iCET, Aug 2015

Calculating Urban Transportation Emissions: Private Vehicles

Lessons from existing tools' development, design and implementation

This report is part of a project designed to equip Chinese urban policy-makers with a City Transport Emission Calculator that will assess vehicle emissions levels in the city, given varying policy measurements' impacts on fleet composition and efficiency.

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Acknowledgements

The project is jointly executed by the Innovation Center for Energy and transportation (iCET), Tsinghua University Shenzhen Graduate School, China Urban Sustainable Transportation Research Centre (CUSTReC) of China Academy of Transportation Sciences (CATS) and E4Tech. The authors of this report extend their appreciation to the following organizations for their valuable advice and inputs: World Research Institute (WRI), German Developmental Institute (GIZ), Vehicle Emission Control Center (VECC) of MEP, and China Automotive Technology and Research Centre (CATARC).

Disclaimer

We are gracious for the generous support of the Rockefeller Brothers' fund, Blue Moon Fund, and the UK-Strategic Prosperity fund (SPF); Views expressed throughout this work are the authors' alone and do not represent the supporter's views.

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1. Introduction

Over the past two decades, climate change triggered the emergence of various transportation emissions measurement tools aimed at guiding policy-making towards more sustainable urban development. As transport accounts for over a quarter of GHG and have significant contribution to urban air pollution, mainly in developing countries, curbing emissions from on-road transportation may arguably result in impactful air quality improvement. Between 1980 and 2012, the carbon dioxide emissions in China's transport sector increased approximately 9.7 times, with an average annual growth rate of 7.4% (Xu & Lin, 2015). China's transportation is highly energy consuming and pollution-intensive, and has been identified as a crucial source of urban PM2.5[1] (Beijing Environmental Protection Bureau, 2014).

Recognizing the role transport plays in China's severe air quality issues, in recent years the central government introduced several mitigation targets. These include the 12th Five Year Plan (2011 – 2015) calling for the transition to low-carbon economy. In the private transport sector, the plan translates to overall energy consumption intensity reduction of 6%, and carbon intensity reduction of 7%. The Action Plan for Air Pollution Prevention and Control, announced in September 2013, targets the reduction of average PM10 in large cities by 10% between 2012 and 2017. Three strategic corridors of economic development, the Beijing-Tianjin-Hebei corridor, the Yangtze River Delta corridor and the Pearl River Delta corridor – a PM2.5 reduction target of 15 - 25% has been announced (Ministry of Environmental Protection, 2013).

Subsequently, China's national and local governments are seeking evidence-based decisions on transport policy, without which transportation development and management would rely on inaccurate measurements that would in turn hinder the transition towards effective low-carbon city transportation. There is a vital need to measure transport emissions and PM2.5 levels accurately during the national plan implementation period and going forward for achieving meaningful air quality improvements. This report is part of a project design to equip Chinese urban policy-makers with an Urban Transport Emission Calculator that includes GHG emissions (CO2e) and major pollutants (e.g. PM2.5) from private vehicles, one of three major urban transport segments.

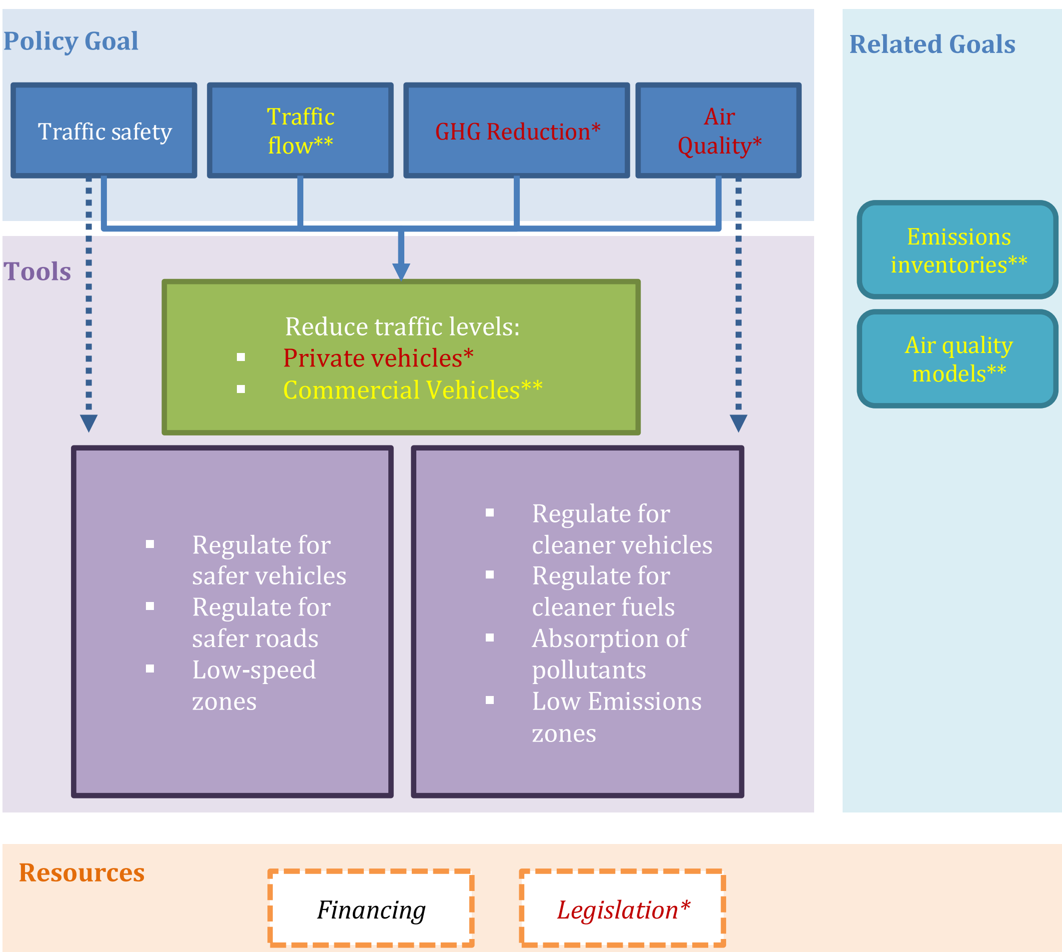
Since private vehicles are argued to have greater impact on emission reduction than freight transport due to the surge in private car population and its low energy efficiency (Xu & Lin, 2015), the private vehicle segment was chosen to be introduced prior to the public and freight urban on-road segments. Although private vehicle emission levels and fuel consumption has being regulated in the past three decades, fleet emission levels measurement has become more complex. This is mainly due to the fact that exhaust gas after-treatment systems increase the difference between individual vehicle emissions and therefore decrease the prediction power of modeling approaches (De Haan & Keller, 2004). The system effectiveness decreases when treatment system is cold therefor a split between warm and cold emissions is also required for arriving at satisfying results, making effectiveness more complex to model.

[1] And NOx; Both mainly from (Diesel) vehicles pre China 5 (EURO VI).

This report is designed to provide context to the Urban Transport Emissions Calculator and screen existing modeling approaches for devising effectiveness. The report provides a synthesis review of tools that were developed for the purpose of measuring urban transport emissions towards more informed policy-making. Transportation policies can be derived from different goals and objectives; however tools employed may provide a partial solution to several policy-making targets altogether. Although this report is aimed at setting the scene for passenger vehicle transport GHG and pollutant reduction policies on the urban level, the calculator could potentially contribute to: (i) the assessing various policies that have an impact on fleet structure, (ii) pollution and GHG impact prediction of policies considered, and (iii) impacts of vehicle technologies and travel behavior. Going beyond transport planning, a transport calculator could provide inputs to inventories databases (which are necessary for reporting requirements) and contribute to air quality models.

The report highlights the objectives of various transport policy emissions measurement tools, reviews available frameworks and methodologies globally and in the specific case of China, as well as stresses limitations of and lessons from previous similar work.

Figure 1: Transport Policy Objectives and Major Strategies



Note:
Marked * are at the center of the Urban Transport Emissions Calculator's goals;
Marked * are potential City Transportation Emission Calculator's beneficiaries.

Source: Adapted from Jones et al., 2014

2. Review of transport emissions policy motivations and tools employed

There is a wide selection of existing tools that are meant to capture the level of emissions from various transportation modes. These tools are typically designed to inform policy makers and consumers towards better decision making that will ultimately improve air quality and/or reduce GHG emissions.

Emissions estimates are calculated to provide a picture of the important sources of emissions and related trends. They also provide the information needed to track progress towards meeting greenhouse gas emissions and harmful air pollutants reduction targets agreed between countries. Many governments in the EU and US mainly, as well as international bodies, rely on emissions inventories to help focus resources on important emission sources and trends and in designing future policies and agreements. Existing international agreement motivating the developed and adoption of emission models are the United Nations Framework Convention on Climate Change (UNFCCC) and EU Monitoring Mechanism (EUMM).

A widely acceptable framework for modeling energy use and resulting emissions is the Life Cycle Analyses (LCA), often accounting for cradle-to-grave assessment (with slight variations in emission boundaries). In transportation, the term well-to-wheels (WTW) is often used to characterize the equivalent energy or environmental effects of different fuel technologies or fuels qualities (fuel-centric approach). Most LCA models tend to focus on providing a consistent methodology and data for assessing emerging vehicle technologies, engine technologies, and fuel/energy pathways.

This section reviews and compares selected frameworks and models that are in use by policy-makers in the EU, US and China. The results of this review are summarized in the below table, while a detailed review of the processes underpinning the use-phase emissions of these tools is provided in chapter 3.

Table 1: Selected emission inventory and vehicle simulation models that are in use by policy-makers in the EU, US and China

	Users	Tool	Scope	Main objectives	Last update
EU	Austria, Germany, Switzerland, Sweden	HBFRA	Emission Factors	To inform urban transportation planning	1st version: 1995 Last update: 2014
	36 of the leading organizations involved in research on transport emissions from 15 European countries (led by the UK Transport Research Laboratory)	ARMITS	Assessment of emission factors, traffic activity and emissions data, including existing models	To assess and advise best practices towards transport emissions modeling harmonization	Commissioned: 2000 Final report: 2007
	European	COPERT	Emission Data		1st version:

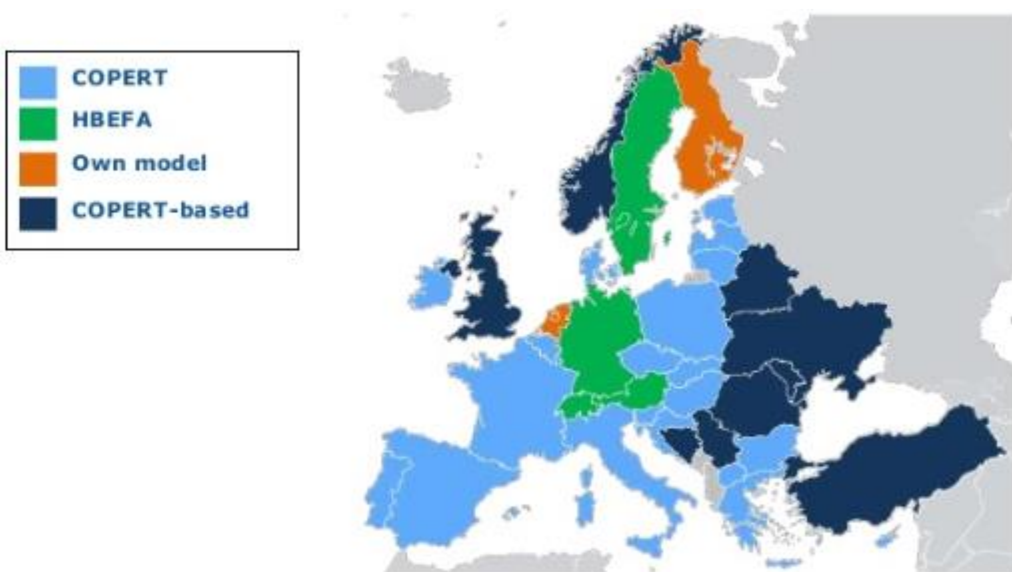
	Environment Agency (EMEA/EEA)	(& COPERT Street Level)			1989 Last update: 2014
	UK	NAEI	Emission Data	International emissions reporting agreements and tracking reduction towards targets.	1st version: 1990s Last update: 2013
	Other models (e.g. ARTEMIS, COPERT, HBFRA)	PHEM (& PHEM light)	Emissions Data (Vehicle simulation model)	To simulate emissions from vehicles using extensive European set of vehicle measurements.	1st version: 1999 Last update: 2014
	Netherlands	VERSIT+ (& VERSIT+micro)	Emissions and Traffic activity data		1st version: 2006 Last update: 2014
	Germany	TREMOD	Traffic activity data		1st version: 2006 Last update: 2014
	Germany	TREMOD	Traffic activity data		1st version: 2006 Last update: 2014
US	Government, universities, and industries in North America	GREET	Life cycle assessment (LCA) of both fuel and vehicle.	Simulate vehicle emission and fuel consumption	1st version: 1996 Last update: 2014
	Buyer and manufacturer in the U.S. light duty vehicle market	ACEEE Green Book	LCA and environmental economics	Provide information for consumer education and market-oriented approaches to improving the environmental performance of automobiles	1st version: 1998 Last update: 2015
	U.S. EPA, state and local agencies in the U.S.	MOVES	Emission Data (feeds into GREET)	Estimate air pollution emissions from car, trucks, and motorcycles. Future model will cover nonroad	1st version: 1994 Last update: 2014

				emissions.	
		MOBILE	Emission factors	Estimates emissions of both exhaust and evaporative emissions.	1st version: 1970ies Last update: 2004
	California	EMFAC	Emission factors		1st version: 1988 Last update: 2013
China	Shenzhen, Tianjin, Harbin	HBFRA-China / CRTEM	Emission Factors		2012
	Beijing	IVE Model - Beijing	Emission data		2010
	National (MPE-VECC)	CVEM	Emission data and factors		2009

2.1 The EU

Several vehicle emissions simulation and emissions factor models have been developed in Europe, and some have been adjusted to Australia and Asia. This section covers leading models developed in Europe.

Figure 2: Major vehicle emissions simulation and emissions factor models developed in Europe



Source: European Commission, DG Joint Research Center, Institute for Energy and Transport, Overview of the European Research for Mobile Emission Sources (ERMES).

2.1.1 COPERT Computer Programme

COPERT4 is a software tool used world-wide to calculate air pollutant and greenhouse gas emissions from road transport. COPERT emission factors are derived from a binomial regression analysis applied to a large dataset of vehicle measurements classified by vehicle type and technology and expressed as a function of the average speed of the vehicle.

The COPERT methodology is part of the European Environment Agency (EEA) air pollutant emission inventory guidebook for the calculation of air pollutant emissions and is consistent with the 2006 IPCC Guidelines for the calculation of greenhouse gas emissions. The use of a software tool to calculate road transport emissions allows for a transparent and standardized, hence consistent and comparable data collecting and emissions reporting procedure, in accordance with the requirements of international conventions and protocols and EU legislation.

The development of COPERT is coordinated by the EEA, in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation. The European Commission's Joint Research Centre manages the scientific development of the model. COPERT has been developed for official road transport emission inventory preparation in EEA member countries. However, it is applicable to all relevant research, scientific and academic applications.

COPERT4 draws its origins in a methodology developed by a working group which was set up explicitly for this purpose in 1989 (COPERT 85). This was then followed by COPERT 90 (1993), COPERT II (1997) and COPERT III (1999). The current version is a synthesis of results of several large-scale activities and dedicated projects, such as:

- Dedicated projects funded by the Joint Research Centre / Transport and Air Quality Unit
- The annual work-program of the European Topic Centre for Air Pollution and Climate Change Mitigation (ETC/ACM)
- The European Research Group on Mobile Emission Sources (**ERMES**) work program
- The **MEET** project (Methodologies to Estimate Emissions from Transport), a European Commission (DG VII) sponsored project within 4th Framework Program (1996-1998)
- The **PARTICULATES** project (Characterization of Exhaust Particulate Emissions from Road Vehicles), a European Commission (DG Transport) PROJECT within the 5th Framework Program (2000-2003)
- The **ARTEMIS**[2] project (Assessment and Reliability of Transport Emission Models and Inventory Systems), a European Commission (DG Transport) PROJECT within the 5th Framework Program (2000-2007)
- A joint **JRC/CONCAWE/ACEA** project on fuel evaporation from gasoline vehicles (2005-2007)
- Some emission factor work was conducted by the **HBEFA**[3] group.

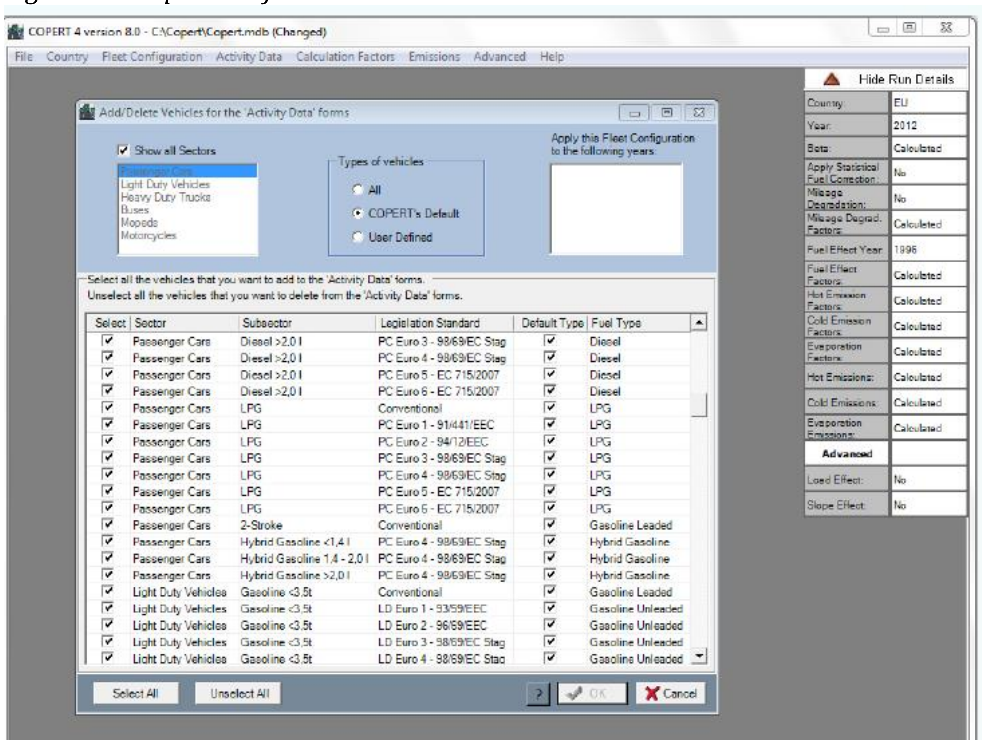
COPERT4 estimates emissions of all major air pollutants (CO, NOx, VOC, PM, NH3, SO2, heavy metals) produced by different vehicle categories (passenger cars, light commercial vehicles, heavy duty trucks, busses, motorcycles, and mopeds) as well as greenhouse gas emissions (CO2, N2O, CH4). It also provides speciation for NO/NO2, elemental carbon and organic matter of PM and non-methane VOCs, including PAHs and POPs.

Emissions are produced from two sources: (i) engine emissions, distinguished into those produced during thermally stabilized engine operation (hot emissions), and emissions occurring during engine start from ambient temperature (cold-start and warming-up effects); (ii) diffuse emissions, i.e. NMVOC emissions due to fuel evaporation and non-exhaust PM emissions from tyre and brake

[2] This tool is covered in this report, as it is significant and operable in the transport emissions measurement landscape.
[3] This tool is covered in this report, as it is significant and operable in the transport emissions measurement landscape.

wear. Total emissions are calculated as a product of activity data provided by the user and speed-dependent emission factors calculated by the software.

Figure 3: Snapshots of the COPERT model



Source: COPERT4 Estimating emissions from road transport.
Learn more: [http://www.eea.europa.eu/publications/copert-4-2014-estimating -emissions](http://www.eea.europa.eu/publications/copert-4-2014-estimating-emissions)

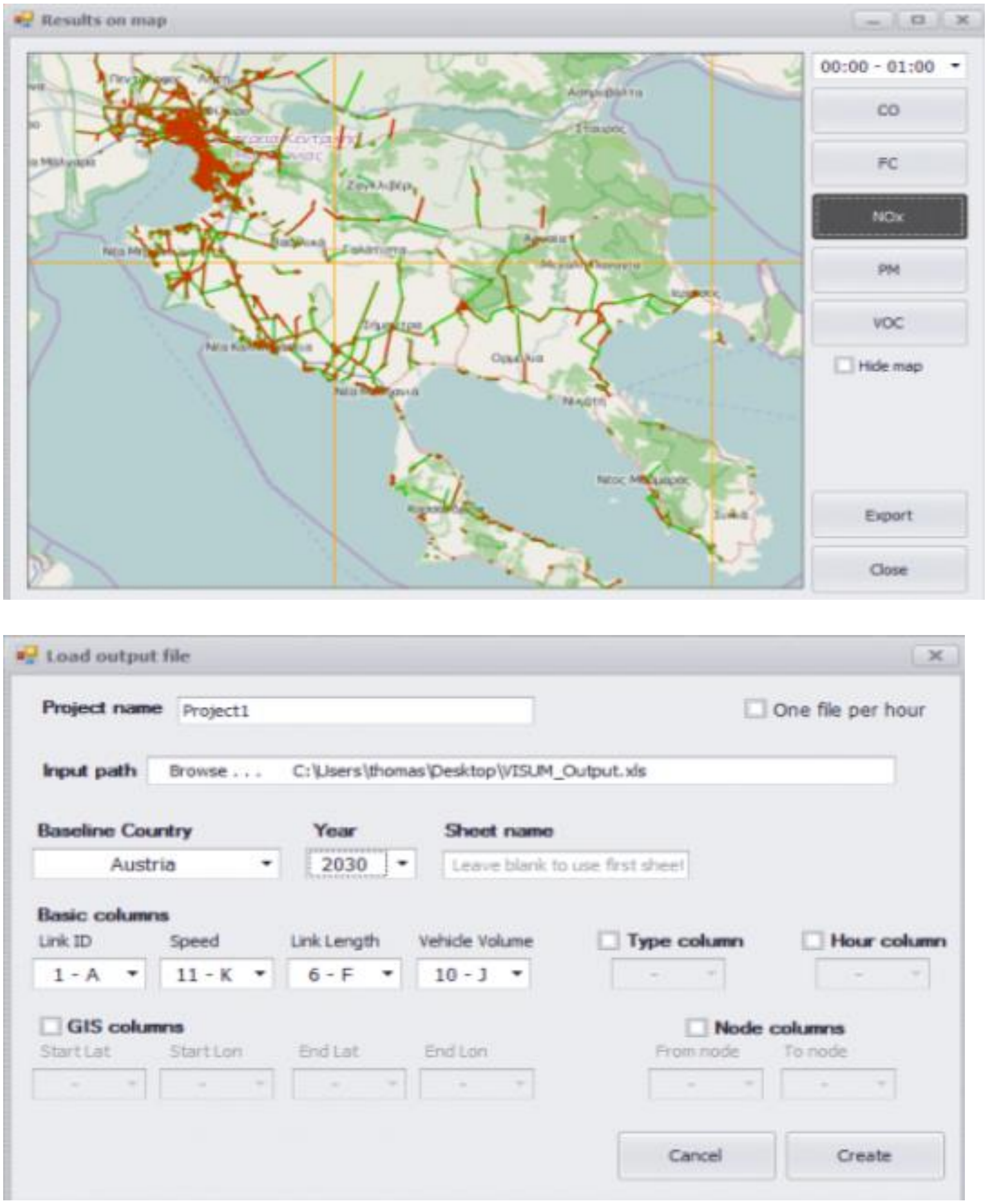
The software application of COPERT 4 methodology has been developed for the compilation of national inventories (i.e. NUTS 0) on a yearly basis. However, it has been shown that the methodology can also be used with a sufficient degree of certainty at a higher resolution too, i.e. for the compilation of urban emission inventories with a spatial resolution of 1×1 km2 and a temporal resolution of 1 hour. The COPERT Street Level presents a new approach to calculating emissions from Road Transport. It is based on COPERT software but enables calculating emissions on a single street or on a full city street network. It requires the minimum set of input data to produce results. Emissions can then be displayed on a GIS map to improve visualization. It is designed to work alongside traffic analysis tools in order to facilitate a wide range of input datasets. It is optimized for fast execution times.

