monitoring boundary being used outside of it (or vice versa), need to be taken into account.

2.1.5. Summary: Collection of data for road transport activities

Comprehensive collection of data is a precondition for credible GHG monitoring results. As mentioned before, the choice of the most suitable calculation approach for each vehicle category also depends on data availability and the resources to collect additional data. The following table summarises the required basic data for determining road transport activities in each calculation approach and gives data sources generally available to gather the respective data.

Table 5: Basic data for road transport activities

	Bottom-up approach			**Top-down approach**
	“Basic approach”	**“Advanced Approach”**	**“Developed Approach”**	
Required data	Number of vehicles Annual VKT per vehicle	*VKT per road type* Average traffic volume per road type Length of road network for each road type OR VKT (resp. traffic volume & length) for each road link	*VKT per traffic situation* VKT differentiated by traffic situations (road types + LOS) *LOS shares per road type (to enhance VKT per road type from advanced approach)* Floating car data over the day for each road type OR GPS data of taxis; mapping to the road network	Total fuel consumption of vehicle fleet (e.g. public bus) by fuel type Advanced: Additional differentiation by bus route
Possible data sources	<u>Base year</u> Local vehicle activity survey or main inspection data Statistics for number of registered vehicles <u>Update years</u> Update number of vehicles If possible: Update vehicle activity survey	<u>Base year</u> Traffic counts on selected roads Statistics of the road infrastructure OR Travel demand model with traffic modelling for the road network <u>Update years</u> Annual: Regular traffic counting on selected road sites Every 5 years: Update travel demand model	*VKT per traffic situation* Travel demand model with highly differentiated VKT data *LOS shares per road type* <u>Base year</u> Floating car analysis for the road network of the city OR Survey with GPS equipped taxis in the city <u>Update years</u> If possible: Update floating car data or taxi GPS survey	Transport authority, bus companies

2.2. Identifying the city-specific vehicle fleet and mileage distribution

The composition of a city-specific vehicle fleet strongly influences local transport emissions. The more private cars run the streets and the larger or older the vehicles are, the bigger their fuel consumption and the higher the related GHG emissions. In other words, GHG emissions depend on the vehicle fleet and on the distribution of VKT across the vehicle mix in the fleet.

If no local data on the fleet composition and VKT is available at all, a first back-of-the-envelope estimation can be done using aggregated GHG emission factors for each vehicle category considering a default fleet composition (based on national averages) and a default distribution of VKT across vehicle categories. Such estimation only informs about the rough magnitude of transport-related emissions based on the fleet size. Due to the lack of local data, the uncertainty is high. Such estimation does not serve to analyse local transport-related emissions, but it can provide a first rough orientation of the approximate size and share of transport emissions compared to other sectors.

In the **basic approach** the vehicle fleet is based on local vehicle registration statistics. If vehicle registration statistics provide numbers of registered vehicles by segment (i.e. by engine capacity in the case of passenger cars) and vehicle age, a locally specific vehicle stock by subsegments can be derived. In the basic approach, the VKT shares for different segments and age dependencies are based on default distributions. Default distributions are ideally based on national defaults derived from vehicle inspection and maintenance data or – if not available – on international defaults, for example those provided in HBEFA China. In short, the basic approach works with a local fleet composition but default annual mileages per segment or subsegment.

The **advanced approach** uses the local fleet composition as described for the basic approach, but in addition uses a localised annual mileage per segment or subsegment based on a VKT survey or local vehicle inspection data.

In the **developed approach** actual VKT shares of different subsegments per vehicle category are determined by analysing local traffic directly on the roads. Ideally this analysis is done separately for each road type.

Figure 21 summarises the three approaches to calculating transport emissions based on city-specific fleet compositions and mileage distribution.

