CRTEM / HBEFA China Road Transport Emission Model

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Registered offices
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Address
Tayuan Diplomatic Office Building 2-5
14 Liangmahe South Street, Chaoyang District
100600, Beijing, PR China
T +86-(0)10-8527 5589
F +86-(0)10-8527 5591

E transition-china@giz.de
I www.mobility.transition-china.org

Responsible
GIZ/Sebastian Ibold

E transition-china@giz.de
I www.mobility.transition-china.org

Author
Dr. Benedikt Notter (INFRAS), Sebastian Ibold (GIZ),
Dr. Ling Xuan (GIZ), Dr. Marie Peters (GIZ),
Wu Yingjie (GIZ), Yuting Huang (SUTPC)

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Summary

The rapid economic development in China has led to a substantial increase in motorised transport. Decision-makers are faced with the question which policies may most efficiently and effectively lower greenhouse gas (GHG) and air pollutant emissions. The "China Road Transport Emission Model" (CRTEM) presented in this paper – also known as "HBEFA China" – is a model for bottom-up emissions calculations for road transport that allows estimating the emission impact of different types of policies.

Top-down methods may offer a simple approach to calculate fuel consumption and CO_2 emissions for entire countries, but cannot be used for cities, and do not allow distinguishing different emission sources (such as vehicle types or road network links). Bottom-up methods, on the other hand, permit assessments at the desired degree of detail, but require models based on up-to-date measurements and methodology. Furthermore, policy impact assessments may require:

- Fleet turnover modelling in order to assess the impact of policies aimed at promoting restricting certain vehicle types;
- Spatial differentiation in order to assess interventions affecting the spatial flow of traffic, and in order to enable subsequent air quality (immission) modelling;
- Differentiation of traffic situations in order to evaluate impacts of traffic density;
- Output of both GHG and air pollutant emissions, in order to compare impacts in case of conflicting outcomes.

CRTEM/HBEFA China fulfils these requirements, and its input data requirements correspond to data availability in most settings.

The "European" HBEFA is developed by the Environmental Protection Agencies of Germany, Switzerland and Austria, Sweden, Norway and France. The first version dates from 1995. Since then, updates have been published in 2- to 5-year intervals.

The first version of CRTEM/HBEFA China was developed as an adaptation of HBEFA Version 3.2 to Chinese cities in 2012-2014 by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in cooperation with the Shenzhen Urban Transportation Planning Center (SUTPC). The China version includes a new traffic situation scheme tailored to Chinese cities developed based on hundreds of hours of GPS data on driving behaviour collected in Beijing and Shenzhen.

The latest version of CRTEM/HBEFA China corresponds to the European Version 4.1 and includes modern technologies (i.e. battery-electric, plug-in hybrid, fuel-cell, or gas vehicles). The software is implemented in Microsoft (MS) Access and features:

- A database of emission factors covering all currently relevant road vehicle categories, technologies, and emission standards;
- An interface for querying the emission factors at various aggregation levels;
- A module for fleet turnover modelling;
- Utilities to import and process input traffic activity data;
- A module for emission modelling;
- A utility for top-down calculation of CO_2 emissions based on fuel sales.
- Utilities for results transfer to GIS software.

Limitations include the fact that air pollutant emission factors are based on European measurements, with validation in Chinese settings still ongoing, and the fact that for micro-scale emission calculations, detailed vehicle emission models such as PHEM or MOVES are more appropriate.

CRTEM/HBEFA China has been practically applied in the cities of Shenzhen, Beijing and Harbin so far. This paper presents two application cases in Shenzhen:

- SUTPC evaluated the environmental impact of the parking charge policy, including two scheme plans. It was found that traffic emissions after the implementation of both plans decrease by 21.5% – 22.3%. The evaluation supported the selection of the parking charge policy. With the policy it was possible to improve parking resources and traffic efficiency, and to reduce the traffic emissions of the whole city.
- CRTEM/HBEFA China has been integrated into China's first sub-district resolution road traffic emission monitoring platform in Longgang International Low Carbon City in the North of Shenzhen. By integrating GPS data with the monitoring data from smart lamp posts and electromagnetic ground detectors, the platform obtains real-time traffic data and uses CRTEM/HBEFA China to calculate high-resolution emission outputs.

Activity data for further cities can be included in CRTEM/HBEFA China. This will enable these cities to carry out future scenario analyses and impact assessments of policies such as those described in this report, and make road transport emission-related interventions more targeted and effective.

1. Background

The rapid economic development in China in the last decades has led to a substantial increase in vehicle population and motorised transport. Between 1990 and 2018, China's greenhouse gas (GHG) emissions grew by 312 % (from 3.65 billion tons of CO_2 equivalents to 13.44 billion tons per year) (CAT 2019). About 10% of these emissions are caused by transport. Regarding ambient air quality, significant challenges remain in spite of recent decreases in the concentrations of some air pollutants (Zeng et al. 2019, Zhang et al. 2020). In recent years, ambitious policies were put in place and measures were taken to reduce air pollution. The emission standard of air pollutants for sintering and pelletizing of iron and steel industry was updated in 2018, and policies such as the Three-Year Action Plan to Fight Air Pollution have been brought forward. However, still particularly during winter, smog periods with high air pollution affect large parts of China, according to monthly reports on air quality released by the Ministry of Ecology and Environment (MEE) of the People's Republic of China.

Electrification and efficiency improvements in the road transport sector will gradually lower emissions in the future, but this strongly depends on the increase of renewable energy share in the overall energy mix. Besides emissions, the growth of motorised transport contributes to congestion, noise, and traffic accidents. Therefore, the negative side-effects of road transport are deteriorating life quality and health conditions of the population living mainly in metropolitan areas (Sun et al. 2014).

Decision-makers from local to national levels are therefore faced with the question which policies may most efficiently and most effectively serve to lower GHG and air pollutant emissions, in order to achieve climate targets (such as China's targets of reaching the CO_2 emission peak before 2030 and climate neutrality before 2060) and comply with air pollutant limit values. At the same time, such policies should be compatible with societal and economic objectives, and they should not shift the problem elsewhere. This means that they must be well-targeted, and their impacts must be estimated as accurately as possible before they are implemented. In China, modelling has been used for scientific measure planning, e.g. measures' outcomes being modelled, verified, and improved in the course of the policy drafting process. For example, the State Council of China published the Three-Year Action Plan to Fight Air Pollution in 2018 (State Council 2018). This policy aimed to reduce air pollutants and GHG emissions, and achieved significant improvements, especially in winter air quality, by the end of 2020. Similarly, the Shenzhen government has also put forward policies to reduce the PM2.5 concentration, such as the Shenzhen Blue Sustainable Action Plan, which started in 2018 and is still yearly updated (Shenzhen Municipal Government). This shows the potential of modelling in supporting policy making and measure designing in specific sectors, such as transportation.