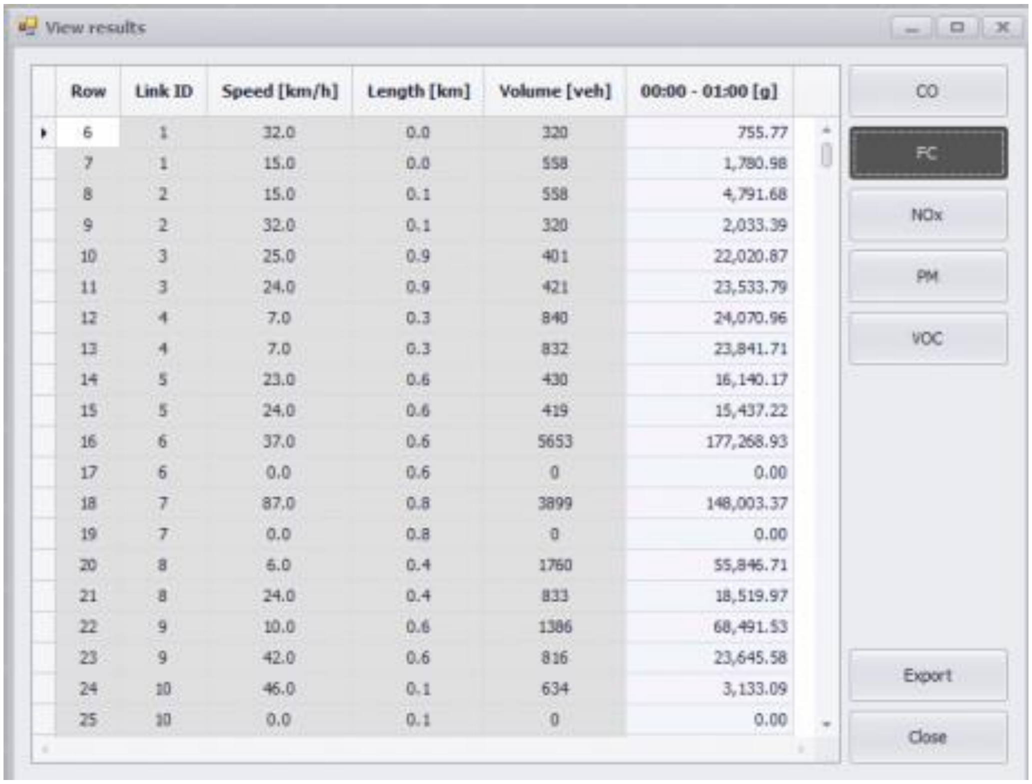
Table 2: COPERT and COPERT Street level comparison

	COPERT	COPERT Street Level
Minimum temporal level	Year	Hour
Minimum spatial level	City	Small road
GIS visualization	No	Yes
Emissions covered	Regulated and non-regulated pollutants, GHG	Regulated and non-regulated pollutants, GHG
Energy consumption calculated	Yes	Yes

Automated scenario execution	No	Yes
Advanced input data	No	Yes

Figure 4: Snapshots of the COPERT Street Level model





Row	Link ID	Speed [km/h]	Length [km]	Volume [veh]	00:00 - 01:00 [g]
6	1	32.0	0.0	320	755.77
7	1	15.0	0.0	558	1,780.98
8	2	15.0	0.1	558	4,791.68
9	2	32.0	0.1	320	2,033.39
10	3	25.0	0.9	401	22,020.87
11	3	24.0	0.9	421	23,533.79
12	4	7.0	0.3	840	24,070.96
13	4	7.0	0.3	832	23,841.71
14	5	23.0	0.6	430	16,140.17
15	5	24.0	0.6	419	15,437.22
16	6	37.0	0.6	5653	177,268.93
17	6	0.0	0.6	0	0.00
18	7	87.0	0.8	3899	148,003.37
19	7	0.0	0.8	0	0.00
20	8	6.0	0.4	1760	55,846.71
21	8	24.0	0.4	833	18,519.97
22	9	10.0	0.6	1386	68,491.53
23	9	42.0	0.6	816	23,645.58
24	10	46.0	0.1	634	3,133.09
25	10	0.0	0.1	0	0.00

More information can be found at http://emisia.com/copert

2.1.2 Assessment and Reliability of Transport Emissions Models and Inventory Systems (ARTEMIS)

There are several tools that have been developed in Europe for informing transport policy-making. While there is still flexibility in the adoption tools and no single tool have been adopted across countries and regimes, two projects were formed in 2000 to devise harmonization in the EU: Assessment and Reliability of Transport Emissions Models and Inventory Systems (ARTEMIS) and Characterization of Exhaust Particulate Emissions from Road Vehicles (PARTICULATES). The ARTEMIS program built upon earlier recommendations arising from the 4th European Commission Framework project MEET and COST Action 319. The ARTEMIS project engaged 40 European research laboratories and had a budget of about €9 million. It was initiated for the setting-up and improvement of the European inventorying tools for application at different spatial and temporal scales. It was meant to enable objectives comparisons and evaluations towards a harmonized emission model for road, rail, air and ship transport, and to provide consistent emission estimates at the national, international and regional levels.

ARMIT had two principal objectives: The first of these was to gain, through a program of basic research, a better understanding of the causes of the differences in model predictions, and thus to address the uncertainties in emission modeling. The project included a large emission measurement program, designed to provide a significant extension to the available databases. For road transport, measurements conducted in many laboratories around Europe were used to examine the reasons for variability in the data, and to form the basis of a 'best practice' guide for future measurements. The second principal objective was to develop a harmonized methodology for estimating emissions from all transport modes at the national and international levels.

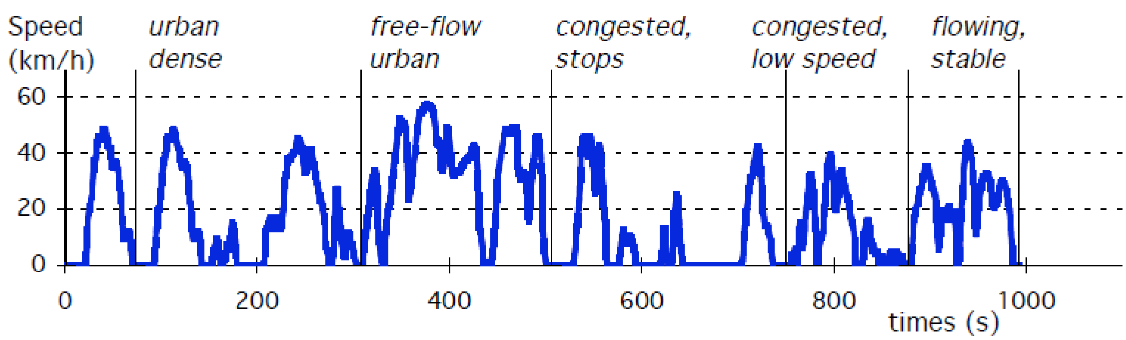
The ARTEMIS tools were designed for three main applications: (i) classical emission inventories (at regional or national scale, per month or year), (ii) scenario calculation for assessing the impacts of alternative measures (time series over years), (iii) inputs for air quality models for assessing local and temporal impacts on the environment. The model was then designed to enable calculation at an aggregated level and at a street level. The daily calculation can be done on an hourly basis or aggregated over a year, for the 1980-2030 period.

The tools manage most of the pollutants: regulated (CO, HC, NOx, PM, Pb, SO2) as well as the fuel consumption and non-regulated pollutants (CO2, methane, ammonia, benzene, toluene, xylene, polycyclic aromatic hydrocarbons, PM in size and number, 1.3-butadiene, acetaldehyde, acrolein, benzopyrene, ethylbenzene, formaldehyde, hexane). These last components are however missing for certain vehicle categories. Hot, cold start and evaporative emissions are managed for the most relevant vehicles concepts (up to EURO4) through actual emissions measurements, while assumptions are made for the future vehicles. The user can also make its own assumptions for future technologies.

The calculation relies on a detailed classification of the vehicles into families (light-duty vehicles, motorcycles, heavy duty vehicles), categories (cars, light commercial vehicles, buses, and coaches, heavy goods vehicles) and sub-categories (rigid-, articulated and truck and trailers). Vehicles categories are broken down into segments by technology and size (i.e. petrol, diesel by engine size, hybrids, CNG, E85 for cars, trucks by vehicle weight and configuration, midi-, standard- and articulated-buses and coaches, fuelled with diesel, CNG or ethanol, moped and motorcycles by engine size and technology - 2- and 4 strokes). These segments are themselves combined with the emissions concepts (pre-Euro, Euro1 to 5 plus several other cases).

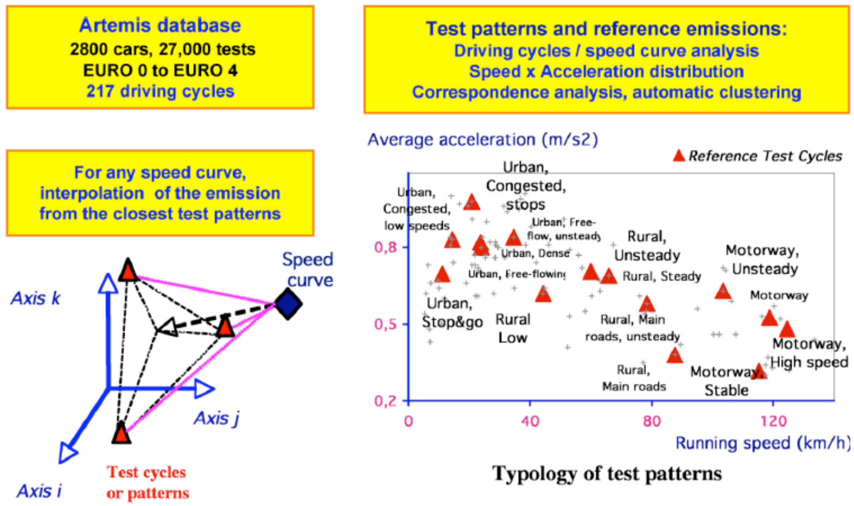
ARTEMIS conducted a systematic analysis of the methodological aspects that lead to uncertainty in the emission estimation (vehicle sampling, test conditions, fuel, etc.). For passenger vehicles, ARTEMIS conducted tests and created a driving cycle recommendations of driving in Europe that later on influenced national emissions testing and test procedures. The test procedures recommendations developed were applied in ARTEMIS tool.

Figure 5: The ARTEMIS urban driving cycle for passenger cars



Source: Keller et al.

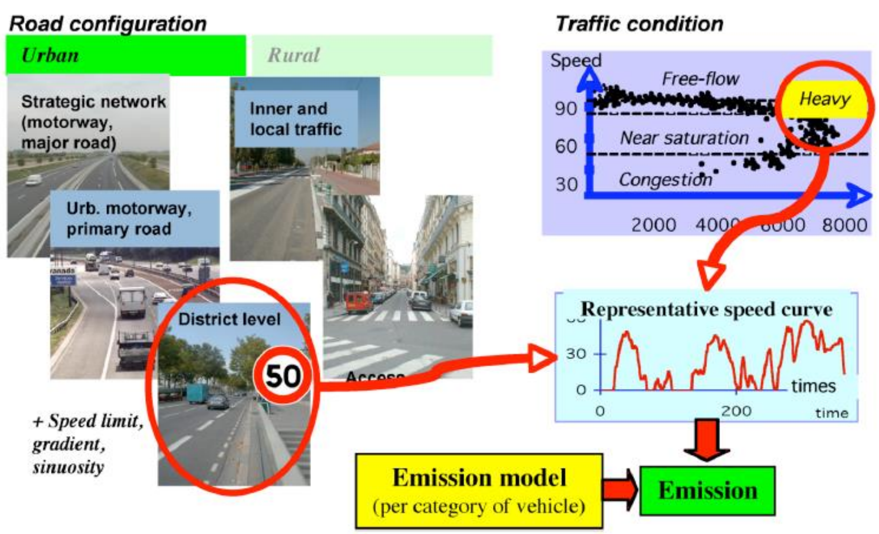
Figure 6: ARTEMIS schematic modeling of the passenger car emissions and fuel consumption



Source: Keller et al.

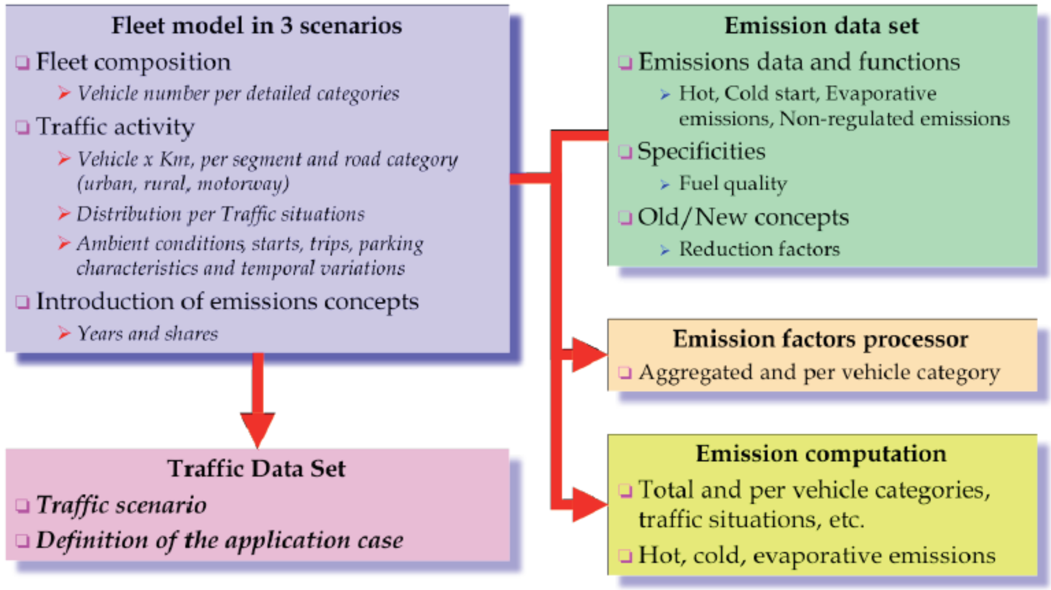
The model employs a traffic situation approach for providing a more accurate estimation of the emissions at a street level. A user- and practices- oriented "traffic situations scheme" was derived from the analysis of existing road classifications. It distinguishes urban and rural areas, the road network functions and hierarchical organization, and declines motorway/road and their most common characteristics and speed limits in Europe. The traffic condition is then described in (i) free-flow traffic (speed at 85-100% of the free speed), (ii) heavy traffic (constraint speed at 65-85% of the free speed), (iii) unsteady saturated traffic (variable speed with possible stops, 30 to 60% of the free speed) and (iv) stop-and-go (speed around 10 km/h).

Figure 7: ARTEMIS schematic illustration of the traffic approach



Source: Keller et al.

Figure 8: Schematic structure of the ARTEMIS tools



Source: Keller et al.

Table 3: ARTEMIS contribution to existing knowledge

Topic	Scope of work
Road traffic characteristics	This aspect of the work focused on the collection, processing, adaptation or application of existing data, and the improvement or extension of the modeling approaches relating to fleets, usage and driving conditions of road vehicles in EU and CEEC countries. The data collection covered all relevant aspects of vehicle operation including, for example, trip profiles and the use of auxiliaries, in addition to the more general information on vehicle types and distances travelled. The sensitivity of emission estimates to traffic-related parameters was also considered.
Establishment of reliable emission factors for passenger cars and light commercial vehicles	An investigation was conducted into the reasons for the differences between emission measurements at different laboratories, and a best practice procedure for measurement was designed. Measurements of regulated and unregulated pollutants from vehicles equipped with the latest emission-control technologies were undertaken, and assessments were made of the effects of road gradient and ambient temperature on emissions. An improved emission calculation model was then developed.
Improved cold-start emissions modeling	An improved method was developed for the modeling of cold-start emissions from passenger cars, taking into account factors such as ambient temperature, speed, and parking duration.

Measurement of evaporative emissions from light-duty vehicles	Evaporative losses represent a significant source of VOC emissions from the light-duty vehicle sector. Prior to ARTEMIS, only very limited information was available on evaporative emissions and the effectiveness of control systems. The existing methodologies for the calculation of evaporative emissions were reviewed, and new measurements were performed to fill some of the gaps.
Validation of road transport model	The emission behavior of the road vehicle fleet is influenced by many parameters, and large numbers of laboratory tests are required to obtain statistically reliable data. It is therefore desirable to use alternative methods to validate the emission data from laboratory tests, or adjust them to real-world conditions. Road tunnels can be used to measure emissions from in-use vehicles under real-world conditions. In this part of the ARTEMIS work measurements were conducted in three tunnels for the purpose of model validation.

Learn more: http://www.trl.co.uk/reports-publications/trl-reports/report/?reportid=6413

2.1.3 The Handbook of Emission Factors for Road Transport (HBEFA)

The Handbook Emission Factors for Road Transport (HBEFA) provides emission factors for all current vehicle categories (PC, LDV, HGV, urban buses, coaches and motor cycles), each divided into different categories, for a wide variety of traffic situations. Emission factors for all regulated and the most important non-regulated pollutants as well as fuel consumption and CO2 are included. Different levels of disaggregation are being offered in HBEFA by: type of emission (hot, cold start, evaporative), vehicle category (car, van, heavy duty vehicles, buses, coaches and motorcycles), year (1990-2030), pollutants, traffic situations, road gradient. HBEFA is also capable of weighting the emission factors (e.g. per vehicle category or per fuel type).

The HBEFA was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria. At this time other countries (Sweden, Norway and France) as well as the JRC (Joint Research Centre of the European Commission) support HBEFA. The first version (HBEFA 1.1) was published in December 1995, an update (HBEFA 1.2) followed in January 1999. Version HBEFA 2.1 was available in February 2004 and HBEFA 3.1 followed in January 2010. The newest version HBEFA 3.2 dates from July 2014.

To develop the emission factors, the original data from various test laboratories was collected and processed with the Passenger Car and Heavy-Duty Emission Model (PHEM4) by the Technical University of Graz (Austria). The current version of HBEFA is based on European emission measurement data collected within the ERMES group[4], which is also the emission data basis for other European models such as COPERT and TREMOVE. The parameter sets are stored under a user-specified name. The program then calculates the desired emission factors. The results can be exported to Excel. Users with a full version of MS Access have direct access to the result database

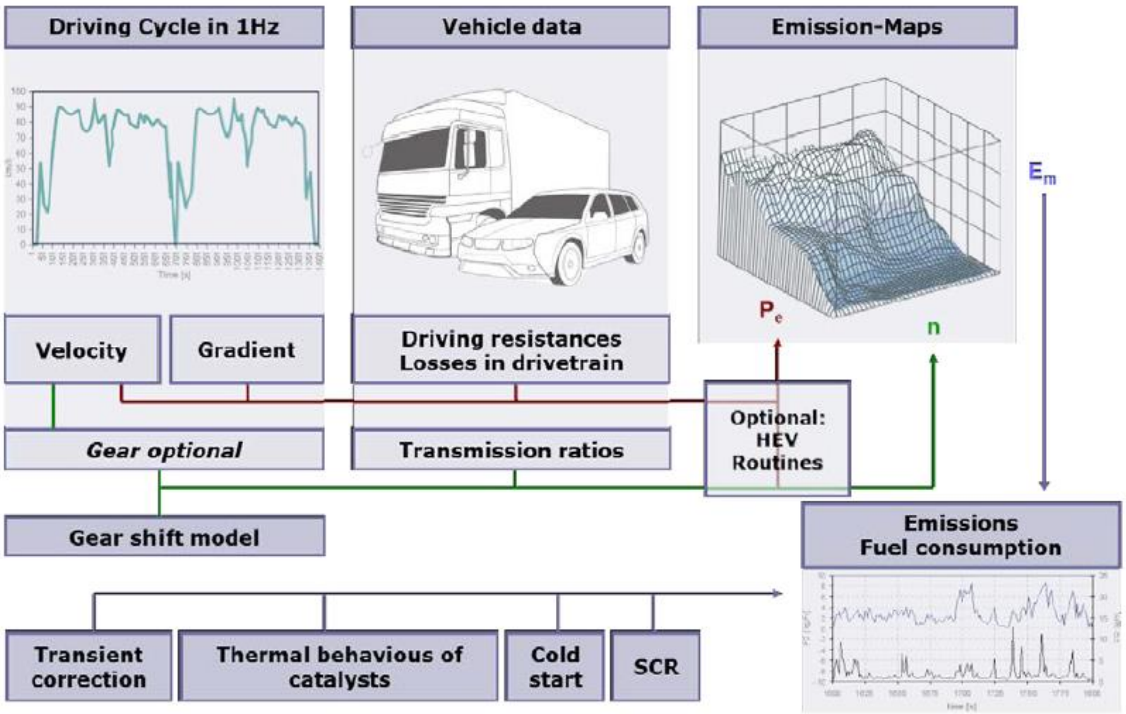
[4] The European Research for Mobile Emission Sources (ERMES) is a group of research institutions, competent authorities, industry associations, whose mission includes the support of cooperative research in the field of transport emission modeling. ERMES partners contribute to the development of the most up-to-date emission estimation tools for policy making and policy implementation purposes. Its members include tens of academic, research, and government institutions from Europe and Australia.

for further processing of the emission factors. The handbook provides emission factors per traffic activity. Different levels of disaggregation are being offered, as articulated in **Table 4**:

Table 4: HBEFA Disaggregation Options

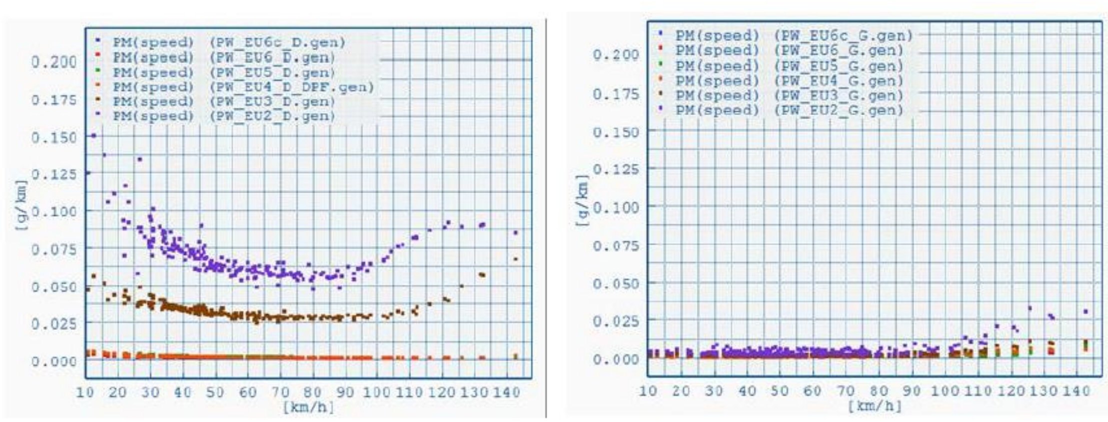
Categorization & disaggregation	Elaboration
By-type of emission	"Hot" emissions, cold start excess emissions, evaporative emissions. The so called "hot" emission factors are given for several traffic situations which have been adapted to the scheme developed in the ARTEMIS project. Differentiated factors are provided for different gradient classes (0%, 2%, 4%, 6%). Also weighted average values (distributions over several traffic situations and gradient classes) are calculated.
By-vehicle category	Passenger cars, light duty vehicles, heavy duty vehicles, buses, coaches and motorcycles.
By-year (1990-2030) and location	Implicitly by varying fleet compositions in the different countries (Germany, Austria, Switzerland, Sweden, Norway and France)
By-pollutants	Factors for the following components are provided: CO, HC, NOx, PM, several components of HC (CH_4, NMHC, benzene, toluene, xylene), fuel consumption (gasoline, diesel), CO_2, NH_3 and N_2O, PN and PM.
By-segment or by vehicle technology concept	The program gives the desired emission factors either as weighted emission factors (per vehicle category), or as emission factors per concept (e.g. conventional passenger cars, passenger cars with catalysts, diesel passenger cars etc.), or as emission factors per fuel type (gasoline, diesel) or as emission factors per "layer" or subsegment (e.g. passenger cars with engine size <1.4 l Euro-4 etc.). PS: The distinction by engine size for passenger cars is used for fuel consumption resp. CO_2-emissions only; for light commercial, HDV and MC though the emission factors are distinguished by size class. The cold start and the evaporation emission factors are based on typical temperature distributions and behavioral parameters (such as trip length distributions, parking time distributions).