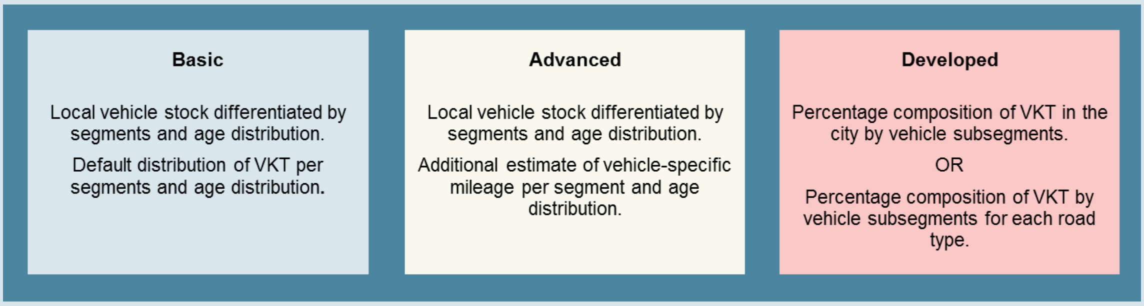


Figure 21: Definition of calculation approaches for city-specific fleet compositions & mileage distribution

2.2.1. Fleet composition and mileage distribution by basic approach

Based on the numbers of registered vehicles by segment and vehicle age a locally specific vehicle stock by subsegments is derived. This composition of the vehicle stock is entered into an adequate emission calculation model with default values for the VKT shares of different segments and for age dependencies, e.g. CRTEM / HBEFA China (see Figure 22).

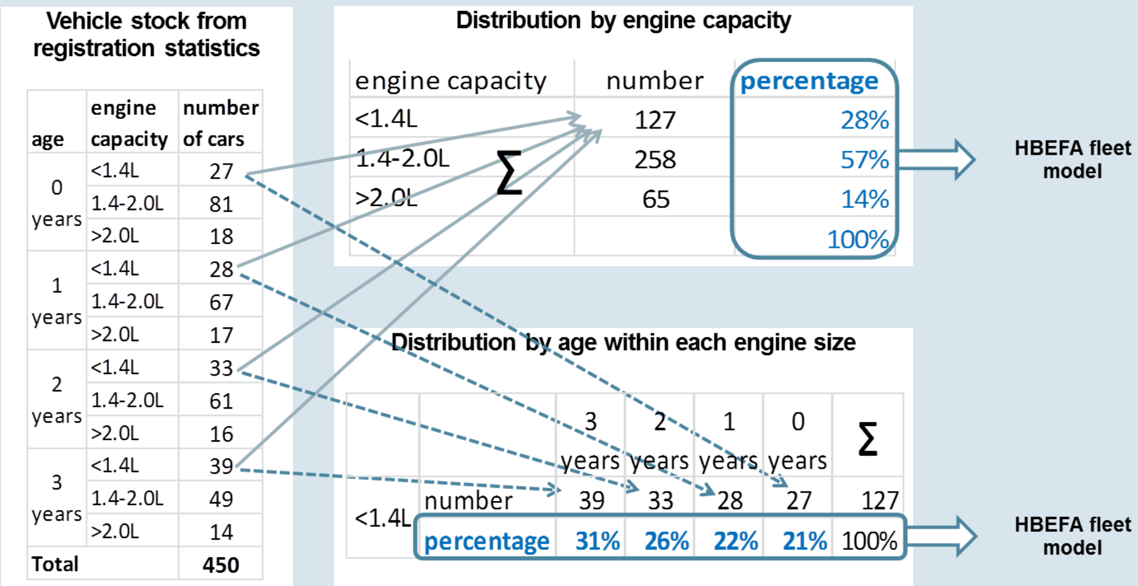


Figure 22: Calculation example for city-specific fleet composition in the basic approach

2.2.2. Fleet composition and mileage distribution by advanced approach

For the advanced approach, in addition to the local vehicle fleet, vehicle-specific mileage per segment and/or per subsegment in the local situation is needed. This information can be used for city-specific adjustments of values for the VKT shares of different segments and for age dependencies (see Figure 23).

Total vehicle numbers based on vehicle registration statistics are evaluated differentiated by size (e.g. engine capacity <1.4L, 1.4-2.0L, >2.0L) and vehicle age (0-15 years). The annual mileage of cars differentiated by size (e.g. engine capacity) and vehicle age is collected in a vehicle activity survey or vehicle inspection data. The real on road fleet composition is calculated in 4 steps (base year):

Step 1: Calculating percentage shares of cars with different size in the vehicle stock.

$$\% <1.4\,L = \sum_{0\,years}^{x\,years} number_{<1.4L} \,/\, number_{total\ stock}$$

Step 2: Calculating the age distribution within each engine capacity class.

$$\%\ 1\ \text{year}_{1.4L} = \text{number}_{1.4L,1year} \ / \sum_{0\ \text{years}}^{x\ \text{years}} \text{number}_{<1.4L}$$

Step 3: Determining average annual mileage per vehicle for each segment from the activity survey.