The "China Road Transport Emission Model" (CRTEM) – also known as "HBEFA China" based on its European counterpart, the "Handbook of Emission Factors for Road Transport"[1] (HBEFA) – is a model for bottom-up emissions calculations for road transport. By its approach that differentiates traffic situations within road networks and considers the dynamic composition of vehicle fleets over time, it allows estimating the emission impact of different types of policies. These can include e.g. policies aimed at improving the fleet penetration with cleaner vehicles, transport planning policies shifting traffic to other modes or other locations, or spatial planning policies aimed at minimizing demand for mobility altogether. CRTEM/HBEFA China has been developed under the umbrella of the "Sino-German Cooperation on Low Carbon Transport", which, on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

This report outlines the approach, the development and the status quo of CRTEM/HBEFA China and illustrates present and possible future use cases.

[1] For more information, see https://www.hbefa.net

2. Requirements for emission calculation tools from a policy perspective

2.1. Basic approaches: Top-down vs. bottom-up

Emissions from mobile sources such as vehicle fleets cannot be comprehensively measured as it is not feasible to carry out measurements at the tailpipes of all vehicles all the time. Instead, there are two basic approaches. In this context, it is important to differentiate between fuel consumption and CO_2 emissions on one hand, and air pollutant emissions on the other hand.

For fuel consumption and CO_2 emissions, a so-called **top-down approach** can be used. Since the carbon in fossil fuels is almost completely transformed into carbon dioxide (CO_2) during combustion, the CO_2 emissions are directly proportional to the consumption of each fuel type, i.e. can be derived from fuel consumption by multiplication with a constant factor per fuel type. Therefore, no measurement is required – only fuel sales figures are necessary in order to obtain a quite accurate overall CO_2 emission estimate. However, the top-down approach has the following limitations:

- The fuel consumption/CO_2 emission estimate is only differentiated by fuel type – this means the emission cannot be attributed more specifically to a source. For example, for diesel fuel, it will not be known which share is consumed by heavy goods transport, by passenger cars or by non-road mobile machinery; therefore it will not be possible to estimate the emission impact of a policy targeting one of these categories (or their sub-categories).
- The fuel consumption/CO_2 emission estimate corresponds to the amount of fuel sold that is reflected in the sales statistic, and not to any geographical area. Road vehicles are mobile and may be fuelled in one place, but then move elsewhere and cause emissions there. If the area in focus is large enough and transport across its boundaries is rather insignificant compared to transport within its boundaries, this effect may be ignored. This is the case for rather large countries. In case of smaller countries or cities, however, fuel transports in the tanks of vehicles across the boundaries cannot be ignored. Therefore, the top-down approach is not suitable for the calculation of territorial emissions within smaller areas.

The **bottom-up approach** can be used for air pollutants as well as fuel consumption and CO_2. Under this approach, detailed activities (e.g. vehicle kilometres, vehicle stock, number of starts, etc.) differentiated by mode, vehicle type, technology/fuel type, emission standard, road type, perhaps even by road segment or trip purpose, are multiplied by corresponding emission factors.

This approach provides the differentiation required for impact assessments. However, the challenge with the bottom-up approach lies in the availability and the accuracy of input data in the required degree of detail. This includes the vehicle data, activity data and the emission factors. Typical data sources for vehicle/activity data include registration databases (for the number of vehicles and their technical characteristics; sometimes they include mileages from periodical technical inspections), transport statistics (for mileages; based on traffic counts and traffic models, which are also used directly, since often the statistics are too aggregated) or energy statistics or fuel sales figures (for the calibration and validation of fuel consumption). Data sources for emission factors include laboratory measurements, on-road measurements using PEMS (Portable Emission Measurement Systems), and remote-sensing measurements.

The effort to carry out a bottom-up calculation is therefore, in most cases, larger than with the simple top-down approach. Of course, the degree of detail and the associated effort can vary depending on the model chosen. But the higher effort of the bottom-up calculation does not guarantee the accuracy of the total emission result. In order to evaluate overall accuracy of fuel consumption and CO_2 emissions, there is the possibility to validate or even calibrate a bottom-up calculation with a top-down calculation. This possibility does not exist for air pollutants – the only way for independent validation would be to use spatially differentiated outputs of a bottom-up emission calculation as inputs for an immission (dispersion) model and compare the resulting concentrations of air pollutants to concentration measurements; however, the uncertainties in immission modelling are so large that this usually does not permit to draw conclusions about the emission input. Therefore, for air pollutants, a bottom-up emission model has to be "trustworthy" in the sense that its emission factors are derived based on up-to-date measurements and a state-of-the art methodology, and depict real-world emissions (as opposed to emissions in a test cycle, for which vehicles may be optimized but are then not able to meet the same standards on the road)

CRTEM / HBEFA China is a bottom-up model, but it includes a utility for top-down calculation of CO_2 emissions based on fuel sales.

2.2. Model requirements for policy impact assessments

From the previous chapter it becomes clear that to answer most questions on impact assessments for policies, a bottom-up model will be required that allows predicting the effect of finely targeted measures.

Examples of such measures and associated model requirements include:

- Policies aimed at improving future fleet compositions require assessment tools that allow modelling fleet turnover. For example, if a policy promotes a new technology – such as battery-electric vehicles (BEVs) or fuel-cell electric vehicles (FCEV) – with incentives, one needs to know how quickly it will penetrate the fleet; or if an old technology is to be phased-out or banned, one needs to know which share of the total mileage of the fleet will actually be affected.
- For assessing future fleets, it is important for a model to be up-to-date with the current knowledge on new technologies (such as real-world energy consumption of hybrid, gas or electric vehicles), estimates regarding technologies for which little or no empiric information exists yet (such as fuel cell electric vehicles), and real-world measurements of vehicles of recently introduced emission standards (such as the current Euro-6d passenger cars in Europe that have to pass an on-road emission test for the first time).
- Fleet compositions may need to be differentiated spatially: If a policy or measure targets a long-haul goods transport corridor (e.g. if a railway line is built to partially shift transport on the affected corridor to rail), this will affect a different composition of vehicles than if it targets roads mostly used by local/short-haul traffic (such as lorry restrictions in cities).
- Transport planning measures that shift traffic to different routes or aim to reduce congestion need to be evaluated with an emission model sensitive to different driving patterns in different traffic situations: Even if the total mileage remains the same before and after the measure, the emissions may differ due to different driving patterns on different road types or in different congestion levels.
- Policies aimed at improving air quality will generally need to be assessed using spatially differentiated emission models, i.e. differentiating road network links, so their results can be used as an input

for dispersion models that will allow estimating the impact on air quality.

- Policies for combatting climate and improving air quality can sometimes conflict. For example, diesel cars are generally more fuel-efficient than petrol cars, which is good for the climate, but they tend to emit more NO_x and particles. Particle filters reduce particle emissions but cause higher fuel consumption. Such conflicting goals can be optimized by using models that can calculate both GHG and air pollutant emissions, and comparing the outcome of different measure mixes.

2.3. Requirements meet data availability with HBEFA

CRTEM/HBEFA China fulfils the requirements for emission models from a policy perspective outlined in the previous chapter. Moreover, the input data required by CRTEM/HBEFA China correspond to what is available in most cases. The activity data needed to run CRTEM/HBEFA China at road network link level can be obtained from the outputs of most traffic models - CRTEM/HBEFA China even includes a feature for easy import of traffic model data (see also Chapter 4.1).