Figure 9: Scheme of HBFRA model



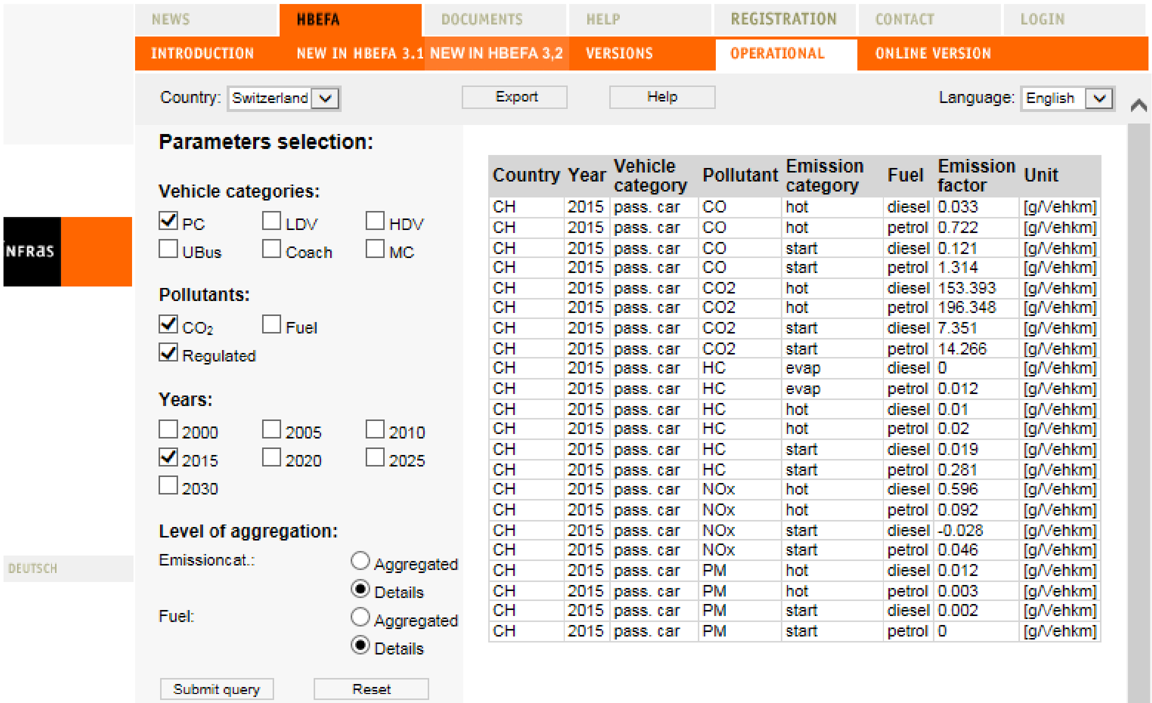
Source: Institute for Internal Combustion Engines and Thermodynamics, 2013

Figure 10: Example of HBFRA3.2 PM emission factors



Source: Institute for Internal Combustion Engines and Thermodynamics, 2013

Figure 11: Snapshots of HBFRA online version



Country	Year	Vehicle category	Pollutant	Emission category	Fuel	Emission factor	Unit
CH	2015	pass. car	CO	hot	diesel	0.033	[g/Vehkm]
CH	2015	pass. car	CO	hot	petrol	0.722	[g/Vehkm]
CH	2015	pass. car	CO	start	diesel	0.121	[g/Vehkm]
CH	2015	pass. car	CO	start	petrol	1.314	[g/Vehkm]
CH	2015	pass. car	CO2	hot	diesel	153.393	[g/Vehkm]
CH	2015	pass. car	CO2	hot	petrol	196.348	[g/Vehkm]
CH	2015	pass. car	CO2	start	diesel	7.351	[g/Vehkm]
CH	2015	pass. car	CO2	start	petrol	14.266	[g/Vehkm]
CH	2015	pass. car	HC	evap	diesel	0	[g/Vehkm]
CH	2015	pass. car	HC	evap	petrol	0.012	[g/Vehkm]
CH	2015	pass. car	HC	hot	diesel	0.01	[g/Vehkm]
CH	2015	pass. car	HC	hot	petrol	0.02	[g/Vehkm]
CH	2015	pass. car	HC	start	diesel	0.019	[g/Vehkm]
CH	2015	pass. car	HC	start	petrol	0.281	[g/Vehkm]
CH	2015	pass. car	NOx	hot	diesel	0.596	[g/Vehkm]
CH	2015	pass. car	NOx	hot	petrol	0.092	[g/Vehkm]
CH	2015	pass. car	NOx	start	diesel	-0.028	[g/Vehkm]
CH	2015	pass. car	NOx	start	petrol	0.046	[g/Vehkm]
CH	2015	pass. car	PM	hot	diesel	0.012	[g/Vehkm]
CH	2015	pass. car	PM	hot	petrol	0.003	[g/Vehkm]
CH	2015	pass. car	PM	start	diesel	0.002	[g/Vehkm]
CH	2015	pass. car	PM	start	petrol	0	[g/Vehkm]

Source: Institute for Internal Combustion Engines and Thermodynamics, 2013

Learn more: www.hbefa.net

2.1.4 VERSIT+

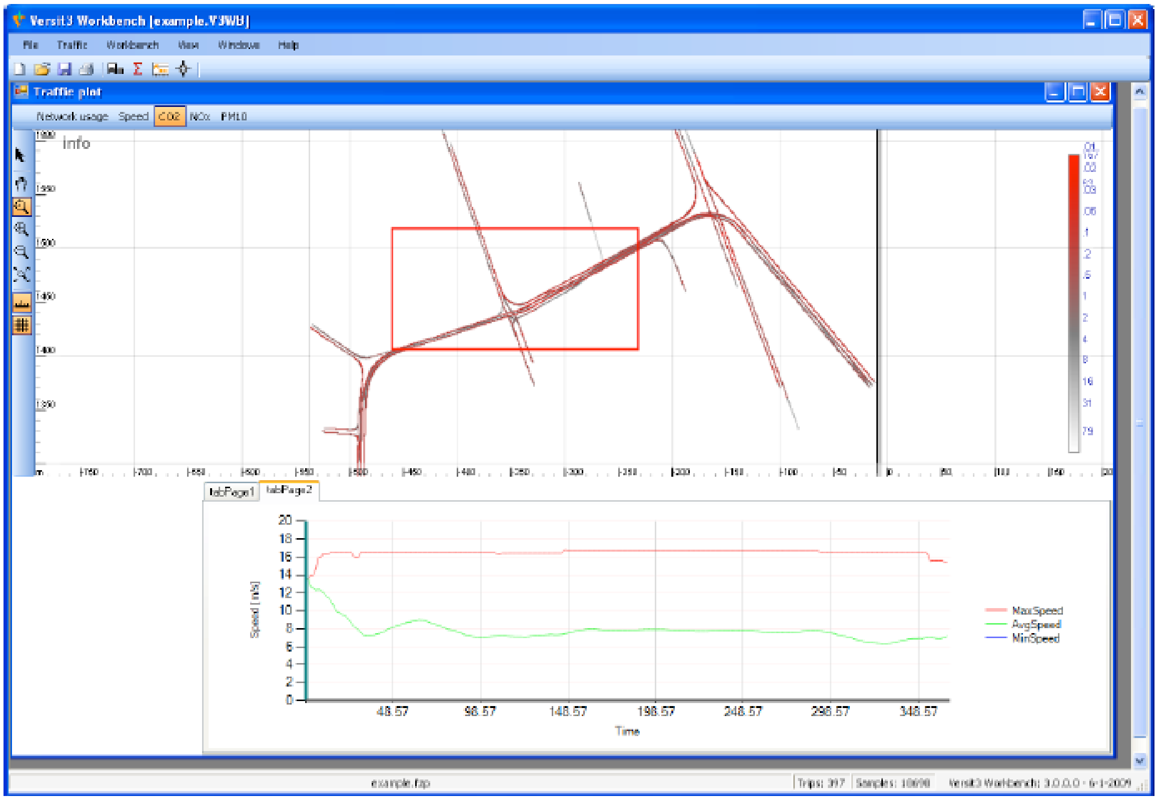
VERSIT+ is constituted by a suite of models used to predict emission factors and energy use factors that are representative for vehicle fleets in different countries. Emission factors are differentiated for various vehicle types and traffic situations, and take into account real-world driving conditions. VERSIT+ can be used for investigating national greenhouse gas reduction strategies but also for local air quality improvement in a consistent manner by projecting emissions for road traffic (trucks, buses, passenger cars and motorcycles) into the future.

Based on measurements of current vehicles and sound knowledge of future emission reduction technologies, VERSIT+ can project car emissions into the future. Emission prediction for road traffic (trucks, buses, passenger cars and motorcycles) is important for governments to make well-informed decisions regarding clean vehicle technology incentives.

VERSIT+ is based on a database of 12,000 measured driving cycles, mimicking all aspects of real-time driving behavior. Using advanced statistical modeling techniques, VERSIT+ finds suited emission factor equation for a given driving pattern. Traffic simulation models are being incorporated into VERSIT+.

DHV and TNO have now implemented an interface between Aimsun and VERSIT+micro, making it possible to include the environmental effects of transport policies into simulation-based assessments.

Figure 12: Snapshot of VERSIT+ micro

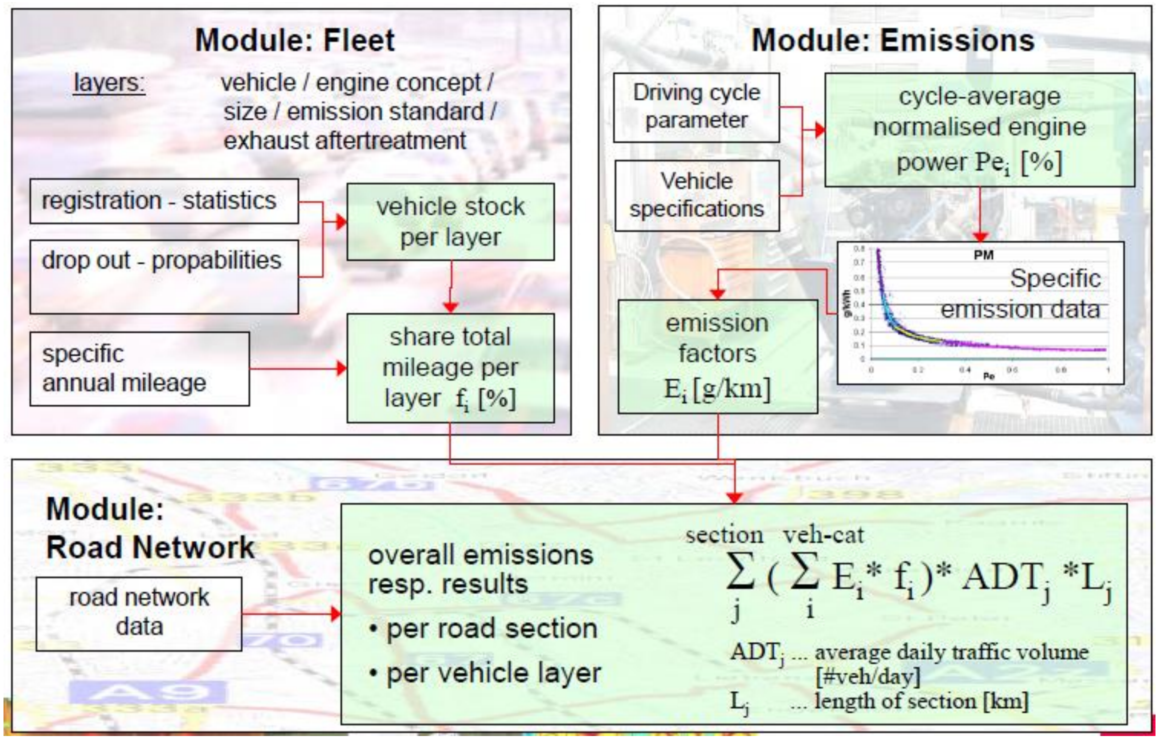


Learn more: www.tno.nl/downloads/lowres_TNO_VERSIT.pdf

2.1.5 Network Emission Model (NEMO)

NEMO is a tool for the simulation of traffic related emissions in road networks. Typical applications reach from emission inventories for cities, regions and countries to complex measures like environmental zones or promotion of alternative propulsion systems. NEMO combines both detailed calculation of the vehicle fleet composition and simulation of emission factors on a vehicle level. The simulation of the emissions of the different vehicle layers is based on the correlation of the specific engine emission behavior (emissions in grams per kilowatt-hour engine work) with the cycle average engine power in a normalized format. The parameterization of NEMO is based on data from European in-use measurements which are also used for the Handbook Emission Factors of Road Transport.

Figure 13: Snapshot of NEMO modeling scheme



Source: Institute for Internal Combustion Engines and Thermodynamics, 2009

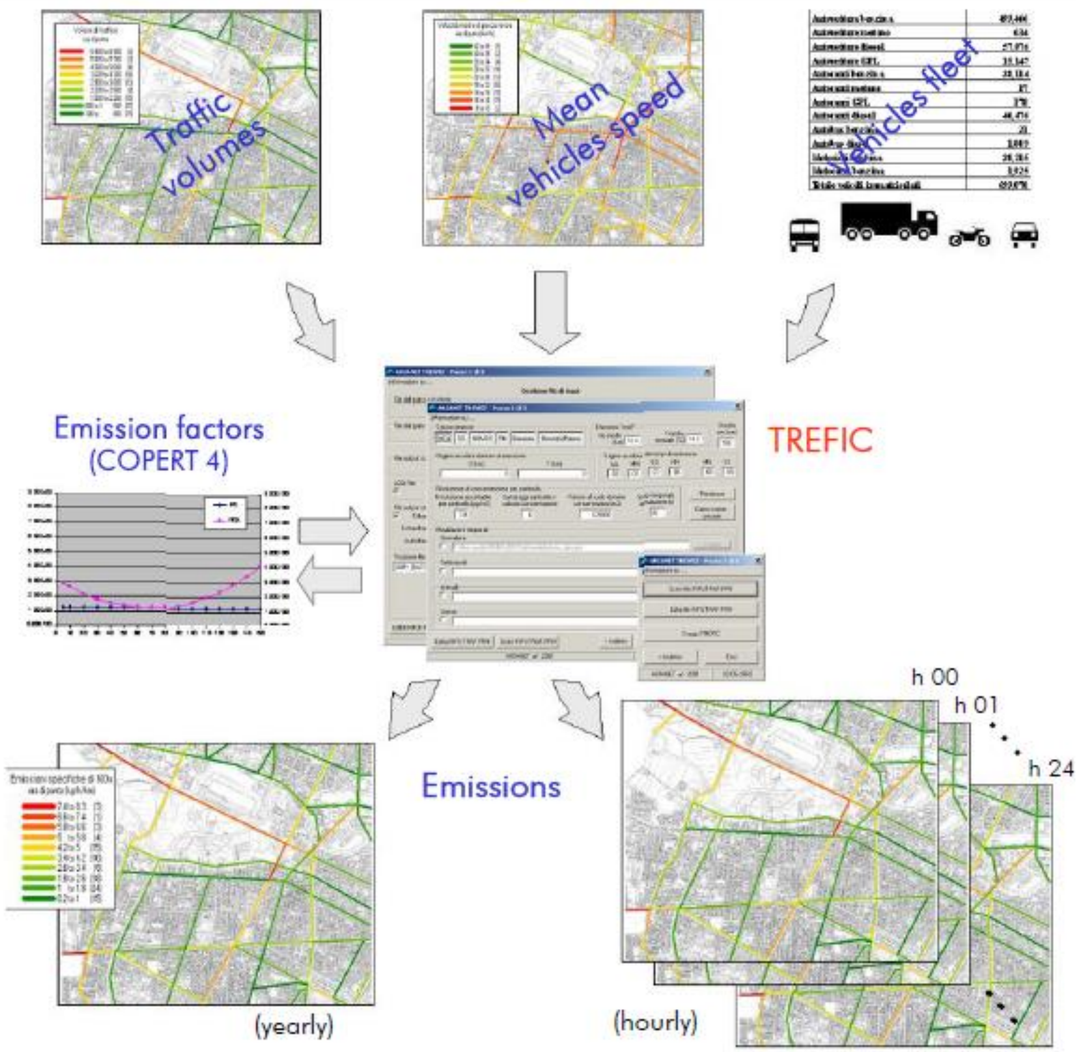
Learn more: http://www.ivt.tugraz.at/de/forschung/emissionen.html

2.1.6 TRaffic Emission Factor Improved Calculator (TREFIC)

TREFIC is a tool to estimate atmospheric pollutant emissions from road traffic. The calculation is currently based on COPERT4 methodology, but a flexible mechanism enables the user to implement its own emission factors. Input data include vehicle fleets, traffic volumes and speeds with the related time modulations. The I/O is GIS-based, allowing describing vehicle fleets, traffic volumes and speeds, with their related time modulations, on arbitrary sets of line and area objects. TREFIC is especially oriented to feed atmospheric dispersion models and its output is compatible with all the main model types: Gaussian, puff, Lagrangian particle and Eulerian photochemical ones, including speciation and lumping. TREFIC has been used on several applications of different complexity, from single roads to urban and national networks with more than 50000 links, for off-line inventories and in real-time modeling applications.

Outputs of TREFIC include: Pollutant emissions for each traffic bin: CO, NOx, SO2, hydrocarbons (e.g. benzene), particulates (TSP, PM10, PM2.5), heavy metals (Pb, Cd, Fe, etc.), PAH (e.g. benzo-a-pyrene) on hourly basis or aggregated (yearly), and Weighted average emission factors for local vehicles fleet

Figure 14: Snapshot of TREFIC modeling scheme



Source: ARIANET
More information can be found at www.aria-net.it

2.1.7 Transport Emission Model (TREMOD)

TREMOD was designed in the late 90s on behalf of the German Federal Environmental Agency to build up a suitable tool that covers the state of knowledge for emission calculation in Germany. It is constantly updated and used for Germany's national annual emission inventory reports, the projection of past trends and future scenarios for all transport modes. For each year between 1960 and now and in scenarios until 2050, TREMOD analyses all means of passenger transportation (cars, two-wheelers, busses, trains, aircraft) and all means of freight transportation (lorries, light-duty commercial vehicles and articulated trucks, trains, inland navigation vessels, aircraft). The transport performance of all these vehicles and for road transport also the vehicle mileage is estimated. This mileage of road vehicles is further differentiated by federal motorways, all extra-urban roads as well as urban roads; additionally the annual mean mix

of traffic situations on the different road types is estimated. Energy use and emissions of nitrogen oxides, sulphur dioxide, hydrocarbons (NMHC, CH4, benzene), carbon monoxide, carbon dioxide, particulate matter and soot can thus be calculated in the respective differentiation. Emissions are presented as direct emissions, i.e. emissions directly emitted by the vehicle, as well as indirect emissions, i.e. emissions from the upstream energy generation and supply chain.
In the road transport sector TREMOD has a close cooperation with the HBEFA: TREMOD uses the methodology and database of the HBEFA for the emission factors of road transport. Vice versa the HBEFA uses traffic activity data for Germany of TREMOD. The emission inventory, therefore, covers the same layers as the HBEFA with a high resolute calculation procedure.

More information can be found at www.tremod.de

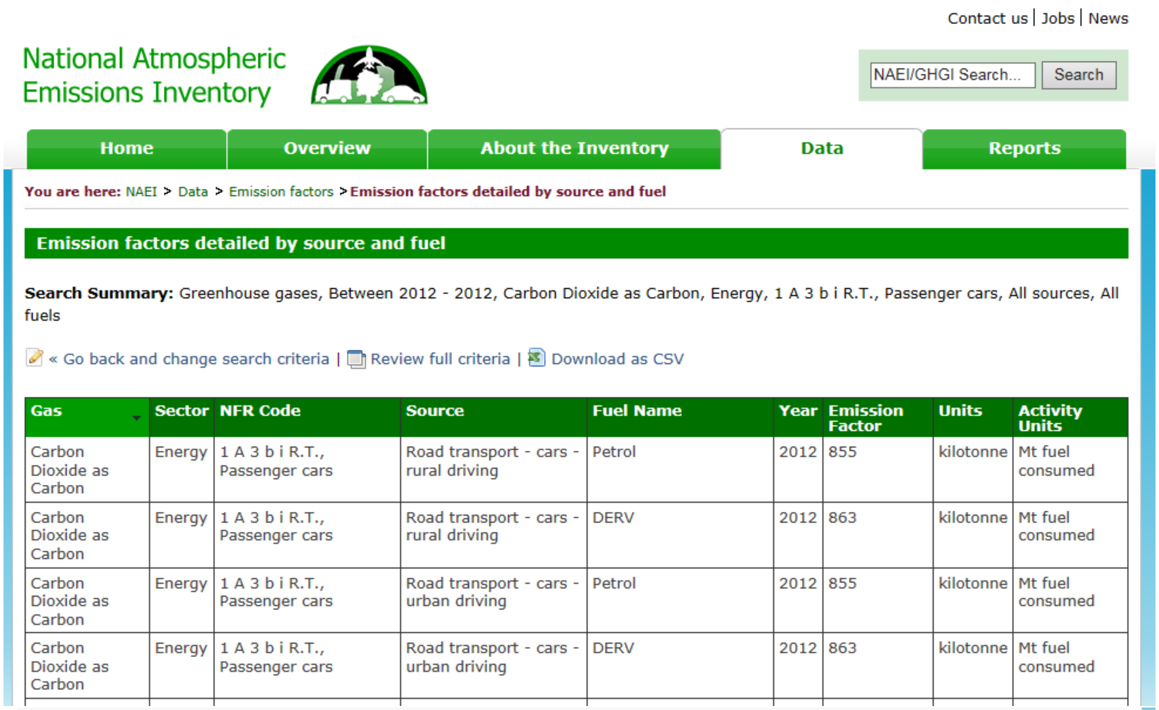
2.1.8 Passenger Car and Heavy Duty Emission Model (PHEM)

PHEM is a vehicle simulation tool capable of simulating vehicle hot and cold emissions for different driving cycles, gear shift strategies, vehicle loadings, road gradients, vehicle characteristics (mass, size, air resistance, etc.). PHEM has been validated by emission measurements both from light and heavy duty vehicles in the laboratories (chassis and engine test bed) and on the road (with PEMS) and under different test conditions. If fed with a detailed list of vehicle specifications PHEM is capable of modeling emission levels on a large variety of conditions not covered by the available measurements. Average emission factor for each vehicle category and then produced taking into consideration the fleet population and technology offer on the market.