Step 4: Weighting of annual mileage for each segment

Calculations are updated in future monitoring years in the same way. Usually, vehicle activity surveys or central inspection data are not available annually. In order to reduce updating efforts, surveys can be repeated only every few years. For the interim years, average mileages per segment and age dependency within each segment are retained from the most recent available year.

If a vehicle activity survey is used to collect data on local VKT distribution, an adequate sample size needs to be met (for each vehicle subsegment), based on the local fleet composition. The statistical requirements for minimum sample size are:

$$\boldsymbol{n} \geq \frac{\boldsymbol{N}}{\boldsymbol{1} + \frac{(\boldsymbol{N}-\boldsymbol{1}) \times \boldsymbol{\epsilon}^{2}}{\boldsymbol{z}^{2} \times \boldsymbol{P} \times (\boldsymbol{1}-\boldsymbol{P})}}$$

Where:

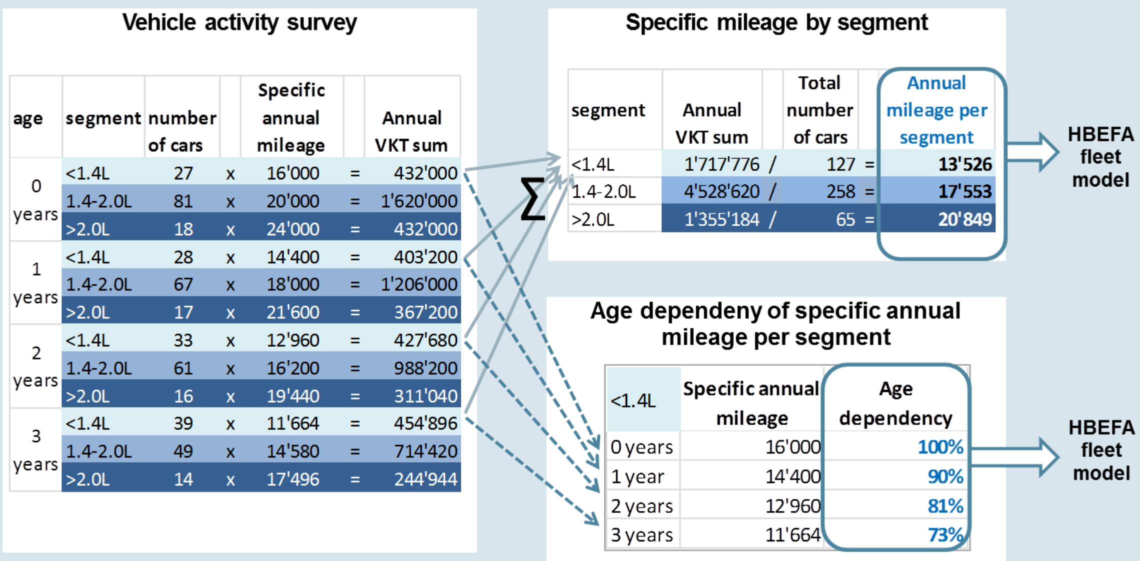
n = minimum sample size

N = total number of vehicles

s = maximum permissible error (in normal cases: 5% = 0.05)

z = confidence interval (95% → z = 1.96)

P = share of vehicle segment in total vehicle stock



Vehicle activity survey

age	segment	number of cars		Specific annual mileage		Annual VKT sum
0 years	<1.4L	27	x	16'000	=	432'000
	1.4-2.0L	81	x	20'000	=	1'620'000
	>2.0L	18	x	24'000	=	432'000
1 years	<1.4L	28	x	14'400	=	403'200
	1.4-2.0L	67	x	18'000	=	1'206'000
	>2.0L	17	x	21'600	=	367'200
2 years	<1.4L	33	x	12'960	=	427'680
	1.4-2.0L	61	x	16'200	=	988'200
	>2.0L	16	x	19'440	=	311'040
3 years	<1.4L	39	x	11'664	=	454'896
	1.4-2.0L	49	x	14'580	=	714'420
	>2.0L	14	x	17'496	=	244'944