But more importantly, the traffic situation approach used by HBEFA allows taking into account the different driving patterns of different vehicle categories in different contexts (road types, surrounding area types, speed limits, levels of congestion) without requiring extensive input data for each model run, because typical driving patterns for all relevant traffic situations have been distilled from hundreds of hours of real-world GPS data and are stored in HBEFA along with the associated emission factors. Each traffic situation is characterised by a typical driving pattern, a series of second-by-second data points representing the speed of a vehicle versus time. Figure 1 presents the typical traffic situations for motorways with a speed limit of 130 km/h and 120 km/h in free-flowing and saturated traffic respectively, as well as for an urban collector (arterial) with a speed limit of 50 km/h in free-flowing and stop-and-go traffic.

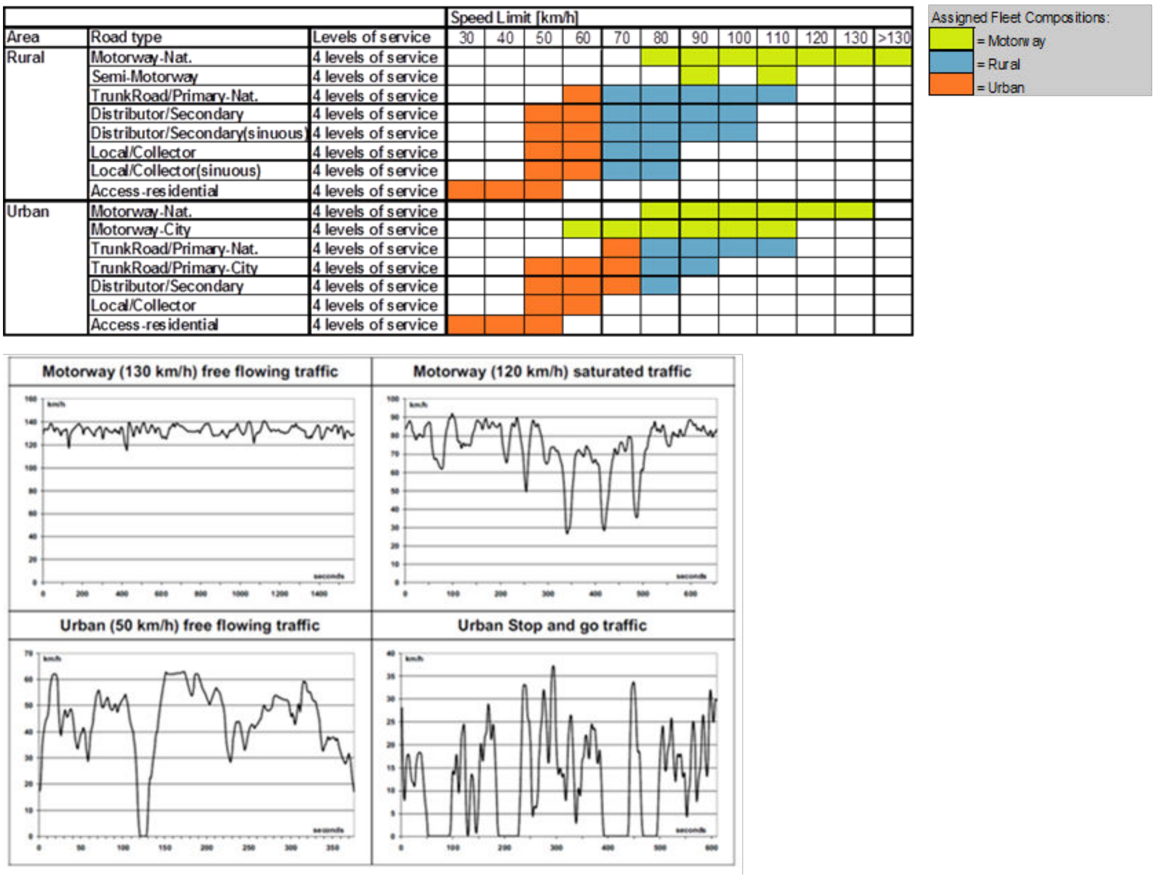


Figure 1: Example of traffic situations in HBEFA (Source: INFRAS 2014)

The traffic situation approach represents an advantage of CRTEM/HBEFA China over other well-known emission models such as COPERT (Computer Programme to calculate Emissions from Road Transport, Ntziachristos et al. 2009, EMEP/EEA 2018) or MOVES (Motor Vehicle Emission Simulator, EPA 2019): With COPERT, the input data requirements are quite low and it is well-suited for national scale emission inventories, but it operates at a too generalized level for city-scale assessments: Since emission factors are only dependent on three road types (motorway, rural, and urban roads) and average speed, e.g. effects of reducing congestion cannot be depicted adequately. In MOVES, on the other hand, activities and emission factors are differentiated by 23 Vehicle Specific Power (VSP) bins containing different degrees of acceleration/deceleration; this permits assessments at a degree of detail equal or higher than HBEFA, but the resulting complexity in the preparation of input data can act as a deterrent in practical application cases. The traffic situation approach in CRTEM/HBEFA China represents a way in between the data/effort requirements of COPERT and MOVES that is suitable from city scale up to national scale.

3. Development of CRTEM/HBEFA China

3.1. History of the European HBEFA

HBEFA was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria. Currently other countries (Sweden, Norway and France) as well as the JRC (Joint Research Centre of the European Commission) support HBEFA. To develop the emission factors, the original data from various test laboratories are collected and processed with the Passenger Car and Heavy-Duty Emission Model (PHEM) by the Technical University of Graz (Hausberger and Rexeis 2018). The first version (HBEFA 1.1) was published in December 1995.

Since then, updates followed in intervals of 2-5 years, based on the available new measurement data (and other inputs). The first update (HBEFA 1.2) dated from January 1999. Version HBEFA 2.1 was available in February 2004. Version HBEFA 3.2, on which the first CRTEM/HBEFA China Version is based (see below) dates from January 2014. With Version 3.3, only the emission factors of diesel passenger cars were updated in the wake of the VW diesel scandal[2]. The latest Version 4.1 dates from September 2019, with its new features focusing on electric mobility and alternative fuels.

3.2. CRTEM/HBEFA China, Version 3.2

In the framework of a cooperation project conducted between 2012 and 2014 with the Shenzhen Urban Transportation Planning Center (SUTPC) implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, the European HBEFA was adapted to Chinese cities. The development of CRTEM/HBEFA China Version 3.2 is described in great detail in Sun et al. (2014). While analyses had shown that the passenger cars used in Chinese cities are very similar to those in Europe regarding engine characteristics, the traffic situations differ:

- Instead of six, only four road types are relevant for Chinese cities. These are: expressways (including

[2] Already before the diesel scandal, HBEFA had published NO_x emission factors of diesel passenger cars that were about five times higher than the limit value – which were confirmed by the diesel scandal. The HBEFA 3.3 update was primarily a response to the communication needs of the German government, which needed to be based on the most recent measurements and findings.

highways), major arterials, minor arterials and branches.