2.1.9 UK National Atmospheric Emissions Inventory (NAEI)

Driven by the UK obligations to report trans-boundary harmful emission levels and GHG reductions, the UK National Atmospheric Emissions Inventory (NAEI) was established by the Department of Energy and Climate Change (DECC), Department for Environment, Food and Rural Affairs (Defra), the Scottish Government, the Welsh Government and the Department of Environment, Northern Ireland. The NAEI was developed and maintained by Ricardo-AEA, in collaboration with Aether, CEH, AMEC and SKM Enviros. The NAEI estimates annual pollutant emissions from 1970 to the most current publication year for the majority of pollutants. A number of pollutants are estimated from 1990 or 2000 to the most current publication year (2012) due to the lack of adequate data prior to the later date and the specific reporting requirements for each pollutant. To deliver these estimates, the NAEI team collects and analyses information from a wide range of sources – from national energy statistics through to data collected from individual industrial plants.

Figure 15: Snapshots of the NAEI online emission inventory



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National Atmospheric Emissions Inventory

NAEI/GHGI Search... Search

Home | Overview | About the Inventory | Data | Reports

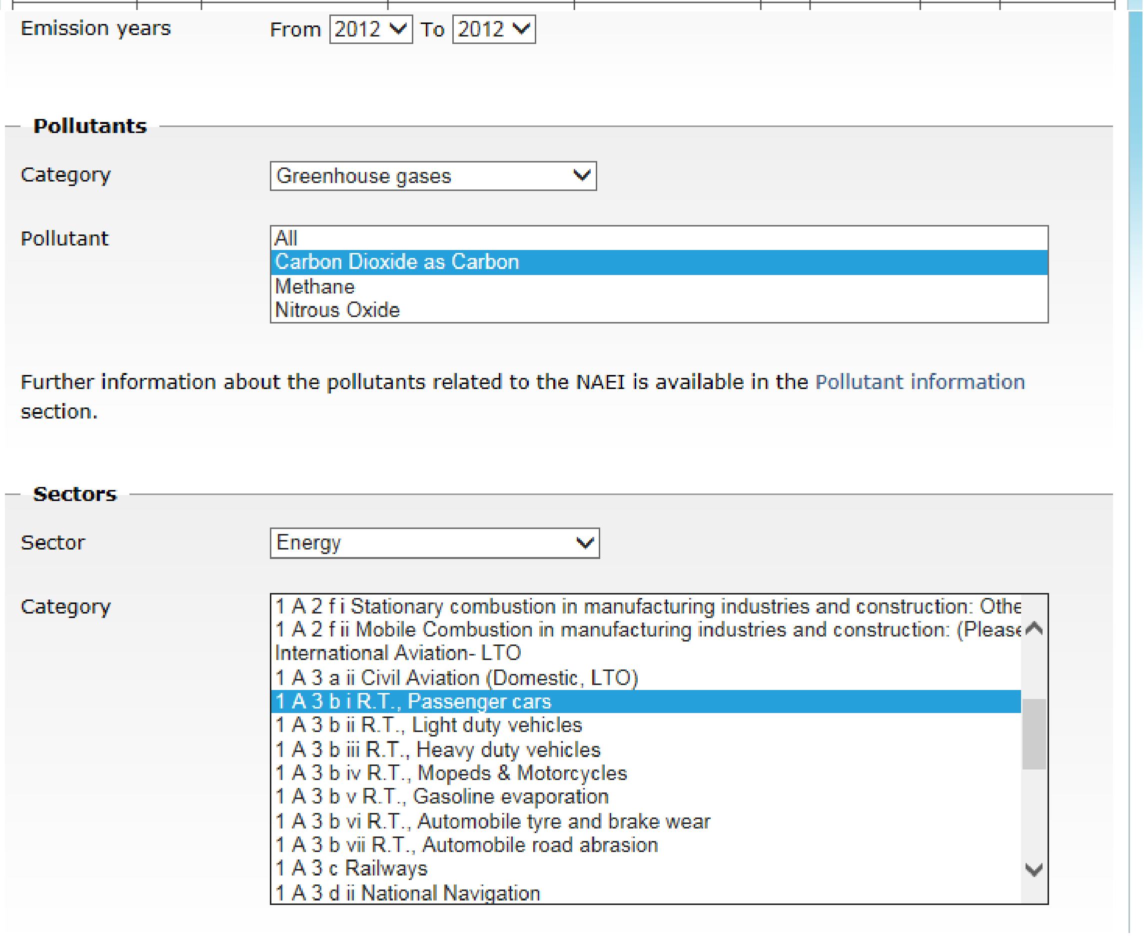
You are here: NAEI > Data > Emission factors > Emission factors detailed by source and fuel

Emission factors detailed by source and fuel

Search Summary: Greenhouse gases, Between 2012 - 2012, Carbon Dioxide as Carbon, Energy, 1 A 3 b i R.T., Passenger cars, All sources, All fuels

« Go back and change search criteria | Review full criteria | Download as CSV

Gas	Sector	NFR Code	Source	Fuel Name	Year	Emission Factor	Units	Activity Units
Carbon Dioxide as Carbon	Energy	1 A 3 b i R.T., Passenger cars	Road transport - cars - rural driving	Petrol	2012	855	kilotonne	Mt fuel consumed
Carbon Dioxide as Carbon	Energy	1 A 3 b i R.T., Passenger cars	Road transport - cars - rural driving	DERV	2012	863	kilotonne	Mt fuel consumed
Carbon Dioxide as Carbon	Energy	1 A 3 b i R.T., Passenger cars	Road transport - cars - urban driving	Petrol	2012	855	kilotonne	Mt fuel consumed
Carbon Dioxide as Carbon	Energy	1 A 3 b i R.T., Passenger cars	Road transport - cars - urban driving	DERV	2012	863	kilotonne	Mt fuel consumed



Emission years From 2012 To 2012

Pollutants

Category: Greenhouse gases

Pollutant:
All
Carbon Dioxide as Carbon
Methane
Nitrous Oxide

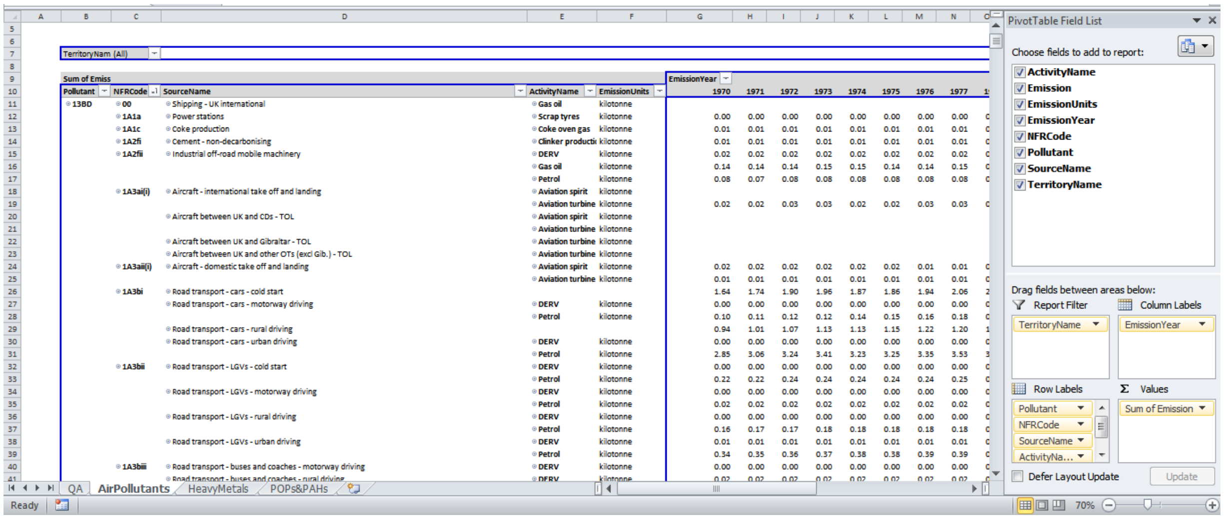
Further information about the pollutants related to the NAEI is available in the Pollutant information section.

Sectors

Sector: Energy

Category:
1 A 2 f i Stationary combustion in manufacturing industries and construction: Othe
1 A 2 f ii Mobile Combustion in manufacturing industries and construction: (Please
International Aviation- LTO
1 A 3 a ii Civil Aviation (Domestic, LTO)
1 A 3 b i R.T., Passenger cars
1 A 3 b ii R.T., Light duty vehicles
1 A 3 b iii R.T., Heavy duty vehicles
1 A 3 b iv R.T., Mopeds & Motorcycles
1 A 3 b v R.T., Gasoline evaporation
1 A 3 b vi R.T., Automobile tyre and brake wear
1 A 3 b vii R.T., Automobile road abrasion
1 A 3 c Railways
1 A 3 d ii National Navigation

Figure 16: Illustration of NAEI spreadsheet-based calculator



Learn more: http://naei.defra.gov.uk/data/ef-all

2.2 The U.S.

A Pew Institute study projected that if example policies were adopted and enforced with minimal leakage, then US GHG emissions could be reduced to 50% of pre-2000 levels by 2030 (Greene & Plotkin, 2011). However, the evaluated impact per policy largely depends on the model used. Nevertheless, the US government has adopted vehicle emission calculation models already in the 90s, and these models are still informing its CAFÉ and newly established GHG standards as well as fuel regulation strategies.

The widely used U.S. transportation emission models are: GREET, MOVES, and ACEEE Green Book. The first of these, GREET, is a life cycle assessment (LCA) model developed by Argonne National Laboratory and sponsored by U.S. Department of Energy. It is most widely used in transportation modeling, and is applied by a variety of users from government to academy and industry. Next, U.S. Environmental Protection Agency (EPA) developed MOVES, which is a model largely influenced by GREET. The EPA created this model so that state and local agencies could accurately estimate pollutants from the transportation sector. Last is the ACEEE Green Book model. This model is the most recognized market-oriented scoring system. It evaluates the life cycle of vehicle performance in the U.S. market each year. These three models offer a comprehensive introduction into transportation emission modeling in the U.S.

2.2.1 GREET

GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) is a life cycle based transportation evaluation tool. The Argonne National Laboratory developed it in 1996, and U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) have since sponsored it. GREET is also co-sponsored by multiple stakeholders across the fuel and automobile industries as well as government agencies. The fuel and automobile industry sponsors include major companies like General Motors Corporation, British Petroleum, and ExxonMobil. GREET is also sponsored by prominent governmental agencies, such as U.S. Environmental Protection Agency (EPA) and Illinois Department of Commerce and Economic Opportunities. GREET has been a widely prominent evaluation tool, influencing governmental analysis, academic research, and corporate strategy.[5]

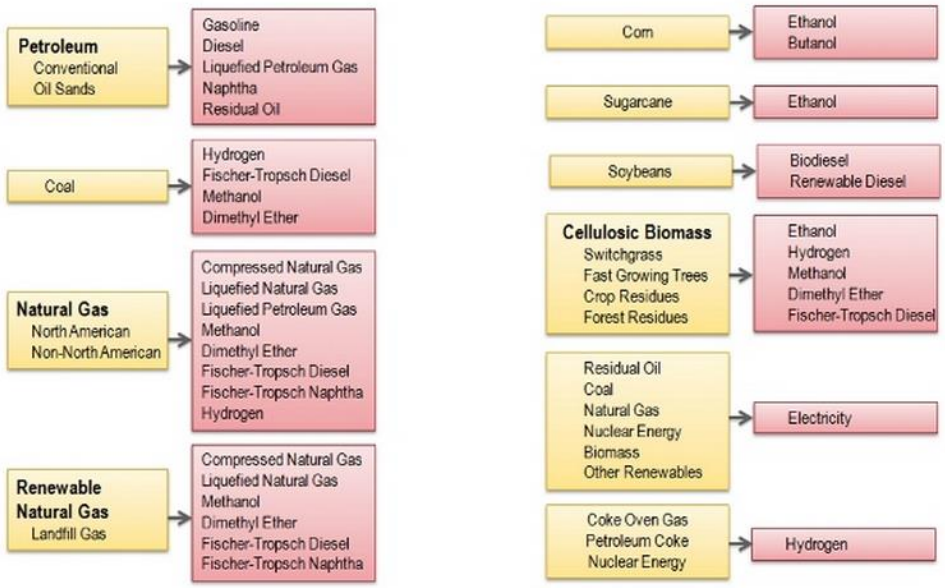
GREET aims to fully evaluate the energy and emission impacts of advanced vehicle technologies and new transportation fuels. This includes the fuel cycle from wells to wheels, the vehicle cycle through material recovery, and vehicle disposal. Moreover, GREET considers a broad diversity of vehicle technologies, such as: conventional spark-ignition engine, direct-injection engine, hybrid electric, plug-in hybrid electric, battery-powered electric, and fuel cell vehicles for passenger cars, class 1 (gross weight < 6000 lb.), and class 2 (gross weight < 8500 lb.) light duty trucks.

GREET models are based on life cycle assessment (LCA). This technique studies the environmental aspects and potential impacts of all phases of vehicle production. It begins with raw material acquisition, includes transportation, production, and use, and ends with disposal.[6] GREET is comprised of several models working together. Broadly, GREET applies the Well to Wheels (WTW) model, which is composed of the Well to Pump (WTP, fuel-cycle) and Pump to Wheels (PTW, vehicle-cycle) models. The fuel-cycle model (WTP) calculates emissions from seven criteria pollutants, including: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter with size smaller than 10 micron (PM10), particulate matter with size smaller than 2.5 micron (PM2.5), black carbon (BC), and sulfur oxides (SOx). The vehicle-cycle model (PTW) calculates three greenhouse gases, including: carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). It also analyzes total energy consumption, fossil fuel consumption, and petroleum consumption when various transportation fuels are used.[7] Finally, the vehicle-cycle model also determines the energy use and emissions that are required for vehicle component production, battery production, fluid production and use, vehicle assembly, disposal, and recycling.[8]

GREET is available in both Excel and software versions, and is free to all users.

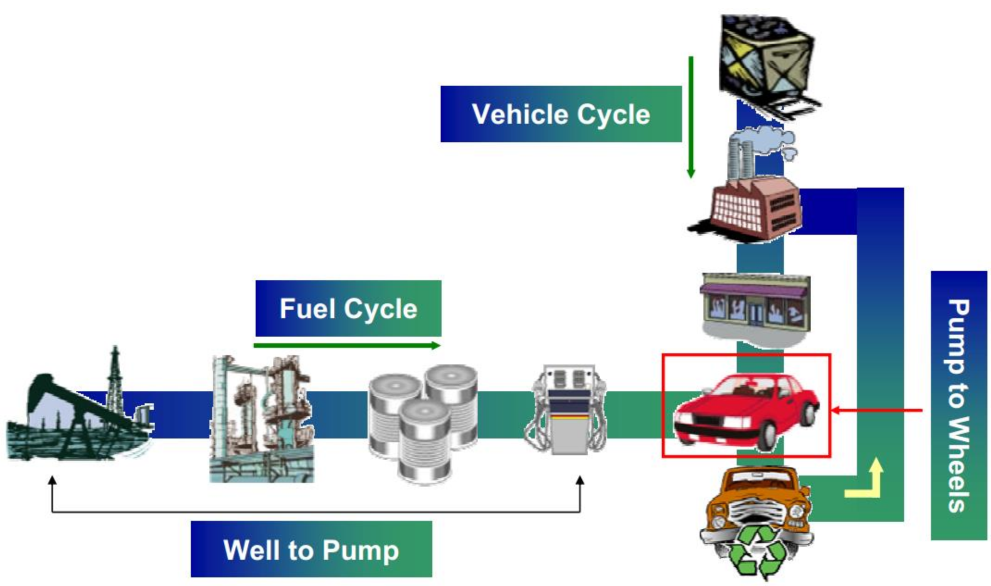
[5] http://www.transportation.anl.gov/pdfs/TA/419.pdf
[6] ISO 14040 http://web.stanford.edu/class/cee214/Readings/ISOLCA.pdf
[7] M.Q. Wang. GREET 1.5 — Transportation Fuel-Cycle Model
[8] M.Q. Wang GREET 2.7 http://www.transportation.anl.gov/pdfs/TA/378.PDF

Figure 17 GREET Fuel Pathways, including both fossil and renewable fuel



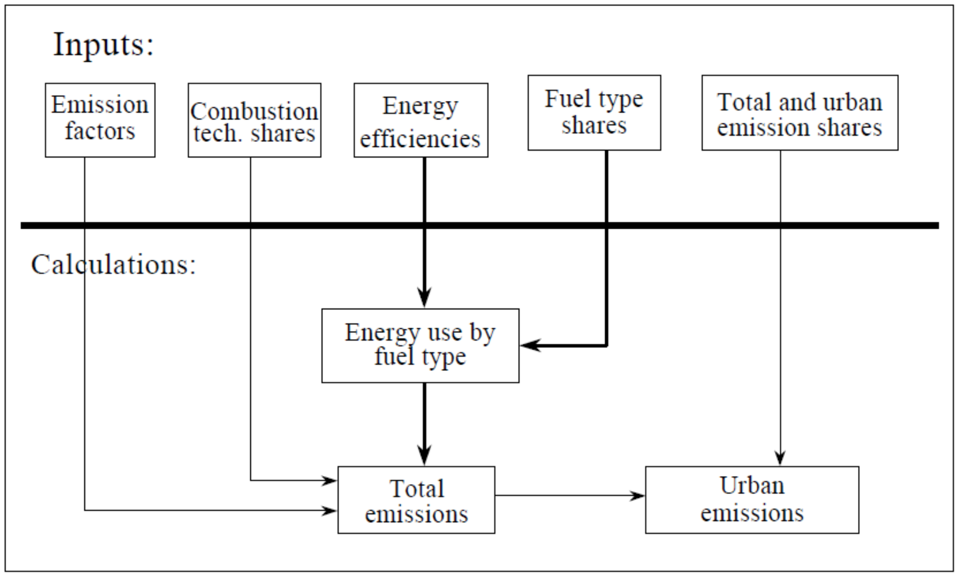
Source: Argonne National Laboratory

Figure 18 GREET Well to Wheels (WTW) model



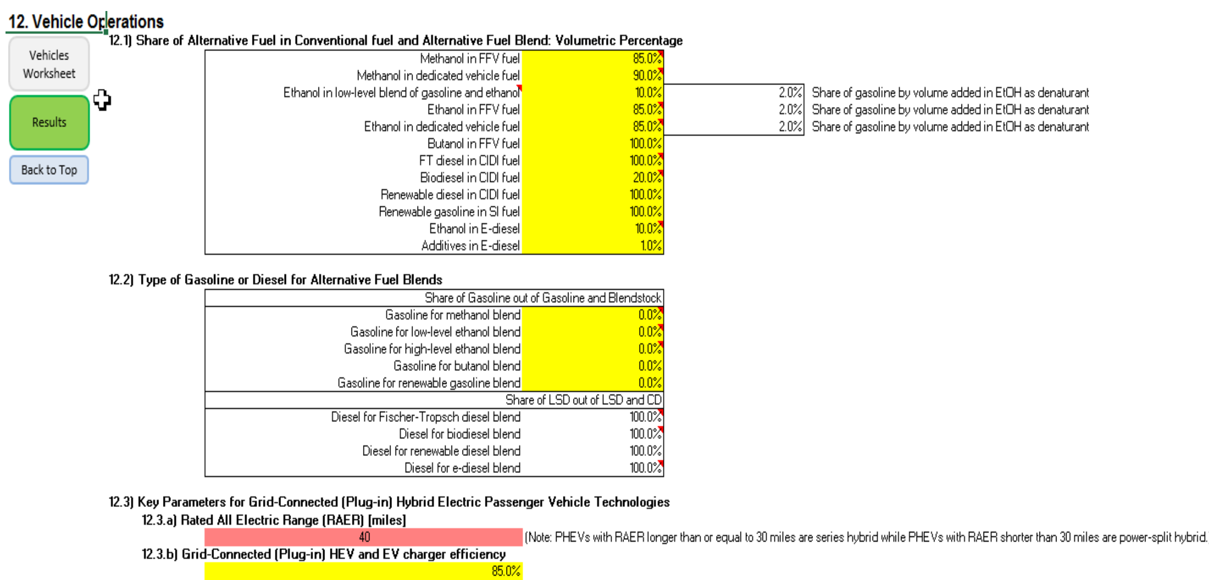
Source: Argonne National Laboratory

Figure 19 GREET's Logistics for Upstream Energy Use and Emissions Calculations



Source: Michel Wang et al[9]

Figure 20 Illustration of Excel-based GREET model



Source: GREET 2014 Model

[9] M.Q. Wang. GREET 1.5 — Transportation Fuel-Cycle Model

Figure 21 Illustration of GREET Result

Home | Inputs | Back to Top | WTP Results | WTW Changes

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

Heavy-Duty Vehicles
Combination Long-Haul Trucks, diesel is baseline fuel
SI Vehicle: CNG
Go

Unit Selection: Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled or Cargo Distance Transported
Energy Unit: Btu Emission Unit: g
Service Functional Unit for Heavy-Duty Vans and Trucks: mile
Service Functional Unit for Buses: mile

Per Energy in Fuels
Energy Unit: Btu Emission Unit: g
Energy Functional Unit: mmBtu

SI Combination Long-Haul Trucks: CNG, NA NG

	Btu/mile or Gallon/mile or g/mile				Btu/mmBtu or Gallon/mmBtu or g/mmBtu			
Item	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Total Energy	2,826	1,245	24,240	28,311	116,572	51,378	1,000,000	1,167,950
Fossil Fuels	2,798	1,058	24,240	28,095	115,423	43,629	1,000,000	1,159,052
Coal	101	682	0	783	4,167	28,131	0	32,298
Natural Gas	2,594	355	24,240	27,188	107,020	14,627	1,000,000	1,121,646
Petroleum	103	21	0	124	4,236	871	0	5,107
Water Consumption	0	0	0	0	5	12	0	16
CO2 (w/ C in VOC & CO)	175	91	1,438	1,704	7,228	3,763	59,307	70,297
CH4	7	0	0	6.906	278.242	6.382	0.269	284.892
N2O	0	0	1	0.971	1.569	0.059	38.441	40.070
GHGs	388	96	1,685	2,169	15,991	3,970	69,502	89,463
VOC: Total	0.263	0.010	0.407	0.679	10.831	0.409	16.783	28.022
CO: Total	0.836	0.030	16.812	17.678	34.487	1.233	693.579	729.299
NOx: Total	1.055	0.114	2.376	3.545	43.517	4.710	98.014	146.240
PM10: Total	0.016	0.028	0.114	0.158	0.644	1.156	4.715	6.516

Source: GREET 2014 Model

2.2.2 MOBILE

The EPA created MOBILE in order to accurately monitor highway vehicle pollution. The first MOBILE model, called MOBILE1, was developed in the late 1970s. Since then, it has been periodically updated to reflect improved technology, additional data and changes in vehicle, engine, and emission control systems. Further, each MOBILE update accounts for changes in applicable regulations, emission standards, and test procedures, as well as a better understanding of in-use emission levels and the factors that influence them. The latest version was MOBILE6.2, built in 2004.