Specific mileage by segment

segment	Annual VKT sum		Total number of cars		Annual mileage per segment
<1.4L	1'717'776	/	127	=	13'526
1.4-2.0L	4'528'620	/	258	=	17'553
>2.0L	1'355'184	/	65	=	20'849

→ HBEFA fleet model

Age dependeny of specific annual mileage per segment

<1.4L	Specific annual mileage	Age dependency
0 years	16'000	100%
1 year	14'400	90%
2 years	12'960	81%
3 years	11'664	73%

→ HBEFA fleet model

Figure 23: Calculation example for city-specific fleet composition in the advanced approach

The following box illustrates experiences with localising vehicle fleet composition and mileage distribution in the northern Chinese city of Harbin.

Experiences with localising vehicle fleet composition and mileage distribution in Harbin

Under the framework of the Low Carbon Transport Development component of the Sino-German Climate Change Programme financed by the German Ministry for Economic Cooperation, data on the local passenger vehicle fleet composition and mileage distribution were collected in the city of Harbin.

Table 6 below shows the distribution of the approx. 600,000 passenger vehicles in Harbin classified by vehicle age and engine capacity. This dataset was derived from the Harbin vehicle registration database maintained by the traffic management department and renders. Since registration data was not available in ready-to-use electronic format, considerable effort was required to transfer the data into excel sheets that can be imported into emission models, such as HBEFA China.

This vehicle fleet composition was then weighted with a localised VKT distribution (average mileage per vehicle category) based on a dedicated VKT survey of private passenger cars with a sample size of around 2000 cars. The VKT survey team interviewed private car users in different parking lots around the city.

Lesson learned: Although the overall sample size in Harbin was big enough for a representative sample, the sample size for each subsegment (of engine size and age) was not, with a concentration of samples in the 1-3 year old cars of an engine size of 1.4-2.0. This would have to be improved in future samples. In addition, data on taxis was not collected through the survey and had to be assessed separately.

Table 6: Age and size distribution of registered vehicles in Harbin, China (2014)

	Engine capacity		
Vehicle Age	**<= 1.4 l**	**> 1.4 & <= 2.0 l**	**> 2.0 l**
< 1 year	4,5%	13,5%	3,0%
1 year	4,6%	11,2%	2,8%
2 years	5,6%	10,3%	2,7%
3 years	6,5%	8,3%	2,4%
4 years	6,6%	7,4%	1,7%
5 years or older	3,2%	4,3%	1,3%

2.2.3. Fleet composition and mileage distribution by developed approach

A reliable methodological approach for determining city-specific fleet compositions is to analyse the actual local traffic directly on the road e.g. by video capturing of licence plate information (Table 7). Ideally, this analysis of local traffic is done on major roads in city centres as they represent a large share of traffic and fleet composition on other roads will not vary considerably.

The developed approach requires a high level of expert knowledge. This monitoring guide can therefore only give a first overview on the basic steps of this methodology.

Table 7: Data sources for mileage distribution based on actual traffic

Data sources	Required data
Traffic counting with video capturing in selected roads	Licence plate data for all vehicles passing the analysed road section
Vehicle registration statistics	Attribution of vehicle subsegments for all captured licence plates

For calculations in the base year, first licence plates are video captured when passing each selected road section (of different road types) in the defined time span. The time span should consider the variation of traffic during the day and on weekends. Then, vehicle subsegments can be identified for all vehicles by comparing the captured licence plates with specific information for the individual vehicles from vehicle registration statistics. Finally, the percentage shares of all vehicle subsegments for each road types are calculated. For calculations in future monitoring years, the licence plate survey is updated regularly.

2.3. Identifying adequate emission factors for road transport considering traffic situations and fleet compositions

As mentioned before, emission factors per VKT depend on vehicle and driving characteristics, as well as local geographic and climatic conditions. Emission factors can be highly disaggregated or summarised to one average emission factor per vehicle category for average fleet composition and average traffic situation – or any aggregation level in between. The emission factors used need to match the level of differentiation in the monitoring approach.

In order to monitor local GHG emissions from road transport, generally the advanced or the developed calculation approach should be considered for VKT as well as for fleet composition.