- Essentially, in Chinese cities, speed limits are linked to the road type and do not have to be considered separately.
- It was shown that the levels of service in Chinese cities are similar to Europe for free-flow, heavy and saturated traffic conditions. However, based on the congestion levels used in Beijing and Shenzhen (see Table 1), it was necessary to distinguish two types of stop-and-go-traffic - a first stop-and-go situation similar to the European one, and a second one with higher shares of stop time and lower speeds, which so far had not been necessary for Europe, but often occurs in large Asian cities. Therefore, five levels of service were defined for Chinese cities to cover all driving situations (compared to the four in the corresponding European HBEFA version), including the additional heavy stop-and-go traffic.

Since the development of CRTEM/HBEFA China is primarily focused on urban areas, for the time being it is sufficient to consider the 20 different traffic situations in total (resulting from 4 road types times 5 levels of service). Traffic situations on highway and in rural areas might be different. Table 1 lists the definitions of the traffic situations for Chinese cities in CRTEM/HBEFA China.

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

Table 1: Definition of level of services based on congestion levels, road types and ranges of average speed in km/h in China

3.3. CRTEM/HBEFA China, Version 4.1

As mentioned in Chapter 3.1, the new features in the European HBEFA Version 4.1 focused on electric mobility and alternative fuels. This led to the integration of new vehicle types such as BEV (battery-electric vehicles), PHEV (Plugin-hybrid electric vehicles), FCEV (fuel-cell electric vehicles), or CNG (compressed natural gas) and LNG (liquid natural gas) vehicles. Actually, some of these vehicle types had already been available in previous HBEFA versions, but their emission factors had only been based on few measurements and rough expert estimates. In HBEFA 4.1, these emission factors are based on detailed measurements and simulation for all traffic situations with PHEM.

All new measurement data available since 2014 were integrated in HBEFA 4.1. Due to the fact that on-road measurements with Portable Emission Measurement Systems (PEMS) became widespread in this period and that methods had been developed to use such measurements in PHEM (Matzer et al. 2019), HBEFA 4.1 is based on a significantly larger amount of measurement data than previous versions.

Furthermore, new traffic situations were added to the European traffic situation scheme; namely the fifth level of service, heavy stop-and-go, first introduced in HBEFA China 3.2 (see Chapter 3.2), was also made available for Europe.

CRTEM/HBEFA China Version 4.1, developed after the publication of the European HBEFA 4.1 in 2019, combines the improvements in the European Version 4.1 with the Chinese traffic situation scheme described in the previous Chapter.

4. Overview of CRTEM/HBEFA China

4.1. Features

CRTEM/HBEFA China is a database application implemented in Microsoft (MS) Access. Version 3.2 was based on MS Access 2010 and Version 4.1 is based on MS Access 2016. The application is distributed as a self-contained installer for Windows. If MS Access is not already present on the target computer, the installer installs the free MS Access Runtime 2016 that CRTEM/HBEFA China will run on.

CRTEM/HBEFA China contains the following features:

- The core of CRTEM/HBEFA China is its database of emission factors, differentiated by vehicle types ("subsegments") and traffic situations. The emission factors have been developed using the PHEM model for the driving cycles assigned to each traffic situation for each vehicle category. They represent real-world emissions (as opposed to optimised emission rates under ideal testing conditions).
- A user-friendly interface for querying the emission factors at various aggregation levels (Figure 2). All previously executed queries (called "cases") are stored and can be retrieved, edited if necessary, and re-run if desired. The results are stored in an open MS Access "user" database and can be analysed in MS Access. They can also be exported in Excel format.
- A selection of traffic situations tailored to Chinese cities (see Table 1).
- CRTEM/HBEFA China covers all relevant road vehicle categories, technologies, and emission standards; Version 4.1 also contains emission and energy consumption factors for new technologies such as BEV (battery-electric vehicles), PHEV (Plugin-hybrid electric vehicles), FCEV (fuel-cell electric vehicles), or CNG and LNG vehicles.
- A module for fleet modelling: It allows building a fleet model from input data on vehicle stock (for historical periods) or new registrations (for future periods), traffic activity, emission standard introduction schemes, fuel efficiency development over time, and several specialised inputs such as the percentage of vehicle with diesel particle filters (required for emission standards with optional diesel particle filters or DPF), the mileage share driven with electricity or combustion for Plug-in Hybrids, or gas/petrol for bio fuel vehicles. The

result of this module is a table containing the shares of stock and mileage by vehicle type and reference year, which are required as weights for the aggregation of emission factors, as well as the cumulative mileages required for the mileage-depending correction factors. The latter account for the deterioration of catalysts with age.

- A module for traffic datasets, containing features to import and process traffic activity data, i.e. vehicle stock, mileage (aggregated, or as traffic volume per road network link), and all inputs required by the fleet model.
- A module for emission modelling, i.e. carrying out the multiplication of activity data (prepared via the module mentioned above) and the emission factors from the core database.
- A utility for top-down calculation of CO_2 emissions based on fuel sales.
- Utilities for data transfer to GIS software. Results can be either exported in ESRI Personal Geodatabase format, or as tabular export by road/zone link that can be linked to any geospatial data format via unique link/zone IDs.

Several features available in CRTEM/HBEFA China are not available in the HBEFA “Public Version” distributed in Europe; they correspond to features in the European “Expert Version” that is not distributed publicly. These include the Fleet model, Traffic datasets, and Emission model modules.

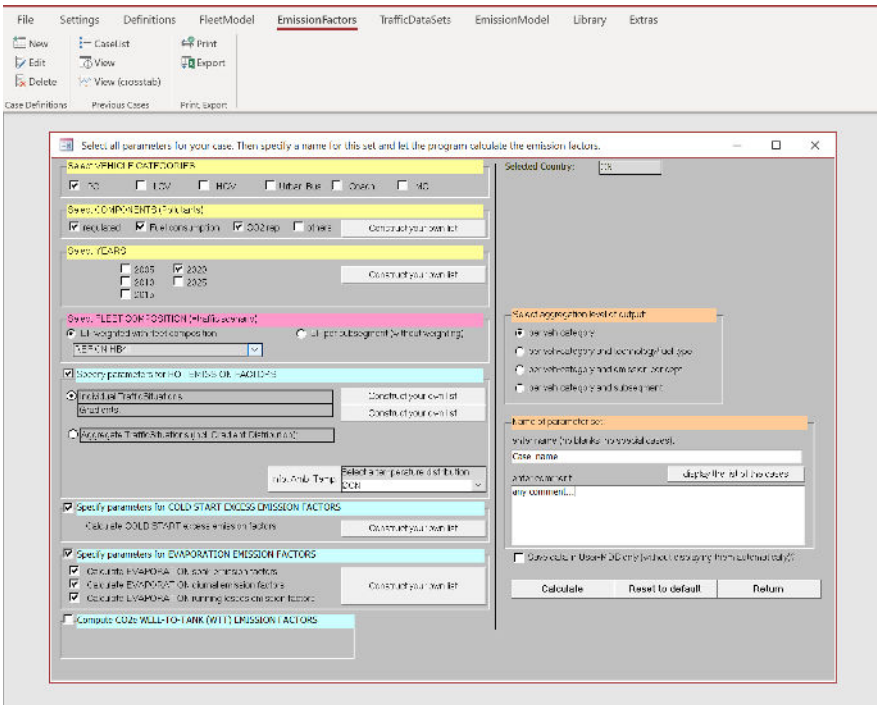


Figure 2: User interface for querying emission factors in CRTEM/HBEFA China (Source: HBEFA, Version 4.1)

Out of the box, with the features described above, CRTEM/HBEFA China can be used to query emission factors at the most detailed level, i.e. at the level of “subsegment” (vehicle type defined by vehicle category, technology, emission standard and optionally size class) and traffic situation. This is already sufficient for applications like the real-time Emission Monitoring System in Shenzhen (Figure 3) in which individual vehicles can be assigned to their “subsegment” via license plate recognition and automatic online query of the registrations database, and the street link they are presently moving on via their GPS position.