MOBILE considers both exhaust and evaporative emissions. The model's output is in the form of emission factors, which can be expressed as grams of pollutant per vehicle per hour (g/hr) or per vehicle mile traveled (g/mi). Consequently, emission factors from MOBILE can be combined with estimates of total vehicle miles traveled (VMT) to develop highway vehicle emission inventories (in terms of tons per day, per month, per season, per year). The change in emission factors for a given vehicle category over time reflects the impacts from fleet turnover. Put another way, older vehicles built to less stringent emission standards are eventually replaced in the fleet by newer vehicles built in compliance with more stringent standards.

Table 5: MOBILE evolvement

Year of publication	Version	Specification
1978	MOBILE1	The first model for highway vehicle emission factors. Be able to calculate the emission factors of HC、CO and NO_X of 6 types of vehicles during 1970-1999.
1981	MOBILE2	Updated with new data on emission-controlled vehicles (i.e., catalytic converters, model years 1975 and later) at higher ages/mileages. Provided additional user control of input options.
1984	MOBILE3	Eliminated California vehicle emission rates. Continued to model low- and high-altitude emissions. Added tampering rates and associated emissions impacts and anti-tampering program benefits. Adjusted non-exhaust emissions to account for "real world" fuel volatility as measured by Reid vapor pressure (RVP).
1989	MOBILE4	Added evaporative running losses as a distinct emission source for gasoline powered vehicles. Modeled fuel volatility (RVP) effect on exhaust emission rates. Expanded user-controlled options for input data.
1991	MOBILE4.1	Added features allowing user control of more parameters affecting in-use emission levels, including more inspection/maintenance (I/M) program designs. Added the effects of various new emission standards and related regulatory changes (e.g., test procedures). Included the impact of oxygenated fuels (e.g., gasohol) on CO emissions
1993	MOBILE5	Based new basic emission rate equations on much larger database derived from State-implemented IM240 test programs. Included effects of new evaporative emission test procedure. Added effects of reformulated gasoline (RFG). Added the impact of oxygenated fuels on HC emissions. Added effect of light duty Tier 1 emission standards and new NOx standard of 4.0 g/bhp-hr for heavy-duty engines. Added July 1 evaluation option. Allowed modeling of low-emitting vehicle (LEV) programs patterned after California regulations. Revised speed corrections.
1993	MOBILE5a	MOBILE5a was issued about 4 months after MOBILE5 to correct a number of minor errors detected under certain specific conditions.
1996	MOBILE5b	Updated to reflect impacts of new regulations promulgated, including: onboard refueling vapor recovery systems, detergent gasoline additives, and Phase II RFG requirements. Reactivated calculation of idle emission factors and expanded calendar year range for which

		emission factors can be calculated from 2020 to 2050. Increased flexibility of modeling of I/M programs, providing easier modeling of retest-based hybrid I/M programs, evaporative emission system pressure and purge tests, technician training and certification (TTC) credits, and ASM tests. Corrected phase-in of emission benefits for first cycle of I/M program operation.
2001	MOBILE6	Updated with new and improved data in many areas, including in-use deterioration of 1981-and-newer vehicles, light duty speed effects, gasoline sulfur effects, and evaporative emissions. Revised I/M benefit algorithm. Removed calculation of purge test benefit. Revised algorithms for air conditioning and high acceleration driving. Added the effects of Tier 2 and new heavy duty engine and diesel fuel rules. Expanded number of vehicle sub-classes from eight to 28. Added hourly calculation of emissions and emission estimates by roadway type. Separated start and running exhaust emissions. Removed calculation of idle emissions. Allowed user entry of more detailed vehicle activity information
2002	MOBILE6.2 (2002,2004)	Added ability to model emission factors for particulate matter and six air toxics (Benzene, Methyl Tertiary Butyl Ether, 1,3-Butadiene, Formaldehyde, Acetaldehyde, and Acrolein). Added ability to model additional air toxics with user-supplied emission factors. Added spreadsheet output option. Improved carbon monoxide emission factors.

Source: http://www.epa.gov/otaq/models/mob-hist.htm

In 2010, the MOBILE series of models was replaced by MOVES as EPA's official model for estimating emissions from cars, trucks and motorcycles.

2.2.3 MOVES

Office of Transportation and Air Quality (OTAQ) developed Motor Vehicle Emission Simulator (MOVES), and it is used in U.S. Environmental Protection Agency (EPA). MOVES allows state and local agencies to estimate a variety of volatile organic compounds (VOCs), including: nitrogen oxides (NOX), particulate matter (PM2.5 and PM10), carbon monoxide (CO), and other precursors from cars, trucks, buses, and motorcycles. These estimates are then used for state implementation plans (SIP) and conformity determinations outside of California. Unlike the previous versions, MOVES2014 also incorporates the effects of three new federal emissions standard rules, including greenhouse gas (GHG) emission and fuel efficiency standards for Light-duty vehicles, Medium- and heavy-duty engine and vehicles.[10]

Another feature of the MOVES model is that it can be used to answer real world *what if* questions. Questions like, how would particulate matter emissions decrease in a state on a typical weekday if truck travel were reduced during rush hour? Or, how does the total hydrocarbon emission rate change if the fleet switches to gasoline from diesel fuel? The purpose of MOVES is to provide an

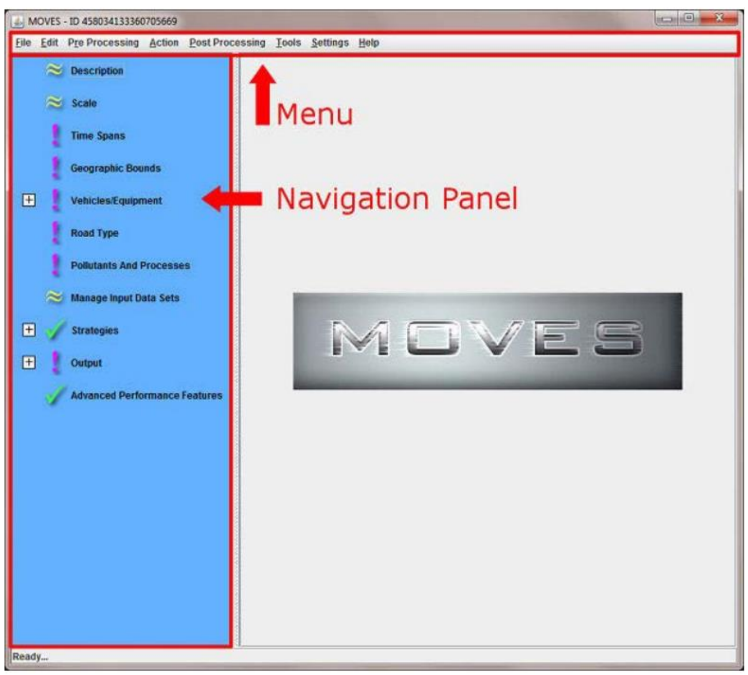
[10] http://www.gpo.gov/fdsys/pkg/FR-2014-10-07/pdf/2014-23258.pdf

accurate estimate of emissions from highway vehicles and off road mobile equipment under a wide range of fact-specific conditions.

When beginning the modeling process, the MOVES' user creates the parameters. Anything from equipment or vehicle types to time periods, geographical areas, pollutants, vehicle operating characteristics, and road types can all be personalized. This gives the user the ability to simulate how a vehicle would act under a specific set of conditions. Once the conditions are set, MOVES will perform a series of calculations to determine the outcome of the scenario. What makes MOVES so useful is that it is developed to reflect real vehicle operating processes, such as cold start or extended idle, and then it provides an accurate estimate of what the bulk emissions or emission rates would be.

The MOVES model is able to incorporate data from a variety of databases. These databases include EPA research studies, Census Bureau vehicle surveys, Federal Highway Administration travel data, and other federal, state, local, industry and academic sources. In addition, when new data becomes available it can be easily incorporated into the existing model. Finally, MOVES allows and facilitates the import of personalized data, so if a user would like to see how a vehicle *may* react under a certain set of conditions, which is also an option.

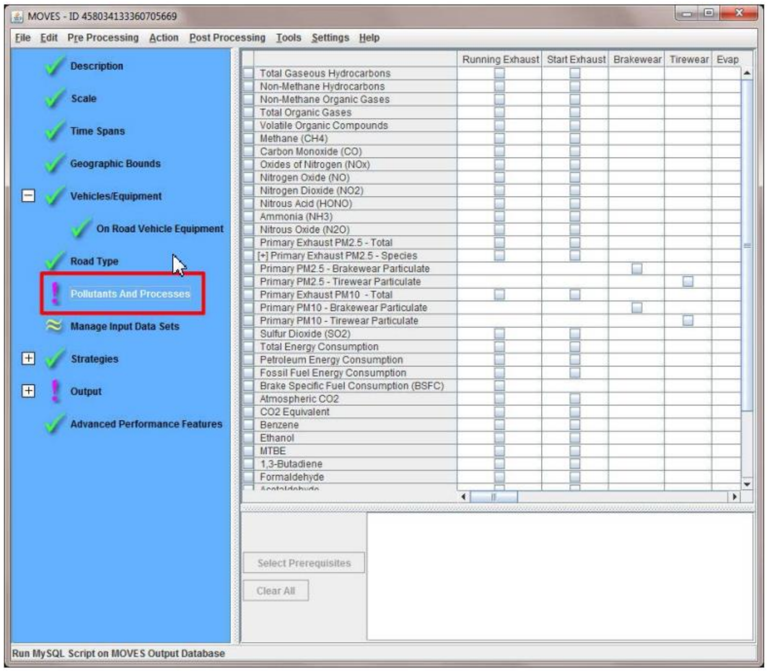
Figure 22 Illustration of MOVES 2014



Source: US Environmental Protection Agency - MOVES User Guide 2014[11]

[11] http://www.epa.gov/oms/models/moves/documents/420b14055.pdf

Figure 23 Illustration of MOVES 2014--pollutants



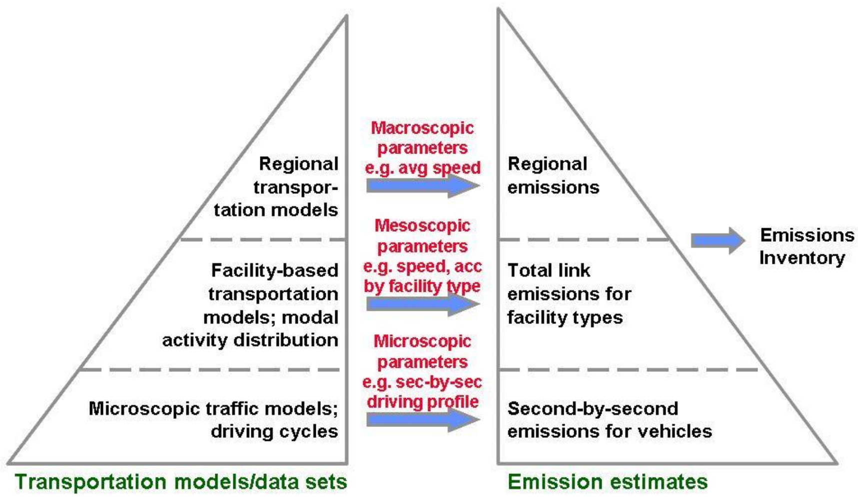
Source: US Environmental Protection Agency - MOVES User Guide 2014

2.2.4 CMEM

CMEM[12] was initially developed in the late 1990's with sponsorship from the National Cooperative Highway Research Program (NCHRP) and the U.S. Environmental Protection Agency (EPA) to fulfill the need for microscopic emissions modeling. This type of model is necessary for evaluating emissions benefits of project-level or corridor-specific transportation control measures (e.g. HOV lanes), intelligent transportation systems (ITS) implementations (e.g. electronic toll collection), and traffic flow improvements (e.g. traffic signal coordination).

[12] http://www.cert.ucr.edu/cmem/

Figure 24: CMEM model illustration



Source: http://www.cert.ucr.edu/cmem/

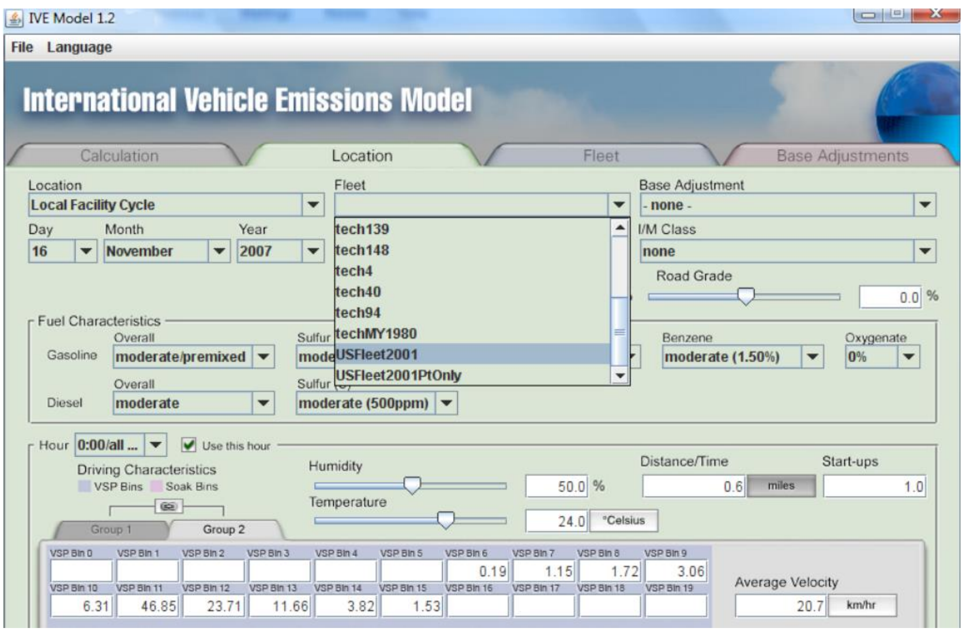
CMEM predicts second-by-second tailpipe emissions and fuel consumption based on different modal operations from an in-use vehicle fleet. One of the most important features of CMEM is that it uses a physical, power-demand approach based on a parameterized analytical representation of fuel consumption and emissions production. In this type of model, the entire fuel consumption and emissions process is broken down into components that correspond to physical phenomena associated with vehicle operation and emissions production. Each component is modeled as an analytical representation consisting of various parameters that are characteristic of the process. These parameters vary according to the vehicle type, engine, emission technology, and level of deterioration. One distinct advantage of this physical approach is that it is possible to adjust many of these physical parameters to predict energy consumption and emissions of future vehicle models and applications of new technology (e.g., after-treatment devices).

The required inputs for CMEM include vehicle activity (second-by-second speed trace, at a minimum) and fleet composition of traffic being modeled. The initial version of CMEM contains 23 light-duty gasoline vehicle/technology categories characterized by emission control technology, emission certification standard, mileage, power-to-weight ratio, and high emitting characteristic. With the continued support by the U.S. EPA, CMEM has been maintained and updated by adding new vehicle/technology categories as they emerge. For example, ultra-low emission vehicles (ULEV), super ultra-low emission vehicles (SULEV), and partial zero emission vehicles (PZEV) are now incorporated into CMEM. In addition, CMEM has been expanded to include the heavy-duty diesel vehicles. The current version of CMEM (version 3.0, 2005) includes 28 light-duty vehicle/technology categories and 3 heavy-duty vehicle/technology categories.

2.2.5 IVE

The International Vehicle Emissions (IVE)[13] Model is a computer model funded by the US Environmental Protection Agency (EPA). This model is used to estimate emissions from motor vehicles in developing countries. IVE is intended to assist developing cities and regions acquire accurate emissions estimates that will enable them to: focus control strategies and transportation planning on those that are most effective; predict how different strategies will effect local emissions; and measure progress in reducing emissions over time. In addition, the model makes estimates of local air pollutants (criteria pollutants), greenhouse gas emissions, and toxic pollutants. Lastly, IVE is specifically designed to be flexible enough to meet any problem a developing nation may face with regards to mobile source air emissions.

Figure 25: IVE model demonstration



Source: http://www.issrc.org/ive/

2.2.6 EMFAC[14]

The California Air Resources Board designed the first version of EMFAC, and it was published in 1988. The model theory behind EMFAC is similar to MOBILE, which is a modified experiential model. EMFAC has played a unique and important role in California. To determine the emission factors associated with the vehicle fleet, speeds, and environmental conditions, project-level air quality modeling is necessary.

The latest version "EMFAC 2011[15]" was released by ARB on September 30, 2011, and was made available for conformity use by U.S. EPA on March 6, 2013. All new air quality analysts must use

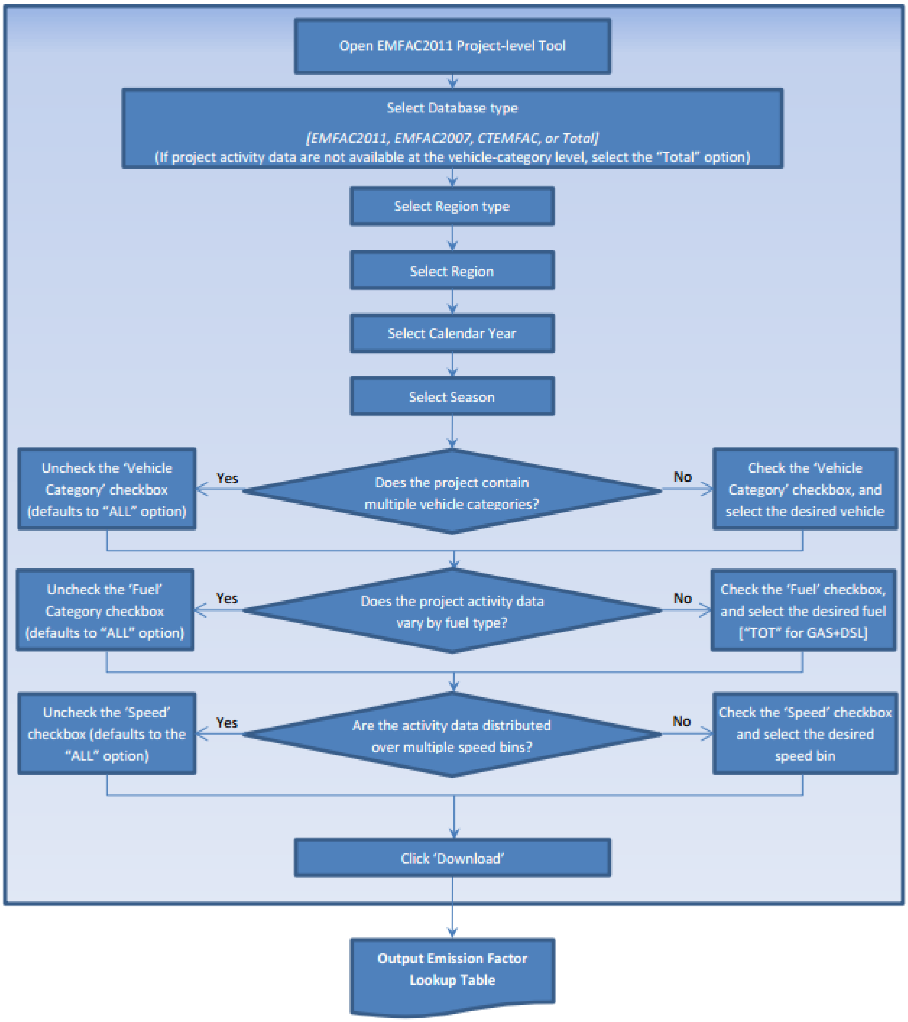
[13] http://www.issrc.org/ive/

[14] http://www.arb.ca.gov/msei/msei.htm

[15] The current version of the EMFAC model, future model versions, and supporting documentation can be downloaded from the CARB website at: http://www.arb.ca.gov/msei/msei.htm

EMFAC 2011 as of September 6, 2013. NEPA and CEQA (non-conformity-related) air quality reports that started during or after September 2011 should be using EMFAC 2011 for new studies.

Figure 26: Simplified Approach for Project-level Assessment



Source: http://www.issrc.org/ive/

2.2.7 ACEEE Green Book

American Council for Energy-Efficiency Economy (ACEEE) introduced Green Book Online[16] in order to provide comprehensive information about the environmental performance of automobiles for buyers and manufacturers. Green Book Online is an annual consumer-oriented guide providing an environmental rating for every new U.S. light-duty vehicle model on the market. This includes gasoline, electric, plug-in electric, plug-in hybrid, and fuel cell vehicles. The 0-100 scale scoring system was established based on principles of life cycle assessment (LCA) and environmental economics. This approach combines the impacts of regulated criteria pollutants with the impacts from greenhouse gas emissions, vehicle life cycle, upstream emissions, manufacturing, and disposal.

[16] http://greenercars.org/

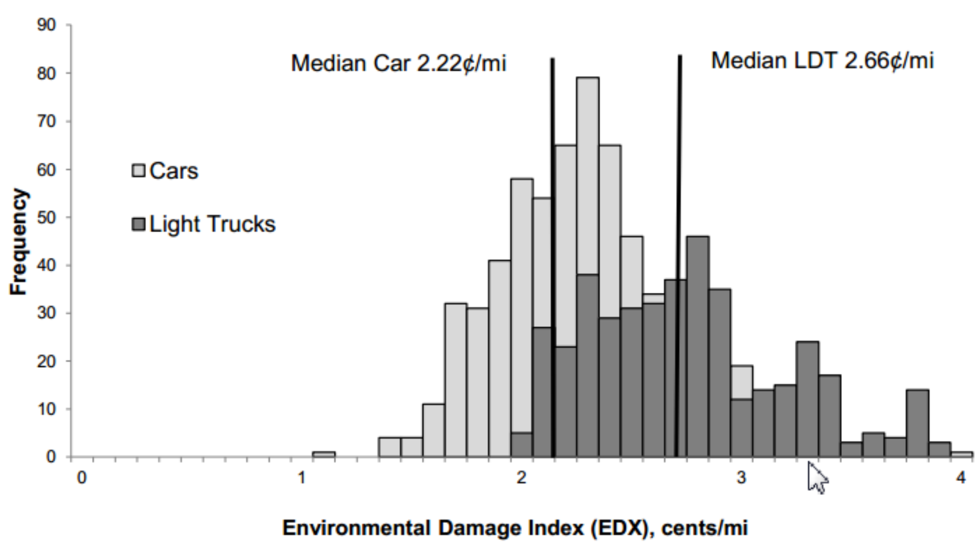
The Green Book methodology provides a rating system that integrates four types of data along with parameters for weighting the various items in order to provide a model-specific index of life cycle environmental impact. This data includes: (1) vehicle emissions data, addressing most aspects of use phase air pollution; (2) vehicle fuel consumption data, addressing other aspects of use phase air pollution as well as energy use and GHG emissions; (3) vehicle mass, addressing materials production, manufacturing and disposal impacts; and (4) battery mass and composition for hybrids and plug-in vehicles.[17]

Drawing from the LCA, the Green Book assesses the full environmental impact of automobiles from production to use to disposal. However, to formalize the life cycle impact, and in order to reduce the results to a single metric applicable to any vehicle, Environmental Damage Index (EDX) was created. EDX is defined as a sum of damage functions, each based on attributes associated with the life cycle of the vehicle and its fuel.