If detailed local emission factors are available as is the case in HBEFA China (cf. Figure 9 and 10 on differentiation by fleet composition and LOS), average emission factors can be generated at any level of aggregation to match the chosen calculation approach and data availability regarding local vehicle fleets and mileage distributions. Different calculation approaches can be combined for VKT and fleet composition. Imagine the following hypothetical example: Local VKT is calculated based on traffic situations (road types and LOS) (developed approach), but no information on the local fleet composition is available (basic approach, using a default national fleet composition). In this case, the

GHG calculation combines VKT as per developed approach with fleet data as per basic approach, requiring emission factors differentiated by traffic situation, but aggregated for a default fleet composition.

Figure 24 illustrates different aggregation options of emission factors, in this case for passenger cars in the category 1.4-2.0 l engine capacity. The chart on the left shows emission factors differentiated based on levels of service and road types. The chart on the right shows the respective aggregated emission factors: One average over all road types and LOS, averages per road type (averaged over LOS) and averages per LOS (averaged over road types). The same can be done for all vehicle segments and also weighted by mileage per vehicle category.

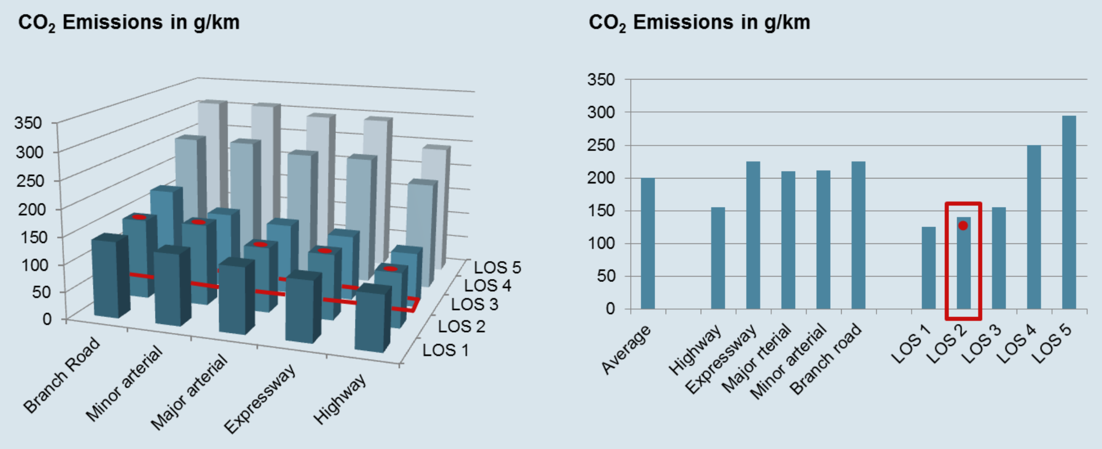


Figure 24: CO_2 emission factors for passenger car 1.4-2.0 l in HBEFA China (Source: INFRAS, 2013)

Calculation approaches are also independent for each vehicle category, meaning that different calculation approaches can be applied for each vehicle category, depending on respective data availability. For example, often more detailed data is available on passenger cars than on urban freight trucks, allowing a developed approach for passenger cars, but only a basic approach based on averages for trucks.

If detailed local emission factors are not available one has to decide whether to use a more aggregated approach (national averages are usually available at least at the level of vehicle categories) or whether an adaptation of international emission factors, such as those from the European Handbook for Emission Factors for Road Transport, to local driving situations is warranted and possible. In China, this has already been done for passenger cars and explained in the box on adopting HBEFA to local conditions (page 17). Using default values instead of local characteristics always increases uncertainties; the more default values are used the higher the uncertainty of the accuracy of emissions calculations.

Wherever cities are required to monitor and report their transport-related emissions regularly, it is worthwhile adapting detailed emission factors to country-specific traffic situations. That is why the China Road Transport Emission Model / HBEFA China includes a 5th level of service called 'heavy stop-and-go traffic' while the European version of HBEFA only has four traffic situations. However, it is not recommended to define city-specific traffic situations that are no longer comparable. Instead, the city-specific *distribution* of nationally defined levels of service should be identified.