In addition, users can create fleet compositions (using the fleet modelling module) or aggregated traffic situations (distribution of mileage among individual traffic situations), if they wish to query emission factors at more aggregated levels, calibrate the fuel consumption factors to local passenger car fleets, or calculate own future scenarios.

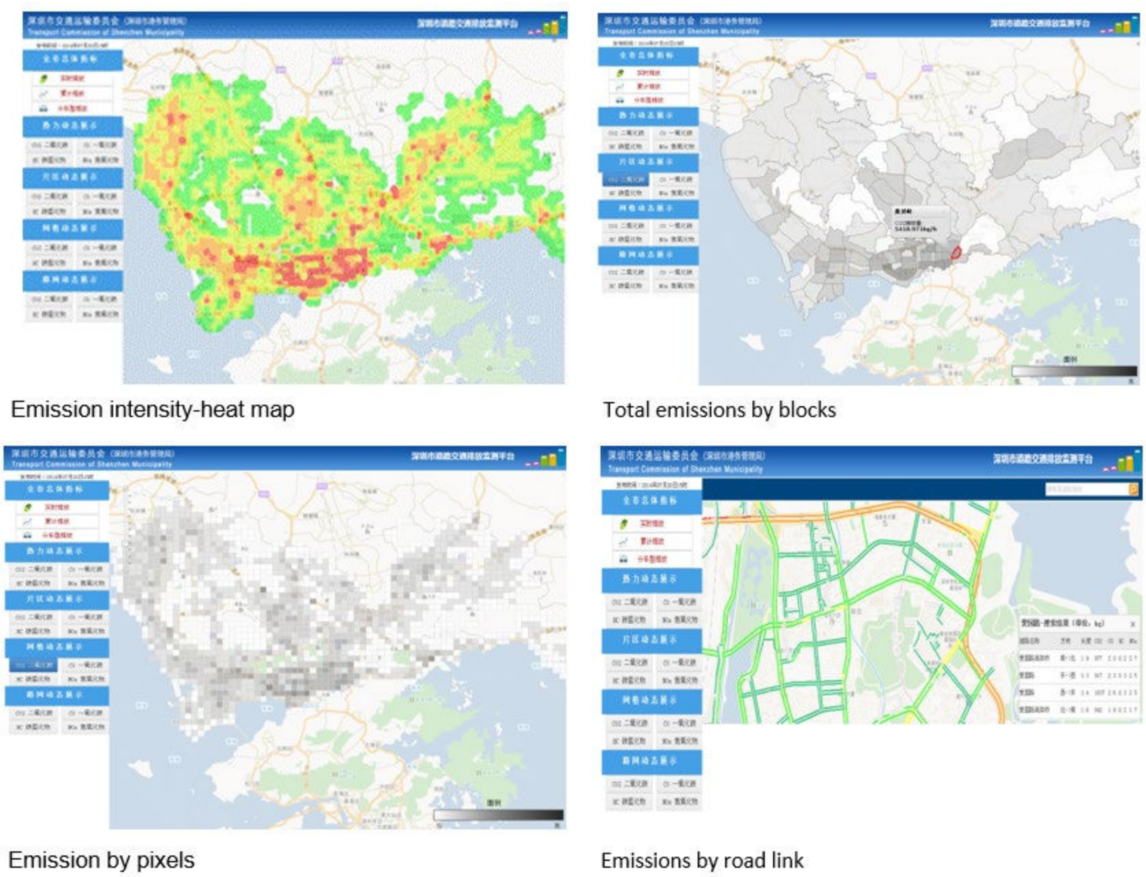


Figure 3: Screenshot of the Emission Monitoring System in Shenzhen (Source: Sun et al. 2014).

4.2. Limitations

Users should be aware of the following limitations of CRTEM/HBEFA China:

- The emission factors of air pollutants are based on European measurements. Since the China emission standards are similar to the Euro emission standards, and the vehicle types circulating in China are similar to their European counterparts, it can be assumed that the differences should not be too large. Investigations of the Technical University of Graz within this project have confirmed this assumption in principle. However, the emission factors of air pollutants should still be validated with local measurements. Such validations are currently carried out by the Shenzhen Urban Transportation Planning Center (SUTPC) using an on-road plume chasing and analysis system (OPCAS) (Figures 4 and 5).

OPACS System

Figure 4: OPCAS emission measurements in action.

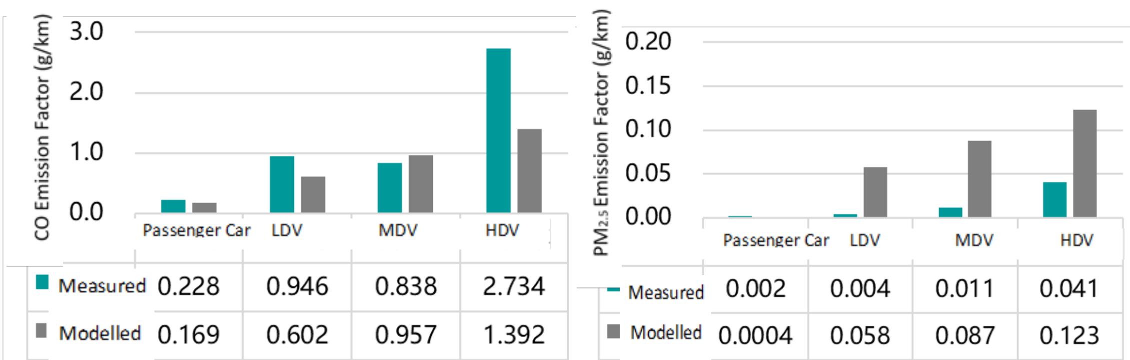


Figure 5: Emission factors calculated by OPCAS and HBEFA (Source: SUTPC)