When determining the environmental impacts of the *use phase*, fuel consumption, driving, storage, maintenance, air/water/noise pollution, and greenhouse gas (GHG) emissions are all considered. The in-use emissions in the methodology are both regulated and non-regulated. This includes CO, non-methane organic gases (NMOG), HC, NOx, particulate matter smaller than 10 microns (PM10), sulfur dioxide (SO2), methane (CH4), nitrous oxide (N2O), and carbon dioxide (CO2). The pollutants are estimated as a function of fuel type and consumption rate, independent of the emission standards. The estimation of pollutants took multiple factors into consideration, including but not limited to tailpipe emission, evaporative emission, fuel economy, and fuel consumption[18].

The rating scores are converted into vehicle class based on range of EDX values. The vehicle class includes superior, above average, average, below average, and inferior.

Figure 27: Green Book Environmental Damage Index (EDX) for cars and light trucks, cents/mi



Source: ACEEE website

[17] http://www.greenercars.org/greenercars-ratings/how-we-determine-ratings
[18] http://aceee.org/sites/default/files/publications/researchreports/t111.pdf
http://www.greenercars.org/sites/default/files/file_room/2015methodologyupdate.pdf

Figure 28: GreenCars Ratings by ACEEE Green Book

Year	Make	Model	Specification	Emission Standard	MPG City	MPG Hwy	Green Score	Ranking	Compare	Details
2015	MERCEDES-BENZ	SMART FORTWO ELEC. DRIVE CONVERTIBLE	Electric (Li-ion bat.)	ZEV / Bin 1	3.61	2.77	**61**	Superior		
2015	MERCEDES-BENZ	SMART FORTWO ELEC. DRIVE COUPE	Electric (Li-ion bat.)	ZEV / Bin 1	3.61	2.77	**61**	Superior		
2015	CHEVROLET	SPARK EV	Electric (Li-ion bat.)	ZEV / Bin 1	3.81	3.24	**59**	Superior		
2015	FIAT	500E	Electric (Li-ion bat.)	ZEV / Bin 1	3.63	3.21	**59**	Superior		
2015	NISSAN	LEAF	Electric (Li-ion bat.)	ZEV / Bin 1	3.75	3.01	**57**	Superior		
2015	TOYOTA	PRIUS C	1.5L 4, auto CVT	SULEV II / Bin 3	53	46	**57**	Superior		
2015	BMW	i3 REX	Electric (Li-ion bat.) / 0.6L 2, auto	Bin 5	3.77 / 41	3.16 / 37	**56**	Superior		
2015	VOLKSWAGEN	E-GOLF	Electric (Li-ion bat.)	ZEV / Bin 1	3.73	3.12	**56**	Superior		

Source: Greencars.org

2.3 China

This section covers major transport emission calculators developed specifically for China, and tested in several targeted locations throughout the region. This section first provides a general overview, and then narrows, analyzing case-by-case reports of recent calculators.

2.3.1 General overview of transportation calculator's development in China

China's vehicle emission control program history dates back to the early 1980's. It began with successively issuing emission standards on motor and crankcase emissions, and also enacting "Supervision and Management measures on vehicle exhaust emission[19]." Although the modern nationwide control program did not begin until the 1990's, Tsinghua University first brought in MOBILE5 model from the US for China's vehicle emission factor and emission inventory development. In 2001, new vehicle emission standard[20] equal to the EU standard saw implementation, triggering interests in European models. Since then, models designed by the US and Europe, such as MOBILE5/6, COPERT, EMFAC, CMEM, and IVE, etc. have been widely used to

[19] http://www.zhb.gov.cn/gkml/zj/wj/200910/t20091022_172477.htm?COLLCC=2843832267&
[20] http://www.mep.gov.cn/image20010518/1920.pdf

calculate the vehicle emission factor and inventory in Beijing, Nanjing, Chongqing, Chengdu, Shenzhen, Shanghai, Macau and Hong Kong[21].

Tsinghua University (Hao, et al., 2000)[22] has done comprehensive research on vehicle emission, and has made vehicle emission inventory in several cities in China, such as Beijing[23], Shenzhen, Nanjing[24], Macau[25], etc. with vehicle emission models. Tongji University (Li et al., 2004)[26] has modified MOBILE6 by testing the emission factor in both European and FTP cycle, and estimated the emission factor and emission amount in Shanghai.

Hong Kong[27] utilized a modified EMFAC model, named as EMFAC-HK, to estimate the cities transport pollution. The model has been modified in 4 aspects: vehicle category, emission standard, I/M and emission control. The transport agency provides the vehicle activity data in road level to support the emission model.

Beijing Technology and Business University (He et al., 2006)[28] calculated the emission factor of light-duty vehicles in Beijing with the CMEM Access 2.0 model. The data and parameters were collected from 9 light-duty vehicles with typical technology characteristics. The CO_2, CO, HC, and NO_X, emission factors for 4 types of typical individual light-duty vehicles and comprehensive fleet in Beijing were determined under different transport situations.

In 2002, Peking University (Xie et al., 2006) [29-30] used the COPERT model to calculate the vehicle emission factors of CO, NOx, NMVOC and PM in China, and developed vehicle emission inventories with 40kmx40km spatial resolution using GIS. The required parameters were determined based on the actual categories, driving cycles and fuel characteristics of motor vehicles in China. Peking University also compared the emission factors derived from the COPERT and MOBILE E models with chassis dynamometer.

The Chinese Academy of Science[31], a key laboratory and institute of urban environment and health, developed a transport model named Xiamen-2008Tra using a Long Range Energy Alternatives Planning System (LEAP) to estimate the reduction potential of energy consumption and transport emissions of CO2、SO2、NOx and PM10 in Xiamen from 2008 till 2030.

By introduction and practical application of international models, macroscopic models based on average speed have been used sophisticatedly, and meso-scopic and microscopic models are being developed. The basic transport database has been well developed in cities like Beijing, Shanghai, and Shenzhen, for example. However, vehicle emission inventories have yet to be established in

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21 马因韬, 栾胜基,等. 机动车排放模型的应用及其实用性比较[J]. 北京大学学报, 2008.
22郝吉明, 傅立新, 贺克斌, 吴烨. 城市机动车排放污染控制：国际经验分析与中国的研究成果[M]. 中国环境科学出版社,2000.
23北京市机动车排放因子模型软件 V2.0，2013
24南京市机动车排放因子模型软件 V1.0， 2014
25澳门机动车排放因子模型软件 V2.0，2014
26李潭峰.上海市机动车排放因子及排放总量研究.同济大学硕士论文.2004.
27 Hong Kong Environmental Protection Department. Guideline on Modeling Vehicle Emission, HK EPD, 2005. http://www.epd.gov.hk
28何春玉,王岐东.运用 CMEM 模型计算北京市机动车排放因子[J].环境科学研究,2006.
29宋翔宇,谢绍东.中国机动车排放清单的建立[J]. 环境科学,2006.
30谢绍东,宋翔宇,等.应用 COPERT3 模型计算中国机动车排放因子[J], 环境科学,2006.
31周健, 崔胜辉, 等.基于 LEAP 模型的厦门交通能耗及大气污染物排放分析. 环境科学与技术, 2011.

most Chinese cities. Lacking related statistical data, it's hard to match the models. Therefore, it's meaningful and important to develop localized vehicle emission inventory models for China. So far, the native environmental protection department and local government together with environmental organizations are working on mainly: i) localizing foreign models by modifying model with real-world transportation data, such as Beijing; and ii) developing brand new models on the basis of model theory for city levels, such as Shenzhen and Chengdu.

2.3.2 China Road Transport Emission Model (CRTEM), GIZ HBEFA-based design for China

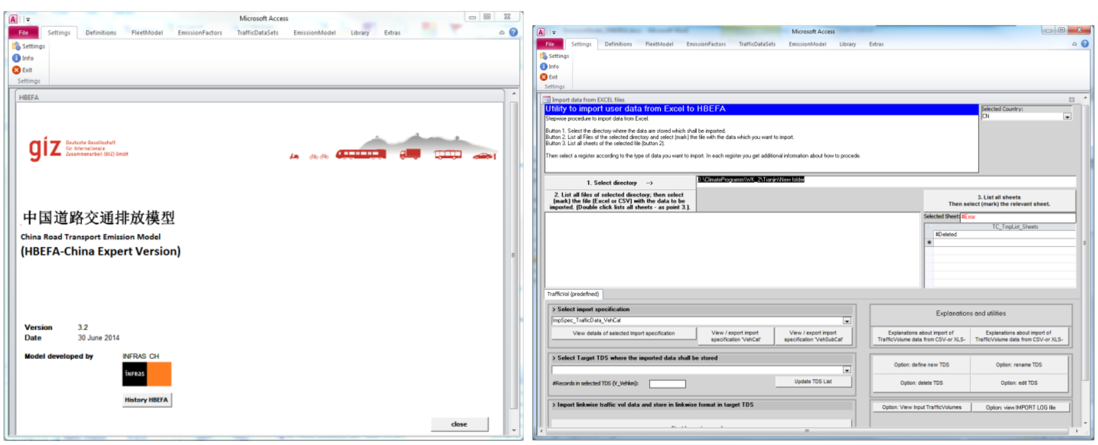
GIZ in collaboration with several partners in China and INFRAS in Switzerland have utilized HBFRA

GIZ, in collaboration with several partners in China and INFRAS in Switzerland, have utilized the HBFRA model (see section 2.1.3) for tailoring a bottom-up emission model for urban transport in China, the China Road Transport Emission Model (CRTEM).[32]

CRTEM/HBEFA-China is a software package that simplifies and facilitates emission calculation. It integrates all components of an emission model with a user-friendly interface. This tool was developed in Microsoft Access and is based on the HBEFA Expert Version of INFRAS.

The model's prime objective 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. It allows Chinese cities to account for their transport emissions and calculate the emission-related impacts of scenarios in travel demand models.

Figure 29: CRTEM /HBFRA China demonstration



HBEFA China includes carbon emission factors for China's road transport and will include air pollution emission factors from 2015 onwards. The factors are CO2, CO, NOX, HC and several components of hydrocarbons (CH4, NMHC, benzene, toluene, xylene), NH3 and N2O, NO2, particle numbers (PN) and particle mass (PM). The model also calculates fuel consumption. It uses Microsoft Access as a platform and can be easily connected to existing travel demand models via a pre-installed interface to compute emissions street-wise. The China specific emission factors are already included within the CRTEM/HBEFA-China model.

CRTEM/HBEFA-China model has been used in Beijing[33], Shenzhen[32], Tianjin and Harbin. Shenzhen[34] developed an internet tool to visualize the CO_2 emissions at street level. Although it is

[32] http://transport-namas.org/modelling-ghg-emissions-of-road-transport-in-china/

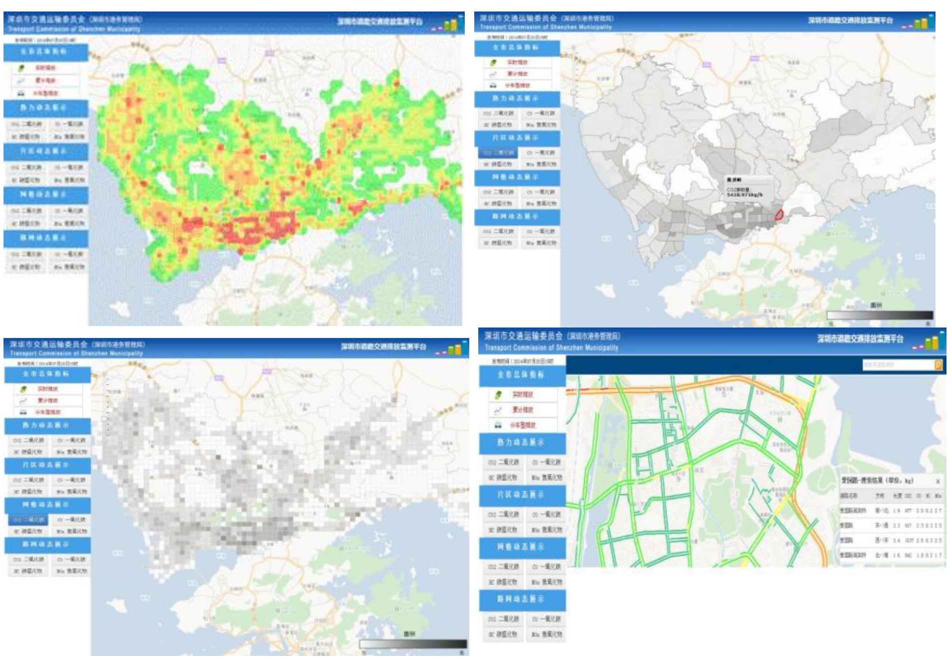
[33] 何巍楠, 刘莹,等.基于 HBEFA 的城市交通温室气体排放模型_以北京本地化建模为例.交通运输系统工程与信息. 2014.

clear that street-level emission data is more interesting when assessing air pollution (e.g. as an input to dispersion models), this example illustrates the potential of CRTEM/HBEFA-China for future applications.

In the first phase, the adoption of HBEFA in China focused on GHG from passenger cars. However traffic conditions for other vehicle categories were also included in the following phases. Currently, the model is calibrated and ready to use for carbon dioxide since fuel economy of a certain vehicle type is basically the same in Europe and China (considering the same traffic situations making carbon emission factors generated by the PHEM model with local driving cycles reliable).

Figure 30: Example of GPS tracking of trip in Beijing

Figure 31: Screenshot of Emission Monitoring System in Shenzhen



Source: Shenzhen TRC, 2014

[34] http://www.sutpc.com/newsinfo.asp?id=508

2.3.3 China Vehicle Emissions Model (CVEM), VECC-MEP

The Chinese Ministry of Environmental Protection (MEP) initiated a first-ever national pollution source census in 2007, and it was completed in 2009. The Vehicle Emission Control Center of MEP (VECC-MEP) was responsible for the mobile source emissions component of the pollution census. Data collection was implemented over the fall and winter of 2007-2008, and entailed the detailed surveying of vehicle population and activity data in 345 Chinese cities. VECC-MEP surveyed existing emission factor models, including COPERT, MOBILE, the IVE model, to determine the most suitable structure and methodology for a China-specific model--named CVEM, the China Vehicle Emissions Model. Key considerations included Chinese data availability and reliability as well as how to model China's unique populations of 2 and 3-wheelers and heavy-duty vehicles.

The specific directive to VECC-MEP is to calculate on-road mobile source emissions for only four pollutants: CO, HC, NOx, and PM. However, VECC-MEP is simultaneously re-designing the model to incorporate off-road mobile sources and to also calculate CO2 emissions[35]. VECC-MEP also plans to calculate historical and projected vehicle emissions in China from 1995 to 2025.

Table 6 : CVEM model design simplification

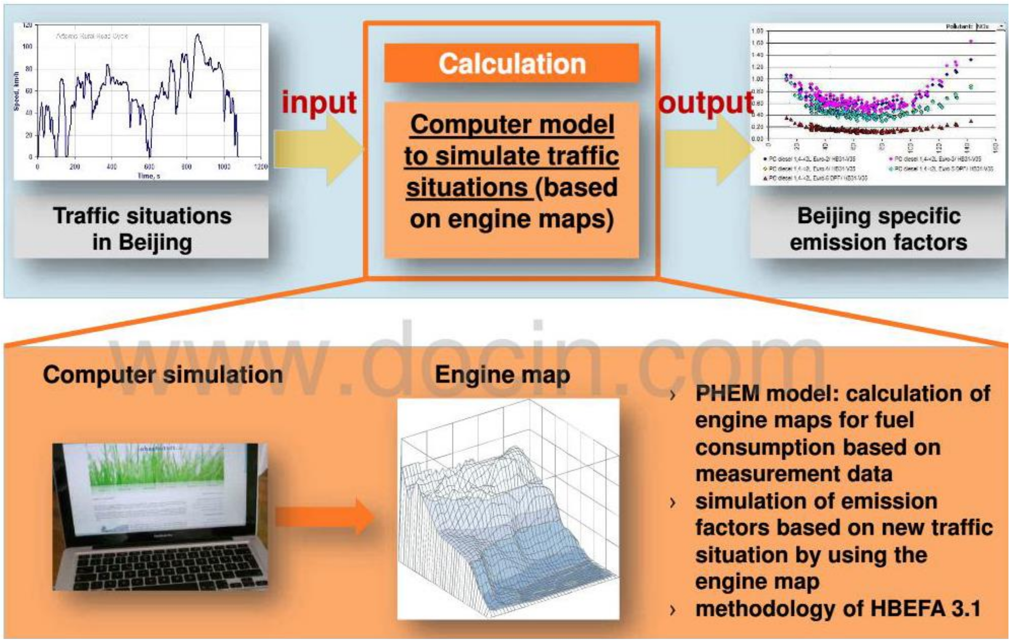
Environmental/Location Factors	Vehicle Activity Factors	Vehicle Fleet Factors
-Temperature **-Altitude** **-Fuel Properties (ethanol content, sulfur content, RVP)**	-Average speed by road type OR Vehicle Specific Power (VSP) bin allocation -Driving share by road type -Annual vehicle miles traveled (VMT) -Number of cold starts per day -Average trip length	-Vehicle population by type, model year, fuel, and emission standard -Odometer mileage by vehicle type

Key factors affecting vehicle emissions that are considered in CVEM.

CVEM considers two overall types of vehicle emissions, like all global models: tailpipe and evaporative. Separate methodologies were chosen for light-duty and heavy-duty vehicles primarily for reasons related to data availability in China. The methodology for light-duty vehicles and motorcycles is essentially an average speed-based methodology similar to that used by international models like the US EPA's MOBILE and Europe's COPERT models. For heavy-duty vehicles and low-speed 3 and 4-wheeled vehicles, on the other hand, CVEM uses a Vehicle Specific Power-based methodology similar to that used in "next generation" models like the US EPA's MOVES and the IVE model.

[35] http://www.vecc-mep.org.cn/download/index.jsp

Figure 32: Illustration of the CVEM model

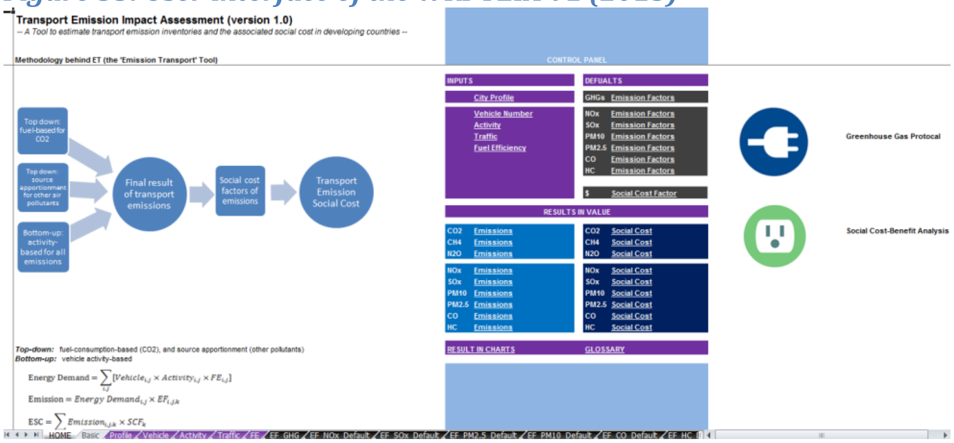


Source: Developing a First-Ever National Mobile Source Emissions Inventory for China

2.3.4 WRI China, version 1.0 (currently under development, name not yet finalized)

World Resources Institute (WRI) developed a methodological guideline and a simple tool based on MS Excel ("Transportation emission and social cost assessment guideline and tool" version 1.0). This tool is used to estimate transportation emission inventory and its corresponding social influence cost, and it took Chengdu as a case in 2004. This tools most helpful for developing countries, cities with an incomplete statistical system, and cities with weak data availability and quality. It is meant to estimate emission inventory of 6 air pollutants: (NO_X, SOX, PM10, PM2.5, CO, HC) and 3 GHG (CO_2, CH_4, N_2O). Additionally, the tool can help policy makers assess the social influence cost caused by transportation emission. Based on the quantification of transportation emission and social influence cost, policy makes can make informed decisions.

Figure 33: User interface of the WRI TEIA V1 (2015)



Source: "Transport emission impact assessment guideline and tool" *version 1.0*

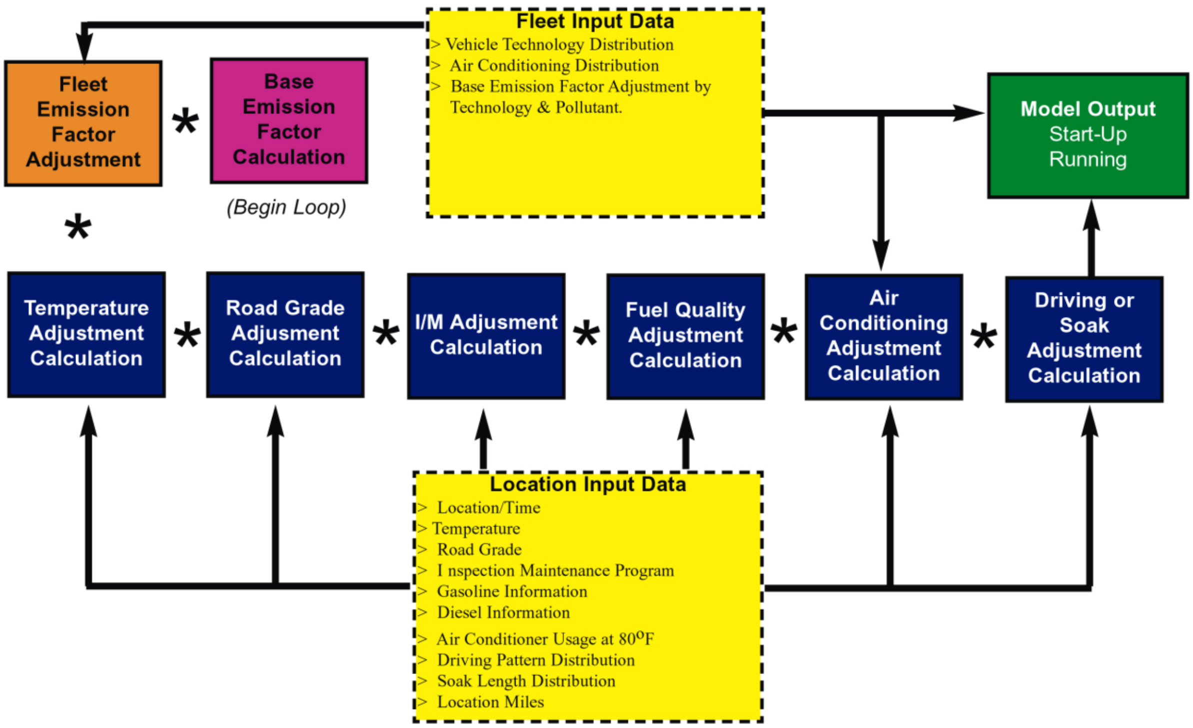
Figure 34: Outputs of the WRI TEIA V1 (2015)

Source: "Transport emission impact assessment guideline and tool" *version 1.0*

2.3.5 IVE-China

The International Vehicle Emissions (IVE) Model is specifically designed to have the flexibility needed by developing nations in their efforts to address mobile source air emissions.

Figure 35: IVE flow chart



Source: A Study of the Emissions from Diesel Vehicles Operating in Beijing, China, 2007
Learn more: http://www.issrc.org/ive/

Tsinghua University (Yao et al., 2006) [36] has taken Beijing as a test case to introduce IVE model, and presented the method to quantify the main parameters, and calculated emissions from different vehicle fleets of Beijing, and compared them with MOBILE 6 model. Shanghai Academy of Environmental Sciences[37] (Wang et al., 2006) has developed vehicle emission inventory with localized IVE model by testing vehicle type parameter, VSP distribution and start—up pattern on 9 typical streets. Zhejiang University (Guo et al., 2007) [38] have evaluated the IVE model by utilizing a dataset available from the remote sensing measurements on a large number of vehicles at five different sites in Hangzhou in 2004 and 2005.