In the CRTEM, the appropriate differentiation level of GHG emission factors is automatically applied for each vehicle category based on the user-specific data input for VKT and fleet composition.

For calculating emissions in the developed approach a software tool with such functionality is recommended to handle the significant amounts of data. In other countries than China - if differentiated emission factors do not exist - then calculations can only be made on aggregated level for each vehicle category.

2.4. Calculating public rail transport activities

For emission calculations, public rail transport activities, similar to bus transport activities, are usually assessed top-down, based directly on energy consumption data – if total final energy consumption (electricity, diesel) is known. In this case, no calculation of transport activities is required. Same as for public bus activity, a top-down approach is only valid if the final energy consumption can be clearly attributed to the monitoring area.

Since in the top-down approach, no information on transport activities is gathered it does not allow comparisons of specific GHG emissions of different transport modes or analyses of mitigation measures due to modal shift. In order to do that, additional information on transport activities is needed.

The best and easiest way to calculate VKT (train-km) or pkm of relevant public rail modes is by using additional data from local public transport companies. By dividing total energy consumption by activity data, intensities per pkm can be derived. Data should preferably be differentiated into electric and diesel trains.

Table 8: Data for public rail transport activities

Required data	Data sources
Total annual final energy consumption by energy type (differentiated for each rail route). Total number of pkm based on user data (IC-card readings).	Transport authority, public rail companies (incl. IC card data)
Grid emission factors of local electricity mix	Official emission factors for local electricity grid (published by NDRC in China)

Calculation procedures and required data are the same in the base year and in update years. Emissions are calculated by directly multiplying the final energy consumption data (e.g. kWh electricity, litres diesel) with the country-specific GHG emission factors of each final energy carrier for the respective monitoring year. Slightly more differentiated data can be generated by sorting energy consumption data according to specific rail routes in the designated monitoring area and then multiplying the sorted energy consumption data with respective GHG emission factors. If the public rail network reaches beyond the boundaries of the monitoring area, transport activities outside the area should be excluded from calculations if separate information for each route is available.

If information on energy consumption and emissions per passenger-km are needed to assess measures, energy data is divided by total passenger kilometres, which are collected through IC-card use in China (or alternatively customer surveys).

3. Reporting

An essential part of GHG monitoring is a regular reporting of monitoring results (e.g. every year) and a discussion of the emissions development compared to the base year. Only with clear and transparent reporting, processes and results become comprehensible and comparable. If a city has defined emission reduction targets for the transport sector, annual or bi-annual monitoring reports can advise decision-makers as to whether the development is in line with the set targets or if adjustments are needed.

Reporting nowadays not only includes printed products, but also electronic reporting formats. By publishing monitoring results and related data online, accessibility of the data is improved – many more readers can reach the information in a shorter period of time, from anywhere.

3.1. Contents of a monitoring report

Monitoring reports usually start with introducing objectives of the GHG monitoring and summarising the intended use of the results. The key part of a monitoring report is the presentation and analysis of GHG emissions calculations. In order to make a monitoring report comprehensible and interpretable by outsiders it is important that the methodology is clearly described. This includes:

- The monitoring boundaries used and reasons for their definition
- GHG calculations and the used approaches for each means of transport, pointing out if there have been methodological changes from one year to the next
- Overview of data sources for transport activities and GHG emission factors
- Explicitly pointing out any assumptions
- Discussion of the accuracy or uncertainty of the applied monitoring methodology and data used, for example if default data is used instead of local data in some areas

Monitoring reports usually include the following sections:

Introduction of objectives: The first part of the monitoring report should explain the general background on why the GHG monitoring has been undertaken. It is especially important to explain the intended further use of the results, e.g. to fulfil national reporting requirements or those of (inter)national funding programmes.

Explanation of monitoring boundaries: In this section the monitoring boundaries are documented, including system boundaries, means of transportation and covered GHG emissions (CO_2 equivalents, well-to-wheel). The documentation of monitoring boundaries also includes information on the reasons for their definition. If limited data availability has been a crucial factor for defining boundaries that are not fully compatible with the objectives, consequences for the further use of monitoring results should be discussed as well.

Explanation of the calculation methodology: Methodological explanations include the used calculation approaches and procedures for transport activities, fleet compositions and related emission factors for each monitored vehicle class (passenger cars, trucks, taxis, buses, urban rail).