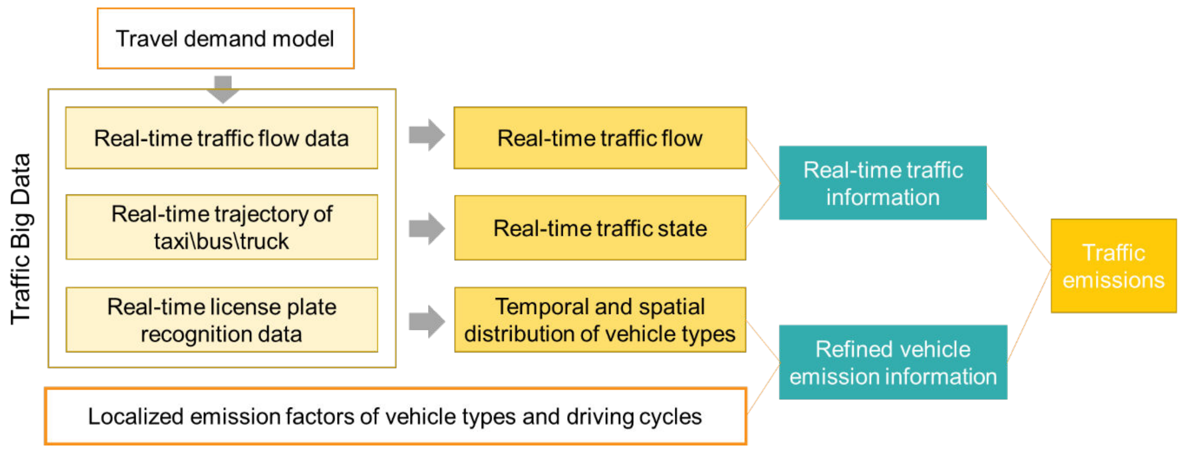
- At the micro-scale level, i.e. for modelling the effect of traffic lights at a junction, or the effect of individual differences in driving behaviour – i.e. beyond the level of detail of a traffic situation on a road link with a typical driving profile (that already includes stops at junctions, deceleration and acceleration due to obstacles etc.) – CRTEM/HBEFA China is not the appropriate tool. For such micro-scale analyses, detailed models such as PHEM or MOVES are more suitable.

5. Application in Shenzhen, China

5.1. Approach

Based on the HBEFA model, transport mileages in Shenzhen were classified by traffic situation and attributed the corresponding emission factors in order to calculate emissions. By using high-precision equipment to collect GPS data every second, the average speed V, stopping time ratio SP, relative positive acceleration RPA, and other indicators of the working conditions were obtained. The local working conditions in Shenzhen were extracted and classified, and the 20 candidate traffic situations for each road type and traffic condition were screened. A localized emission factor database covering energy consumption, CO_2, CO, NO_x, and other air pollutants has been established in Shenzhen for 4 road types, 5 service levels, 5 vehicle types, 4 energy types, and 5 emission standards, with a total of 5,400 emission factors.

Using the HBEFA modelling method, the refined emission model is established "from bottom to top". Based on the traffic demand, operation characteristics, and emission factors, the traffic emissions are calculated. Based on the emissions of a single road section and a single vehicle type, the traffic emissions of a region and a city are calculated to realize the bottom-up emission calculation.



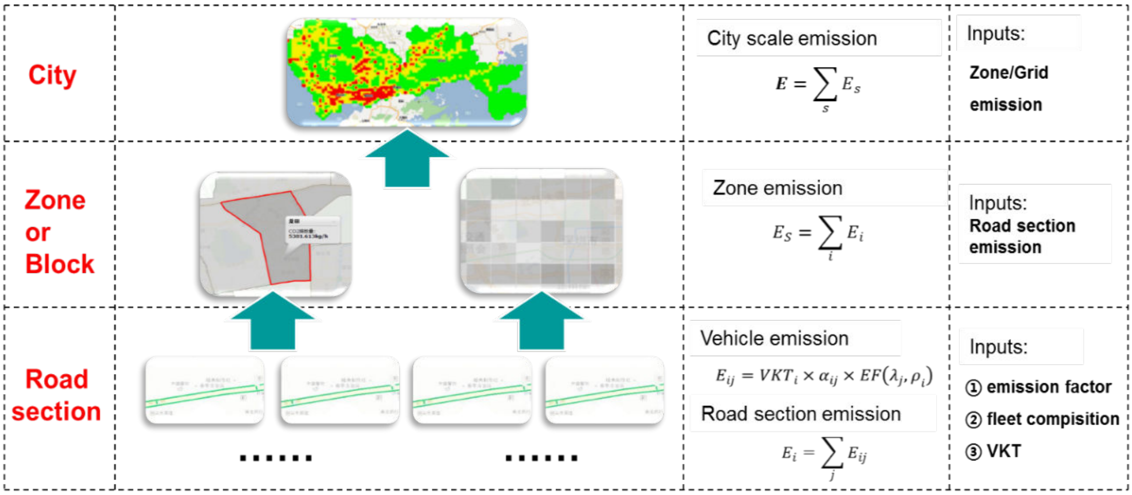


Figure 6: The validation and updating of pollutant emission factors of HBEFA model by SUTPC (Source: SUTPC)

Shenzhen Traffic Emission Monitoring Platform

The HBEFA model is also integrated into Shenzhen's emission monitoring platform that monitors emissions from main roads and transport hubs, such as airports, and ports. The total emissions could be calculated and interpreted in the two Figures below. Figure 7 shows the pollution concentration distribution of road emission diffusion simulation for each sub-district. Figure 8 shows the emissions by road section.

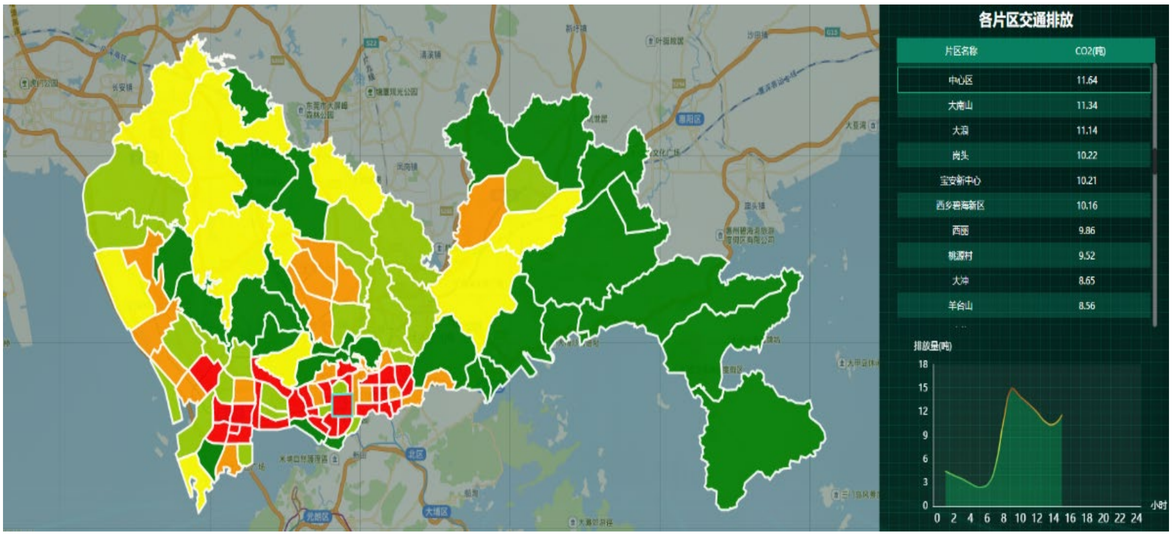


Figure 7: Road emissions in Shenzhen's sub-districts (Source: SUTPC)