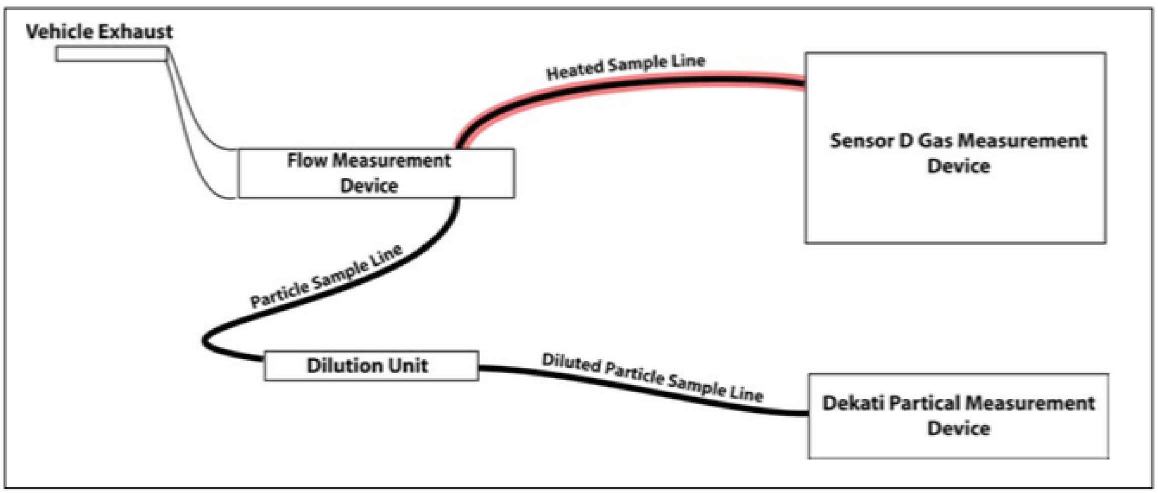
A process of on-road measurement of diesel emissions has been devised and the International Vehicle Emissions (IVE) model was developed to estimate emissions from diesel vehicles under

[36] 姚志良, 贺克斌,等. IVE 机动车排放模型应用研究. 环境科学, 2006.
[37] 王海鲲, 陈长虹, 等. 应用 IVE 模型计算上海市机动车污染物排放[J]. 环境科学学报. 2006.
[38] Guo Hui, Zhang Qingyu, et al. Evaluation of the International Vehicle Emission model with on-road remote sensing measurement. ScienceDirect, 2007.

different driving and control scenarios. The IVE in-use vehicle emissions study is designed to test the hypothesis that similar vehicle technologies will produce equivalent emission results in a given location and to provide some rudimentary data for creating improved emission factors. To date, this on-board emissions measurement technology can be used to measure carbon monoxide (CO), carbon dioxide (CO2), total hydrocarbons (THC), and nitrogen oxides (NOx).

Tsinghua University and ISSRC have studied emissions from diesel vehicles operating in Beijing using IVE on-board measurement. They operated a series of 33 diesel vehicles tests in 2007 in Beijing[39]. 24 of these vehicles were classified as light-duty vehicles. A *Semtech Sensor D*[40] gas emissions testing unit was used to measure the emissions of CO, CO2, total Hydrocarbons (THC), NOx, and NO_2. Particulates were measured on a second by second basis using a *Dekati DMM* testing unit[41]. The IVE model was ran using an FTP driving pattern to develop base emission factors, and using the overall distribution of vehicles tested in Beijing. The average measured values normalized to FTP driving cycles (US-based) were then divided by the IVE predicted values to evaluate the comparisons.

Figure 36: Flow Diagram for the Overall Emissions Testing System



Source: A Study of the Emissions from Diesel Vehicles Operating in Beijing, China, 2007
Learn more: http://www.issrc.org/ive/

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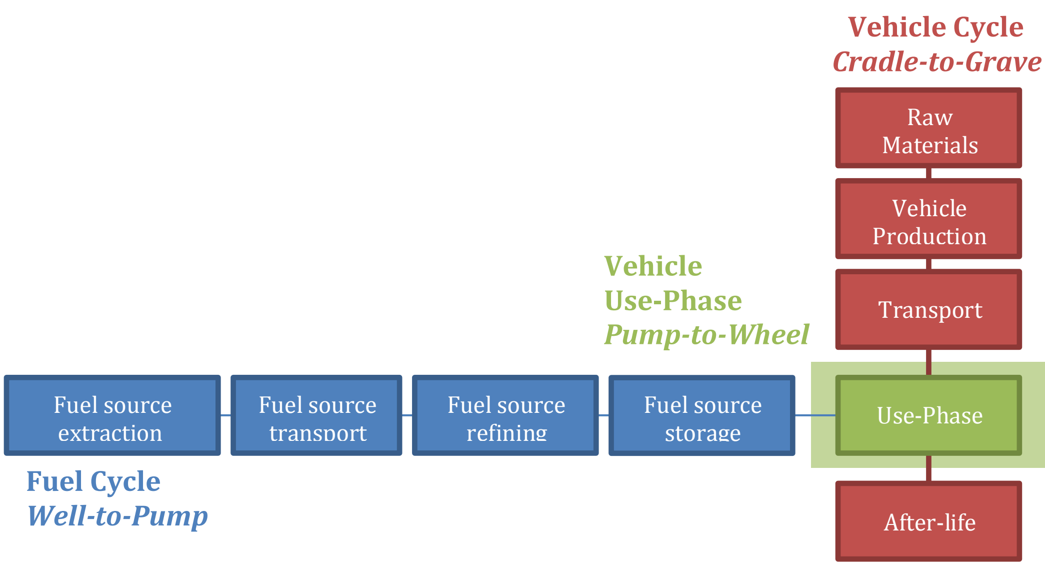
[39] A Study of the Emissions from Diesel Vehicles Operating in Beijing, China
[40] SEMTECH LASAR is an optical feedback, cavity enhanced, laser absorption spectrometer, capable of measuring both trace levels and high concentrations of a wide range of gases. This high precision, multi-gas analyzer has been designed with no moving parts, hygroscopic optics or liquid N_2 cooling requirements and, therefore, has wide applicability.
[41] The Dekati mass monitor (OMM) is an instrument which measures the mass concentration of airborne particles in real time by combining aerodynamic and mobility size particle classification.

3. China Passenger Vehicle Emissions Model Suggestions

Generally, the method for calculating transportation emissions (not only GHG emissions) is to aggregate vehicle emission related factors and run it through a calculation formula, which will provide transportation emission levels[42]. While the previous section reviewed frameworks and tools for evaluating transportation energy emissions (*cradle-to-grave, well-to-pump*), this section will focus on vehicle use-phase emissions methodologies (narrower than *well-to-wheel)*.

Figure 37: China City Transportation Emissions Calculator focuses on Vehicle Use-Phase Emissions



A benefit of evaluating use-phase emissions over cradle-to-grave vehicle emissions is because *local* policy-making is largely motivated by *local* air pollution reduction. Since vehicle manufacturing, transport and after-life process emissions often occur outside of urban boundaries, it is hard to estimate their impacts on local air quality. This same idea applies to fuels. Like manufacturing, their extraction, transport and production emissions are typically beyond the urban boundaries, and are also hard to estimate their impact on local air quality. Due to this, fuel storage and use-phase should be the focus. The scope of vehicle emissions modeling is therefore illustrated in the above figure.

The remainder of this section will proceed as follows. First, it will review the mainstream approach for calculating transportation emissions. Next, methodologies in use for determining the emission factors and their composition in suggested formulas would be analyzed. The below table summarizes the approach for measuring use-phase emissions by selected global models.

[42] Methods for capturing GHG emissions data alone, on the other hand, typically capture and convert transport energy consumption levels to emissions values under certain assumptions that determine GHG emission levels from each fossil fuel unit burnt.

Table 7: Use-phase emissions modeling approaches comparison

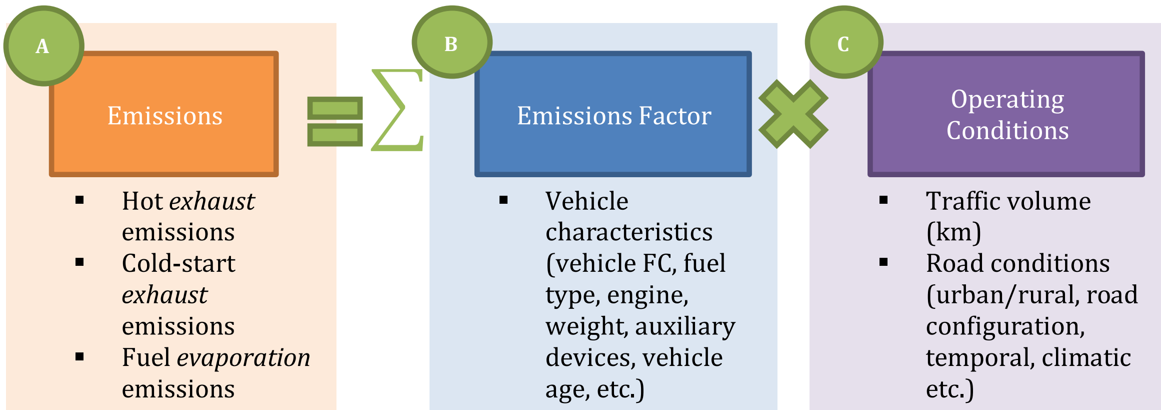
	COPERT 4	HBFRA 3.1	VERSIT+	NEMO	PHEM	CVEM
Geographical scale	Broad	From street level up	From street level up	From street level up	Single vehicle to street level	From street level up
Emission factors	Based on average speed for 3 road types	Based on traffic situations	Based on traffic situations (road types, speed, limits, degrees of congestion)	Based on calculation of driving resistance for average traffic situations	Based on instantaneous vehicle speed trajectories and engine emission maps	Based on average speed for light-duty vehicles, and VSP for heavy-duty vehicles
Pollutants	Regulated + CO2, FC, CH4, N2O, NH3, SO2, heavy metals, PAHs, POPs, NMVOC specification	Regulated + CO2, FC, CH4, N2O, NH3, SO2, and PN	Regulated + CO2, FC, NO2, PM2.5, PAH, PM wear (tire, break, road surface)	Regulated + CO2, FC, NO2, and PN	Regulated + CO2, FC, NO2, and PN	Regulated +CO, HC, NOx, and PM
Typical applications	Large scale inventories and assessment of measures	Inventories, assessment of measures (large and medium scale)	Inventories, assessment of measures (large and medium scale)	Inventories, assessment of measures (based on road networks)	Calculation of emission factors for various traffic situations, driving styles, and vehicle technologies	Inventories, assessment of measures

Source: adapted from European Commission, DG Joint Research Center, Institute for Energy and Transport, Overview of the European Research for Mobile Emission Sources (ERMES).

3.1 Mainstreaming vehicle use-phase emissions modeling approaches

In the simplest terms, the total emission of a given pollutant from road transportation is the product of a specific emission factor and volume of traffic activity, illustrated in the below figure. Several different sources or processes that need to be considered are specified below the figure, and the type of parameters and data for determining accurate emission levels are summarized in the below Tables 8-10.

Figure 38: Vehicle Emissions Formula Simplification



A. The principal **emission sources** are (i) *'hot' exhaust emissions*, (ii) *cold-start exhaust emissions* and (iii) *fuel evaporation emissions*. For particulate matter, abrasion processes such as tyre wear, brake wear and road surface wear should also be considered.

B. The **emission factor** may be therefore expressed in terms of distance travelled (e.g. hot emissions, depending on fuel consumption), per vehicle start (e.g. excess emissions due to cold start), or per unit of time (e.g. evaporative emissions), and there is a need to state these factors accordingly in the calculation formula. Many factors influence the emission factor, and are closely linked to vehicle characteristics. For example, vehicle engine size, fuel type, auxiliary devices, and vehicle age.

C. The vehicle **operating condition** – and therefore the emission factor - varies as a function of the geographical area (urban, rural), the road configuration (urban street to motorway), temporal conditions (peak and off-peak travel), climatic conditions, and other traffic conditions (congestion, free-flow). A set of parameters is required to describe these operating conditions.

Table 8: Traffic data requirements for the specification of hot emissions

Parameter Type	Parameters in the emissions calculation	Data form
Vehicle Category	Fuel: petrol, diesel, etc.	Number of vehicles per year and per segment
	Standard (Emissions Limits)	
	Engine Capacity and technology	
	After-treatment (catalyst, filter etc.)	
	Vehicle type (e.g. Van, 4X4)	
	Vehicles in certain geographies may need to be treated differently (e.g. eastern Europe vs. EU states)	
Activity Level	Mileage (per vehicle segment should commercial vehicles be included, e.g. taxies)	Annual mileage of vehicles per segment
		Evolution of annual mileage as a function of vehicle age
Driving Conditions	Activity distribution for different traffic situations	Distributions of mileage for different traffic situations
	Vehicle driving and operating conditions	Driving conditions (speed patterns, average speeds) and distance travelled for each traffic situations and per each vehicle segment
Other operating conditions	Ambient weather conditions (temperature, humidity, altitude, pressure)	Typical annual, daily distributions/s per state
	Fuel characteristics	Distribution of fuel sales according to fuel specifications
		Fuel specifications per state
		Should be consistent for vehicle categories

Table 9: Traffic data requirements for the specification of cold start, evaporative and air conditioning (A/C) emissions[43]

Parameter Type	Parameters in the emissions calculation	Data form	Remarks
Vehicle concerned	As hot emissions + specific equipment	% of vehicle equip per segment	Other technical specifications could be needed, such as canister equipment for the control of evaporative emissions and A/C equipment.
Activity level	Number of starts	- Number of cold starts and trips - % of driving with A/C on	
	Duration of parking		
	Duration of driving		
	Trip number		
	A/C operation		
Driving	During the cold-start	Detailed knowledge of	Cold start, air conditioning

[43] There are aircon fluid emissions due to leaks and there are extra emissions of the engine due to the increased auxiliary load requirement of the aircon pump

conditions	phase	speeds and driving conditions	and evaporative emissions should be influence by the driving conditions
	During the A/C operation		
Other operating conditions	Trip length	- Typical trip length - Typical annual, daily temperatures per state - Distribution of minimum and maximum daily temperatures (per state)	For A/C, the level of operation, the initial cooling after a trip start and the stabilized operation should be considered
	Ambient and local weather conditions		
	Engine temperature at trip start and at trip end		
	Parking conditions		
	Fuel characteristics	Distribution of fuel sales according to fuel specifications	Density, volatility should be considered for the evaporative emissions
		Fuel specifications per state	
		Should be consistent for vehicle categories	

Table 10: Effects of driving type on vehicle emissions

Vehicle Type	Driving Type	Observations
Diesel	Urban	Emissions of all pollutants increase with stop frequency and relative stop duration.
		Emissions of all pollutants except CO decrease as speed increases. CO emissions are sensitive to high speeds (60-100 km/h).
		NOx and CO2 emissions are sensitive to the frequency and strength of accelerations.
	Rural	Emissions of all pollutants increase with stop frequency and relative stop duration.
		Emissions of all pollutants decrease as speed increases and are sensitive to low speeds (20-40 km/h or less) and acceleration. CO emissions appear to be rather sensitive to the maximum acceleration or deceleration.
	Motorway/ Main road	NOx and CO2 emissions are sensitive to high speeds (120-140 km/h) and to the variation in speed (standard deviation of speed), but emissions decrease at intermediate speeds (60-100 km/h)
		CO emissions increase with the occurrence of intermediate or low speeds, stops and accelerations, but are low at high speeds.
Petrol	Urban	Emissions of all pollutants are sensitive to acceleration (mean, frequency, strength, time spent at high accelerations).
		CO and HC emissions are sensitive to high speeds (60-100 km/h) and strong accelerations.
		Emissions of CO2 and HC increase with the number of stops. CO2 decreases as the speed increases.
	Rural	Emissions of all pollutants are sensitive to acceleration (mean, frequency, strength, time spent at high accelerations).
		Emissions of CO2, HC and NOx increase with the stops duration and frequency.

		Emissions of CO_2 and NOx decrease as the speed increases.
	Motorway/ Main road	Emissions of all pollutants are sensitive to accelerations at high speeds. CO_2 and CO are high at high speeds (120-140 km/h and above) but low at intermediate speeds (60-100 km/h).

Source: Adapted from ARTEMIS final report.

3.2 Data and Figures for the Case of Transport Emissions in China

3.2.1 Data for CRTEM/HBEFA-China

To adapt HBEFA to Chinese conditions, two fundamental components had to be localized:

1. Local driving cycles, representing specific traffic situations in Chinese cities.
2. The emission factors calculated, reflecting the emission and fuel efficiency characteristics of vehicles in Chinese cites (originally based on the EU emissions factors modeled through PHEM).

For typical traffic situations, more than 2,000 hours of GPS data were collected in Beijing and Shenzhen during 2012 and 2013. Installed in 20 taxis and private passenger cars, the GPS devices collected spontaneous information about geodetic coordinates, speed and acceleration for each second for one week in both Beijing and Shenzhen. A broad range of different drivers and vehicles were selected considering gender, age, profession of driver and age of vehicles.

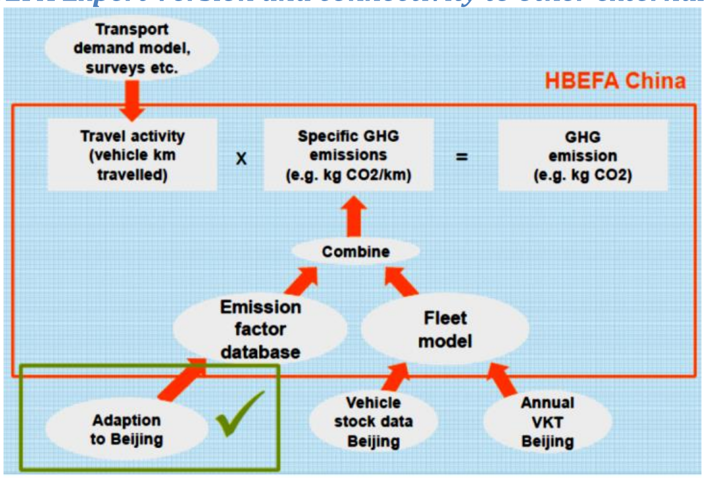
The model estimates energy consumption and carbon dioxide emissions levels of urban road transport. Equipped with China-specific default values, the model is flexible enough to be used by cities without the need for travel demand models. If projections of traffic activity are available, the CRTEM/HBEFA-China can also be used to calculate future emission scenarios.

Table 11: Distance and total time of GPS data collected on different road types

	Distance (km)	%	Time (hh:mm)	%
Highway	2683.08	14%	75:35:00	9%
National Highway	55.26	0%	02:14	0%
Provincial Highway	73.6	0%	02:32	0%
Expressway	5916.15	30%	170:47:00	20%
Expressway Sideroad	2083.92	11%	92:11:00	11%
Major Arterial	3919.51	20%	202:35:00	23%
Minor Arterial	2782.3	14%	169:14:00	20%
Sideroad	201.2	1%	14:01	2%
Branch	1804.3	9%	138:31:00	16%
Total	19519.32		867:40:00	

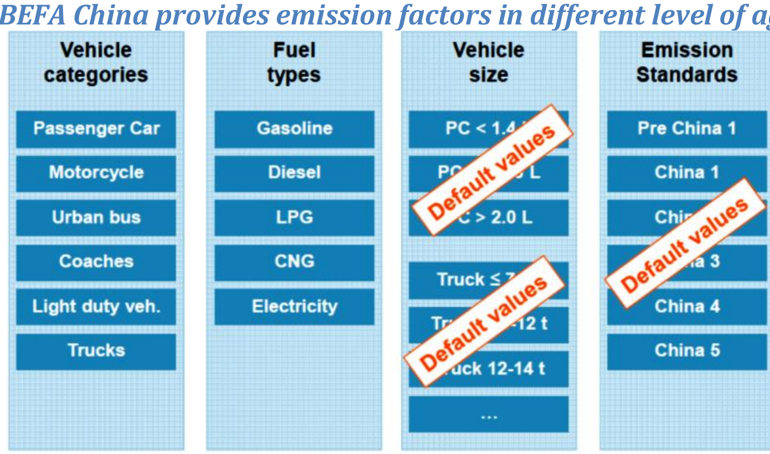
Source: Adapted from "Modeling Energy Consumption and GHG Emissions of Road Transport in China", 2015

Figure 39: HBEFA Expert Version and connectivity to other external data sources



Source: "Handbook on Emission Factors of Road Transport for China", 2014

Table 12 HBEFA China provides emission factors in different level of aggregations



Source: "Handbook on Emission Factors of Road Transport for China", 2014

3.2.2 Data for WRI-Chengdu

Like most cities in China, traffic information in Chengdu is incomplete: while general vehicle volumes can be obtained from statistic yearbook or vehicle registration authority, by-fuel type vehicle volumes are incomplete in the case of city passenger vehicles. Emissions standards and FC levels classification is even more complex data type to obtain.

For VKT data, only commercial vehicle data was available. In Chengdu, according to the total operating distance and vehicle volumes, VKT data can be calculated for other transport segments. Annual VKT for bus was around 50,000km, and annual VKT for taxi was about 120,000km. For other vehicle types, the VKT data was estimated through practical experiences and related articles[44].

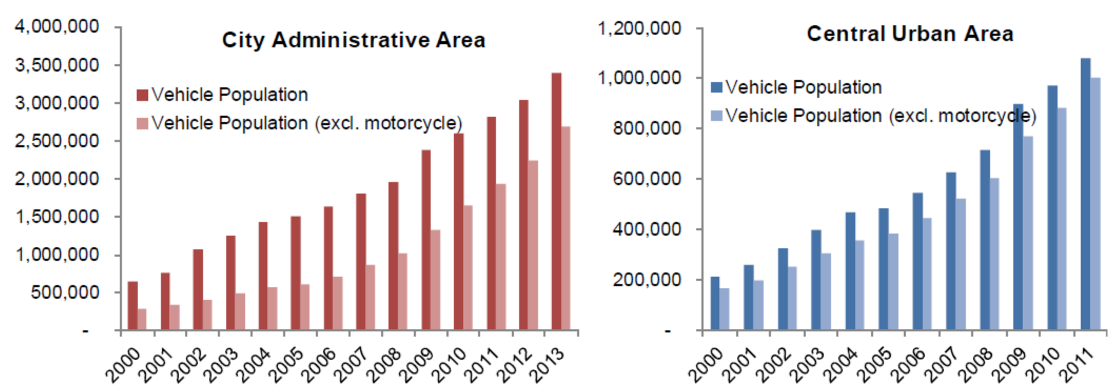
[44] Such as: i) IPCC Good Practice Guidance and Uncertainty Management in National GHG Inventories – Emissions: Energy, Road, Transport; ii) avg. low calorific value: China Energy Statistical Yearbook (NBSC); iii) ERI – tCO2e: calculated from

According to the "*Greenhouse Gas Accounting Tool for Chinese Cities*"[45] designed by WRI and GHG emission factor[46] issued by NDRC, emission factors for CO_2, CH_4, N_2O pollutant types were determined based on different fuel types, namely gasoline, diesel, electric and dual-fuel.