Since different calculation procedures (options depending on data availability) affect the results, consequences of the chosen approach for the accuracy and meaningfulness of the monitoring results should be discussed; caveats should be made transparent.

Documentation of data and data sources: Documentation of the used transport data and GHG emission factors provides an overview of parameters like data type, definitions (e.g. of vehicle classes if more aggregated data is used), unit and temporal resolution; it also notes the organisations providing the data sets or the data collection methodology. Additional information e.g. on update frequency may also be provided (see Table 9). If own data collections are conducted the applied procedures should be explained in more detail.

An issue of special relevance is the assessment of data quality. This includes being transparent on whether locally specific data is used or not, e.g. national averages vs. city-specific yearly VKT per car and on data accuracy, e.g. based on the sample size in data collections.

Table 9: Example for a structure of the documentation of data in the GHG monitoring

Parameter	Description
Data unit	incl. temporal resolution
Description	Description of the parameter and its definition (e.g. well-to-wheel for emission factors or drive concept for passenger cars…)
Source of data	e.g. statistical office
Monitoring Procedures	Relevant in case of own data collection
Data quality	Accuracy and local relevance of the parameter
Update frequency	e.g. yearly, every five years
Comments	Lessons learned?

Presentation and discussion of calculation results: The final step in the first monitoring report is the presentation of GHG calculation results in tables or figures with explanations and discussions. This includes, for example, the identification of the main contributors to total GHG emissions in the monitoring boundaries and a discussion of possible improvements to calculation results in future monitoring periods.

An example for the possible presentation of GHG monitoring results is given in Figure 25. It is based on results from the German city Frankfurt/Main.

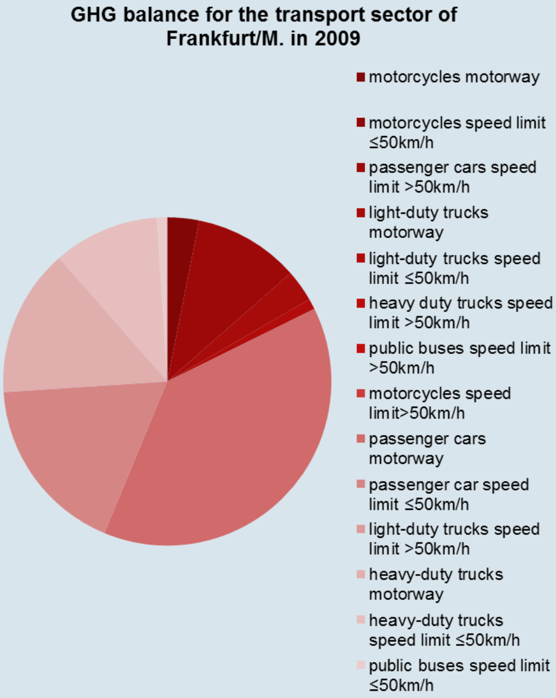


Figure 25: GHG monitoring results for the transport sector by road type in Frankfurt/M. (Germany) (Source: IFEU 2012)

3.2. Regular updates of GHG monitoring reports

Since monitoring of GHG emissions is no singular project but a continuous task, reporting the process and results includes regular updates. The updates do not necessarily require such extensive explanations on monitoring objectives, boundaries, methodology, and data sources as in the first monitoring report, except where changes were made. However, a short summary on these aspects should be included with reference to the first monitoring report.

When a GHG monitoring process begins, the availability of high quality, locally specific data is often still limited so early monitoring may start with a basic approach, improving data availability over time in order to improve the monitoring results. If resources for more substantial data collection are available, e.g. in internationally financed GHG mitigation projects, monitoring should start at least from an advanced approach. Adjustments to the monitoring methodology, consequences for accuracy of results and, especially in the case of changed monitoring boundaries, impacts on consistency over time have to be discussed in the GHG monitoring reports.

The interpretation of monitoring results in the update reports includes identifying main contributors to total GHG calculations in the recent monitoring year and analysing the GHG emissions development related to the base year for the particular means of transportation and for the whole GHG emissions within the monitoring boundaries. If a monitoring methodology and boundaries are changed from one year to another, consistency in the time series also has to be discussed.

List of tables

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