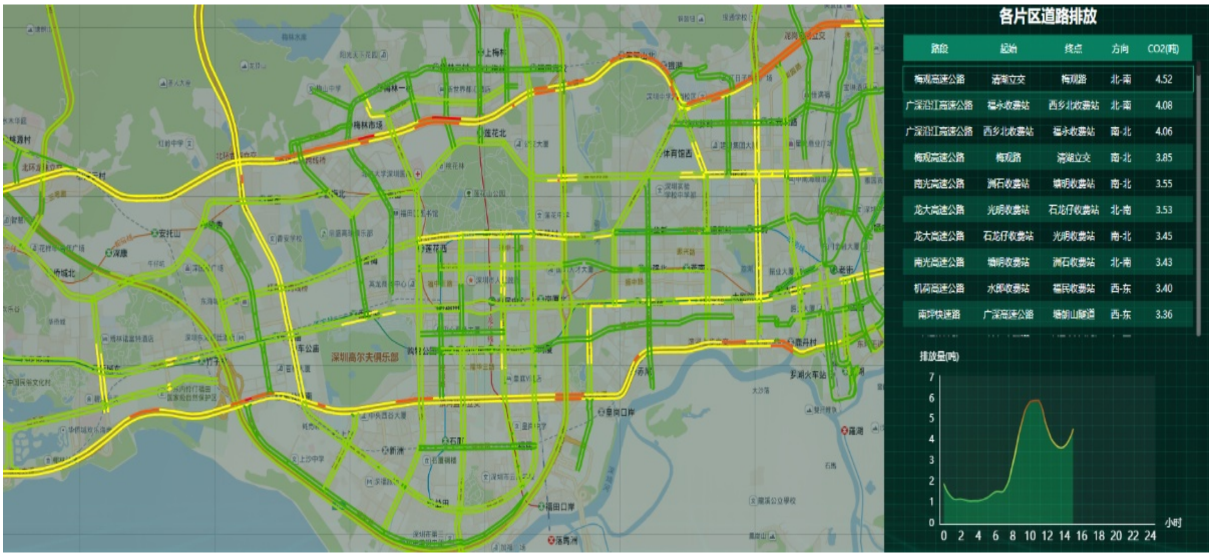


Figure 8: Road emissions in Shenzhen (Source: SUTPC)

5.2. Application Scenario 1: Transportation Policy Evaluation

A quantitative and detailed calculation of urban traffic emissions can support the assessment of the impact of traffic policies on the environment and can function as an important basis for evaluating the implementation effect of policies and measures. Using the HBEFA model, SUTPC evaluated the environmental impact of the parking charge policy in Shenzhen, including two scheme plans (plan 1 and 2, see Table 2 below). By comparing the current traffic emission density of each sub-district in Shenzhen with the simulated traffic emission density after the implementation of the two plans, the expected improvement effect of the two plans can be obtained. It was found that traffic emissions after the implementation of plan 1 decrease by 22.30%, while the emissions decrease after implementation of plan 2 is 21.50%. The evaluation results supported the selection of the parking charge policy in Shenzhen. With the policy it was possible to improve parking resources, improve traffic efficiency, and reduce the traffic emissions of the whole city (see Figure 9 and 10).

Plan 1				Plan 2			
Billable hours	Charge standard (CNY/ 30 min)			Billable hours	Charge standard (CNY/ 30 min)		
	Type 1 region	Type 2 region	Type 3 region		Type 1 region	Type 2 region	Type 3 region
Working days (7: 00 – 21: 00)	6	4	2	Working days (7: 00 – 21: 00)	5	3	2
Nonworking days (7: 00 – 21: 00)	3	2	1	Non-working days (7: 00 – 21: 00)	3	2	1
Carbon emission testing	**Reduced by 22.3% than the status quo**			**Carbon emission testing**	**Reduced by 21.5% than the status quo**		

Table 2: Detailed measures planned under the two plans

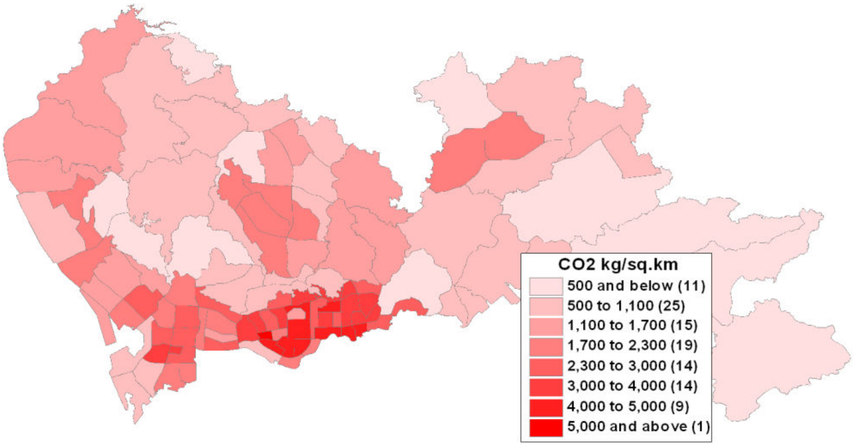


Figure 9: Current traffic emission density of each sub-district of Shenzhen (Source: SUTPC)

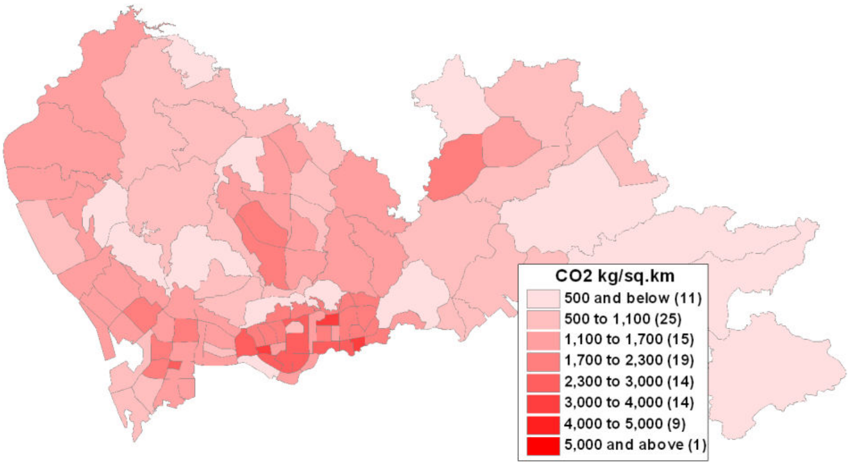


Figure 10: Modelled traffic emission density of each sub-district of Shenzhen after the implementation of the policy plan 1 (Source: SUTPC)

5.3. Application Scenario 2: High-resolution real-time monitoring in the Shenzhen International Low Carbon City

Based on the traffic emission model and monitoring platform, Shenzhen has built China's first sub-district resolution road traffic emission monitoring platform within the five square kilometres of the Longgang International Low Carbon City in the North of Shenzhen to evaluate the area’s traffic planning.

The purpose of the platform is to support the evaluation of environmental benefits of traffic management policies and to facilitate their implementation. By integrating GPS data with the monitoring data from 8 smart lamp posts (see Figure 13) and 304 electromagnetic ground detectors installed on the road, the platform can obtain real-time data on vehicle distribution, speed, flow, and other parameters. By using the traffic emission inventory CRTEM/HBEFA, the fleet composition and the dynamic traffic demand data, the applying authority can extract the high-resolution traffic emission data.