On July 2nd and Aug 20th 2014, China's Ministry of Environmental Protection has issued a series of "Pollutant emission inventory guidelines"[47]. These included traffic emission control guidelines, such as the "On-road vehicle emission inventory preparation guideline (trial)","Off-road moving pollution source emission inventory preparation guideline (trial)" and "direct source of atmospheric particulate matter emissions inventory preparation guideline (trial)", etc. A series of national average basic emission factors (BEFs) was also published by MEP, including 11 vehicle types and 7 fuel types[48].

Environmental protection science research institute of Chengdu has established "On-road motor vehicle emission factor database" and estimated the vehicle emission amount in 2009. By monitoring in fixed spot with simple testing procedure, together with on-road vehicle emission levels test and vehicle operation condition test, the emission factor of light-duty passenger car were determined. And the vehicle emission model and inventory were built based on IVE model in Chengdu. Part of the localized emission factor of Chengdu was quite different with the average emission factor in country level stated by EPA. Although according to experiences, the localized emission factor was more representative and reliable.

Figure 40: Vehicle population data used in the WRI Transport Emissions V1



Source: WRI ET V1 Report (expected 2015), based on Chengdu Transport Statistics Year Book, 2014

ERI internal report and CATS's *"Study of Mid- and Long-term Plan for Energy-Saving in Transport Sector"* (交通行业节能中长期规划研究); iv) ERI tCO2e: 2010 Baseline Emission Factors for Regional Power Grid in China (2010 中国区域电网基准线排放因子) (http://cdm.ccchina.gov.cn/WebSite/CDM/UpFile/File2552.pdf; in attachment 2: coal-fired station).

[45] http://www.wri.org.cn/node/492

[46] ERI – tCO2e: calculated from ERI internal report and CATS's "Study of Mid- and Long-term Plan for Energy-Saving in Transport Sector"

[47] E,g,i) 环保部（2014 年 7 月）"关于征求《城市扬尘源排放清单编制技术指南（试行）》（征求意见稿）等 5 项技术文件意见的函"技(http://www.zhb.gov.cn/gkml/hbb/bgth/201407/t20140708_278382.htm); ii) 环保部（2014 年 8 月）"关于发布《大气细颗粒物一次源排放清单编制技术指南（试行）》等 4 项技术指南的公告"技 (http://www.zhb.gov.cn/gkml/hbb/bgg/201408/t20140828_288364.htm).

[48] Vehicle types: small-mini passenger cars, medium-sized passenger cars, large passenger cars, motorcycles, taxis, buses, heavy duty truck, medium truck, light-mini truck, ship, railway locomotive. Fuel types: Gasoline, diesel, natural gas, liquefied petroleum gas, kerosene, fuel oil and electricity.

Figure 41: Storage amount of Bus & Taxi

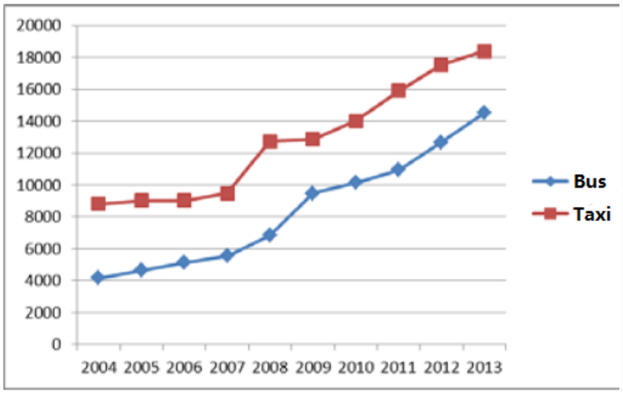
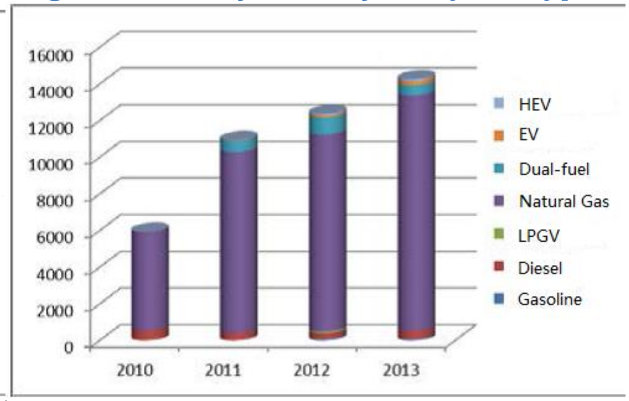


Figure 42: Classification of Bus by Fuel type



Source: Emission of Transport: A tool to estimate transport emission inventories and the associated social impact, 2014

3.2.3 Data for CVEM

Vehicle activity data was generated from detailed investigations of vehicle driving behavior in 17 typical Chinese cities of various sizes[49]. Separate investigations were performed on light-duty vehicles, heavy-duty vehicles, and buses, with a goal of determining typical driving cycle and driving share by road type for each vehicle type. Annual vehicle mileage traveled (VMT) was provided to VECC-MEP voluntarily by typical manufacturers based on annual inspection data across 345 cities in China.

Annual numbers of in-use vehicles and new vehicle registrations was sourced from the China Automotive Industry Yearbook (CATARC 2008). This data was further parsed into emission standard data and fuel type by combining the yearbook data with annual vehicle registration data from China's Ministry of Public Security.

Base emission factors, correction factors, and VSP bin allocation were generated from a combination of existing datasets and original VECC-MEP or project partner research. Original research included emissions certification and degradation testing, dynamometer testing, and testing using Portable Emission Monitoring System (PEMS) devices. Certain additional correction factors were taken directly from international precedent; for example, CVEM currently uses altitude correction factors used by the US EPA's MOBILE model. In expansion and revision of the model, expanding and developing these emissions factors for China is a key area for further research.

[49] Due to lack of publically available information, the list of cities is beyond the scope of this work.

Table 13: Selected nationwide results for vehicle activity in China, 2007

Vehicle Type	Annual VMT (nationwide average, km)	Average Speed (nationwide average, km/h)
Taxis	138,000	35.3
Passenger Cars	25,216	35.3
Public Buses	45,757	15.6
Other Buses	114,800	15.6
Light-Duty Commercial Vehicles	44,000	35.3
Heavy-Duty Trucks	105,600	33.8
Low Speed Goods Vehicles	23,000	14.3
Low Speed 3-Wheeled Vehicles	30,900	22.7
Motorcycles	6,612	28.0

Source: "Developing a First-Ever National Mobile Source Emissions Inventory for China", 2009 http://www.epa.gov/ttnchie1/conference/ei18/session2/wagner.pdf

3.2.4 Data for IVE in Beijing & Shanghai

Beijing (May 23rd -June 4th, 2004)[50] and Shanghai (June 6th-June 18th, 2004)[51] were visited to collect and analyze data related to on-road transportation separately. The data collection effort in Beijing was a partnership between Tsinghua University, Beijing Technology and Business University, and the International Sustainable Systems Research Center (ISSRC) in cooperation with the University of California at Riverside (UCR). And for Shanghai, it was a partnership between Shanghai local and regional governments, Shanghai Academy of Environmental Sciences, non-government officials, and the International Sustainable Systems Research Center (ISSRC) in cooperation with the University of California at Riverside (UCR).

The study collected three types of information on vehicles operating on streets: technology distribution, driving patterns, and start patterns. Of all the areas observed to date by ISSRC and UCR, Beijing has the lowest percentage of trucks, which is because trucks are not allowed to drive on the streets inside of the circle 4th road between the hours of 7 am and 9 pm. Also Beijing has the highest percentage of taxis. Beijing's passenger fleet is comprised of approximately 10% non-catalyst vehicles, compared to 1% in the US; 20-30% in Mexico City, Santiago, and Pune; and 90-100% in Almaty and Nairobi[49]. And Shanghai has the lowest percentage of passenger vehicles and the highest percentage of buses and trucks and a very large fraction of mopeds. Shanghai's relatively new passenger fleet is comprised of 6% non- catalyst vehicles, compared to 1% in the US; 20-30% in Mexico City, Santiago, and Pune; 90- 100% in Almaty and Nairobi and 10% in Beijing[50].

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50 Beijing Vehicle Activity Study. http://www.issrc.org/ive/

51 Shanghai Vehicle Activity Study. http://www.issrc.org/ive/

According to the contribution of various vehicle types to the inventory, it was determined that: i) to reduce PM (and toxic) emissions in Beijing, buses and trucks must be controlled. ii) to reduce NOx, CO, VOC, CO_2, passenger vehicles must be further controlled. Compared to Shanghai, most of the overall fleet emission factors for the two cities are similar, such as emission factors for CO2 and VOC. But the emission factors of NOx, and PM of Beijing are just half of those of Shanghai. This is mainly because Shanghai has a three times greater fraction of trucks and buses than Beijing. The overall CO emission factor for Beijing is a little higher than in Shanghai, because Shanghai has a larger fraction of 2-wheels motorcycle in the traffic fleet, while Beijing has a very high percentage of passenger cars.

3.2.5 Transport Emissions data from other research

- ***Tsinghua University (Zhang, Wu, Liu, Huang, & et al., 2014)*** has measured on-road emissions for 60 LDPVs (light-duty passenger vehicles) in three China's cities and calculated their fuel consumption and CO2 (carbon dioxide) emissions. They also further evaluated the impacts of variations in area-averaged speed on relative fuel consumption of gasoline LDPVs for the urban area of Beijing (UBA). The research also analyzed on-road fuel consumption in China in comparison to the fuel consumption levels achieved through the NEDC (new European driving cycle) and found an average of 12% gap for the case of gasoline vehicles. The study observed very strong correlations between relative fuel consumption and average speed and showed traffic control applied to LDPVs driving within the UAB during weekdays can reduce total fleet fuel consumption by 5% during restriction hours (by limiting vehicle use and improving driving conditions).

- ***Yan and Crookes (2009)*** developed a detailed model to derive a reliable historical trend of energy demand and GHG emissions in China's road transport sector between 2000 and 2005 and to project future trends. Two scenarios have been designed to describe the future strategies relating to the development of China's road transport sector. Energy demand and GHG emissions in China's road transport sector up to 2030 are estimated in a Business-as-Usual (BAU) and best case scenarios.

- ***Geng, G., Zhang, Q., Martin, R. V., van Donkelaar, A., Huo, H., Che, H., & ... He, K. (2015)*** studied transport fine particulate matter (PM2.5) using satellite remote sensing of aerosol optical depth (AOD), a widely used method in estimating ground-level PM2.5 concentrations. Combining satellite remote sensing and a chemical transport model, the study derives PM2.5 concentrations over China for 2006–2012. The study found significant spatial agreement between the satellite-derived PM2.5 concentrations and the ground-level PM2.5 measurements collected from literatures ($r = 0.74$, slope = 0.77, intercept = 11.21 μg/m3). The population-weighted mean of PM2.5 concentrations in China is 71 μg/m3 and more than one billion people live in locations where PM2.5 concentrations exceed the World Health Organization Air Quality Interim Target-1 of 35 μg/m3. The results from this work are substantially higher than previous work, especially in heavily polluted regions.

- ***Jiang, T., Wu, Z., Song, Y., Liu, X., Liu, H., & Zhang, H. (2013)*** sought to inform transport policy making by a comprehensive database to ensure a sustainable and healthy development of urban transport. This paper introduces the China Urban Transport Database (CUTD) framework that was designed for the purpose of constructive data-driven decision making, including user management, data warehouse, and application modules. Considering the urban transport development features of Chinese cities, sustainable urban transport development indicators were proposed to evaluate the public transport service level in Chinese cities. CUTD has been applied in urban transport data processing, urban transport management, and urban transport performance evaluation in national and local transport research agencies, operators, and governments in China, and projected to be applied to a broader range of fields.

- ***Wang, Chen, Huang, &Fu (2008)*** presented a bottom–up methodology to develop the vehicle emission inventory for Shanghai. They conducted a two-week field study on 9 typical Shanghai roads with the help of the University of California Riverside (UCR) to capture accurate fleet profiles. The roads covered residential streets, arterials and freeways, and they were chosen in three representative districts, including Huangpu district, Xuhui district and Putuo district, which represent the city center, commercial area and lower-income area respectively. The field study consists of video road surveys and parking lot surveys. 8 GPS units were used. And the test vehicles consisted of passenger vehicles, taxis, buses, motorcycles, and trucks. The analysis indicated that the emission factors calculated in this paper are close to those factors measured during on-road testing, and the difference between the VKT used in this paper and other calculations is less than 10%.

- ***He, Hu, Xie, Song, Zu, & Xie (2010)*** developed a reliable CH_4 & N_2O emission inventory from motor vehicles in China to support the mitigation of non-CO2 GHG emissions in 2010. The activity data and emission characteristics were collected from annual reports, yearbooks and information released by government, literature investigation and field survey of representative fleets in over ten typical cities including Beijing, Guangzhou and Chongqing. With the basic information, the vehicle population, annual mile age traveled and emission factors in the distribution of vehicle type, fuel and age were estimated. Results showed that, automobiles were the greatest contributor to the vehicular CH_4 and N_2O emissions, by sharing 77.99% and 94.22% of the total emissions respectively. And the contribution of emissions from motorcycles and agricultural vehicles were much smaller. Among automobiles, the light-duty gasoline vehicles and natural gas powered taxis were the major sources of CH_4 emission. And N_2O emissions mainly originated from the light-duty gasoline vehicles.

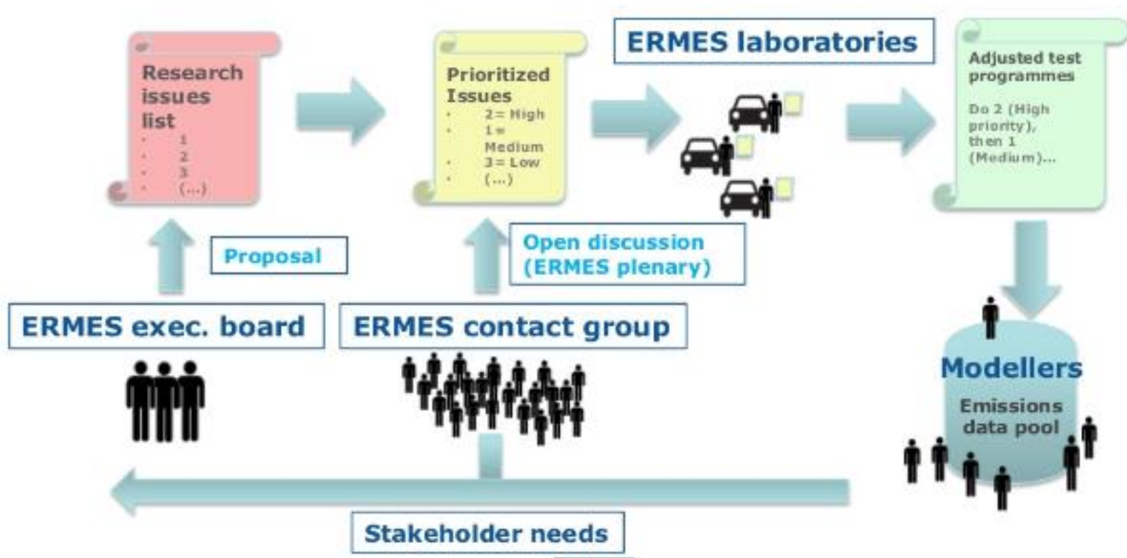
3.3 Limitations of studies to date, and lessons learnt

Issues around data and statistics in China stem from: i) Institutional divide of responsibilities and compartmentalization, combined with lack of effective inter-institutional coordination mechanisms; ii) Data collection methods and tools are neither consistent nor complete; iii) Dependent and non-transparent statistical system. In evidence of these major issues, emission figures and estimated are insufficient for making informed and data-driven transport planning and regulations. Albeit recent efforts to obtain reliable data and improve the system (e.g. new China-based test driving cycle is underway), this chapter seeks to understand what are the possible limitations of transport emissions calculator development. Although recognizing the challenges may not improve its performance, the calculator may be adjusted to current conditions and introduce user recommendations for overcoming data issues.

3.3.1 Limitations of transport modeling

There are several limitations to the transport emissions calculation methodologies and tools that are in use:

- The representation of transport emissions calculated of its **specific geography**: since transport boundaries are not confined in real-life, the geographic scope defined for a tool may suffer from leakages due to high level of visits or in-ward travels at a certain period for example.
- Another major limitation is ***access to data***. All models to date use estimations for overcoming data gaps, and studies show that even "official data" (e.g. type approval test cycles) may be circumvented. The situation in China is even more complex.
- ***Data updating and model adjustments*** to the evolving real-world conditions is yet another issue that requires well-though model management and multi-stakeholder collaboration. The European Research for Mobile Emission Sources (ERMES) for example, as a coalition of mainly European stakeholders, has a structured work stream for ensuring alignment across data sources for providing periodical model updates. ERMES work-stream is described in the below figure.



Source: European Commission, DG Joint Research Center, Institute for Energy and Transport, Overview of the European Research for Mobile Emission Sources (ERMES).

3.3.2 Lessons learnt from existing transport modeling

Conferences and reviews of models, through the EU ARTEMIS project in particular, articulate the lessons:

- ***Input data versus user data***
  - Users have a good knowledge of the traffic activity data relating to their own case studies. It is therefore not necessary to provide the traffic activity data in the model itself as a given, but the data structure does need to be defined and clear for the inputter.
  - The detailed vehicle fleet composition is generally not known by users. Fleet composition information is therefore required for EU Members States and for years between 1980 and 2020 in the case of major EU models. The same should apply for the case of modeling in China.
  - Traffic activity data should be managed as both vehicle-km in a given area (for macroscopic applications) and as number of vehicles per road section (for microscopic applications). Traffic activity may be adjusted taking into account external data (e.g. official transport statistics, academic case studies).

- ***Structural aspects***
  - Traffic activity should be broken down into vehicle categories and traffic situations or operational conditions. Vehicle and traffic classifications need to be flexible and adaptable.
  - Traffic situations may include geographical aspects (urban/rural, road type) and temporal aspects (e.g. level of congestion as a function of the time-of-day). Traffic situations have to be common for the different road transport modes, and they should be defined with reference to effects on emissions and the availability of data.
  - While most models have an average speed associated to the type of road (urban, extra-urban and highway) and the time of travel (peak vs non-peak), it may be useful to consider a more simple representation of vehicle traffic implications on average speed; this way, data limitation can be overcome through the insertion of default values based on current knowledge and the model may allow for more flexibility.
  - The fleet composition (per vehicle segment) is the combination of the number of vehicles, their annual mileage, their age distribution, correction factors for vehicle age, and assumptions regarding the introduction of new technological concepts. Various fleet compositions can occur for different traffic situations.
  - Vehicle segments can be divided to vehicle groups that matter for policy-makers, for informing technology-forcing policies for instance.
  - Although the traffic activity should be left to the user to define, the prediction of future levels of activity and fleet turnover can be included in the model itself. Appropriate methods include the one used in MEET (modeling of the evolution of vehicle numbers and survival rates), or one based only on vehicle age distributions.

4. Conclusions

Amid China's air quality degradation, coupled with China's massive urbanization rates and economic development, air pollution control has become a pivotal component of national and local governance. The impact of energy consumption on air quality has gradually attracted the attention of the general public and policy-makers alike, as evidenced through various reporting initiatives and multiple air improvements targets announced in the last couple of years. Worth noting is the Action Plan for Air Pollution Prevention and Control, announced in September 2013, targeting the reduction of average PM10 levels in large cities by 10% between 2012 and 2017. For three strategic corridors of economic development – the Beijing-Tianjin-Hebei corridor, the Yangtze River Delta corridor, and the Pearl River Delta corridor – a PM2.5 reduction target of 15 - 25% has been announced (Ministry of Environmental Protection, 2013). These targets require solid baseline emissions data and effective planning for ensuring emissions reduction, without which targets would be missed and reporting efforts may lose their credibility.

Different estimations from 2014 show varying impacts of the transport sector on urban PM2.5 emissions in China, ranging from 20% to 35%. For example, Beijing estimates transport contribute to 31% of urban PM2.5, Shanghai estimates 25%, Guangzhou estimates 23%, Shenzhen estimates 31%, Chengdu estimates 20%, and Hangzhou and Qingdao estimate 33% and 14% respectively. These variations can stem from varying geographic conditions, traffic conditions and travel behaviors as well as variations in levels of other pollution sources and energy mix[52]. Furthermore, various local authorities may suggest different figures for reflecting the impact of transport on local air quality. In addition, Beijing motor vehicles account for 58% of nitrogen oxide (NOX) emissions and 40% of VOC emissions, showcasing how transport plays an important role on health risks through air quality degradation. An inventory and emissions calculation tool for informing current baseline emissions and planning policies that would effectively reduce air pollution would be instrumental for standardizing vehicle emissions policies towards their sustainable development.

This report overviews traffic emission model created and used by the international community, such as the European COPERT, HBEFA, VERSIT+ (Chapter 2.1), and the US GREET, MOBILE, MOVES, and IVE (Chapter 2.2). The report is not aimed at detailing the development nor providing an in-depth description of the tools and models, but is rather aimed at suggesting what tools have been developed for equipping policy makers that were faced with the challenges now faced by China. Major differences between these tools and their applicability for China are also outlined throughout the report. In particular, some tools have been adjusted for the case of China, e.g. CRTEM-HBEFA, CVEM, IVE-China (Chapter 2.3), yet none seem to have succeeded in impacting local planning beyond a pilot, mainly due to data availability and/or complexity issues. This report therefore prepares the ground for the development of the China Urban Transport Emissions Calculator through deriving lessons from previous work done in this area (Chapter 3).

The overview of various models has enabled the authors to identify that most models follow the same principle and use vehicle type and technology specific emission factors. The emission factors are split into hot and cold: hot emission factors are vehicle speed dependent, while cold emissions are treated as additional factors to the hot emissions depending on the technology. A split in models

[52] iCET "*China Real World and Certified Fuel Consumption Gap Analysis*" report release in July 2015 overviews some of the sources of vehicle FC and emissions variations. Download for free: http://www.icet.org.cn/english/reports.asp?fid=20&mid=21

and emission factor data sources would likely reveal that there are many less independent data sources than models and it is the data sources that are most important.

Although international models are very useful in measuring emissions and tracking adherence to global agreements, and are capable of converting macro to micro level data for informing various vehicle emissions' policies and regulations, they are not easily applicable for the particular case China and the wide spectrum of driving conditions and habits it its various cities. Since specific local traffic, geographic, climatic, and driving conditions, and vehicle and fuel technical aspects (often guided by emissions regulations) are all at the heart of the models, Chinese emission factors needs to be further characteristics. Models converted to date, due to lack of data accessibility, have used national average estimations that may account for major gaps between real-world and modeled emissions data.

In order to overcome these barriers for sound development and smooth usage of a China tailored transport emissions model, not only credible data needs to be sufficed but also simple multi-layer model should be designed. Furthermore, the model should consider major policy levers that are relevant for the case of China so that the tool would be able to easily simulate the impact of policy tools on emissions levels going forward (e.g. PM2.5 and CO2e). Most importantly, the tool should include simple convertible inputs not only for updating driving conditions but also vehicle fleet combinations that account for existing policy goals, e.g. New Energy Vehicle (NEV) percentage of a total fleet.

Since private vehicles are argued to have a greater impact on emission reduction than freight transport due to the surge in private car population and its low energy efficiency (Xu & Lin, 2015), the private vehicle segment was chosen to be introduced prior to the public and freight urban on-road segments. Should the initial phase of the tool, tested in the city of Shenzhen, be found to effectively meet local policy makers' needs, it will be expanded to include public and commercial vehicles.

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