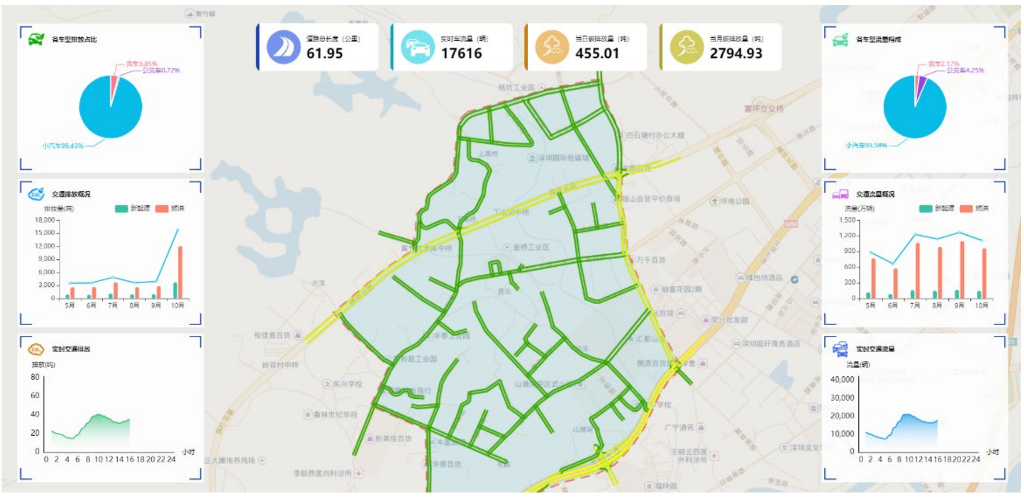


Figure 11: Carbon Emission Monitoring Platform in Longgang International Low Carbon City (Source: SUTPC)

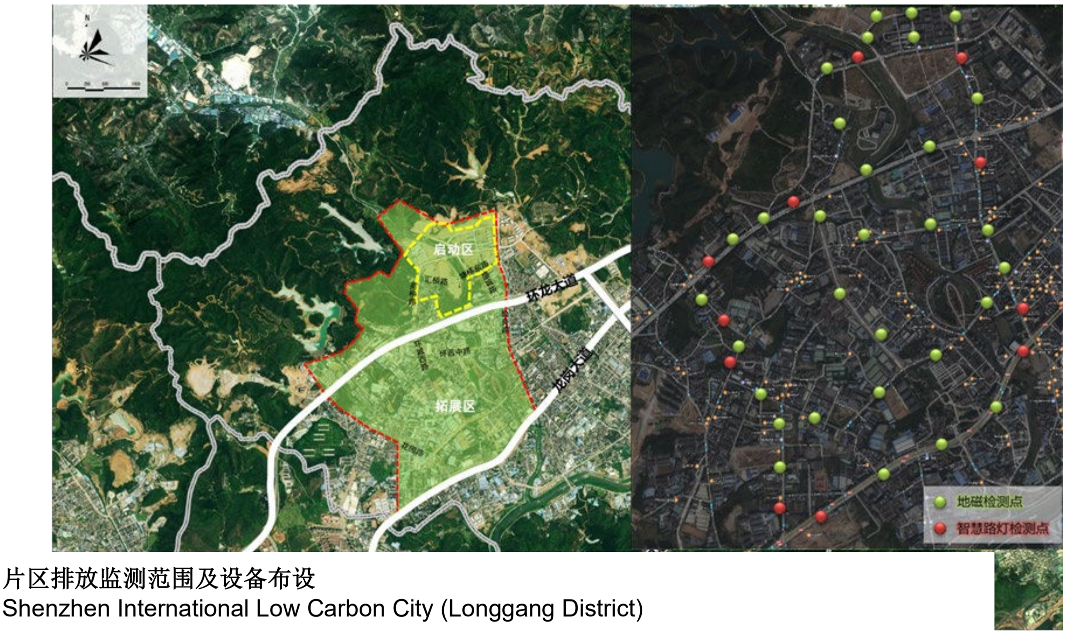


Figure 12: Monitoring Instrument Layout in Shenzhen's Longgang International Low Carbon City (Source: SUTPC)

Figure 13: Example of smart lamp posts with vehicle recognition device (Source: SUTPC)

5.4. Summary

Since 2014, CRTEM/HBEFA China has been established and further developed in Shenzhen. It has been deeply adapted into the city traffic emission administration platform operated at Shenzhen Traffic Carbon Emission Engineering Lab. Based on the big data derived from the platform, it has directly supported the traffic control planning, and environmental mitigation policy/measure development in Shenzhen.

6. Outlook

CRTEM/HBEFA China has been applied in the cities of Beijing, Shenzhen and Harbin. GIZ China plans to further promote and support the use of CRTEM/HBEFA China in Chinese cities for impact assessments of policy options regarding transport, ranging from urban transport planning or air quality monitoring to decarbonisation.

As shown in the application case of Shenzhen, existing users such as SUTPC have integrated CRTEM/HBEFA China into existing emission administration platforms and will continue ongoing efforts to validate the air pollutant emission factors in the Chinese context using CRTEM/HBEFA China. As a next step, it is planned to employ more intelligent and portable environmental monitoring instruments into the platform to realize the verification and validation function between modelling and monitoring data. The outcome of this work is expected to enrich the traffic scenario building to further traffic flow and thus decrease emissions, and to support the environmental department and other authorities to achieve the carbon cap as early as possible

Activity data for further cities can be included in CRTEM/HBEFA China, and the time series of activity data can be extended. Thus, the model can be used in the respective cities for future scenario analysis and impact assessments of policies such as those described in this report, in order to make these policies more targeted and effective.

References

CAA 2013: *China to Tackle Air Pollution with a New Action Plan. CAA (Clean Air Asia). http://cleanairinitiative.org/portal/node/12066 [Accessed 17. February 2020].*

CAT 2019: *China country summary. Climate Action Tracker (CAT). https://climateactiontracker.org/countries/china/ [Accessed 17. February 2020].*

EMEP/EEA 2018: *EMEP/EEA emission inventory guidebook 2016. Technical guidance to prepare national emission inventories. 1.A.3.b.i-iv Road transport (2018 update). European Monitoring and Evaluation Programme (EMEP), European Environment Agency (EEA), Luxembourg. https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i/view [Accessed 21. November 2016].*

EPA 2019: *MOVES and Other Mobile Source Emissions Models. United States Environmental Protection Agency (EPA). https://www.epa.gov/moves [Accessed 17. February 2020].*

Hausberger, S., Rexeis, M. 2018: *PHEM. Passenger car and Heavy duty Emission Model. Institute for internal combustion engines and thermodynamics, Technical University of Graz, Graz, Austria. https://www.ivt.tugraz.at/images/stories/Files/Emissionen/PHEM_en.pdf [Accessed 4. June 2018].*

INFRAS 2014: *HBEFA 3.2. Handbook of Emission Factors for Road Transport; im Auftrag des Bundesamts für Umwelt, des Umweltbundesamtes Berlin, des Umweltbundesamts Österreich, der schwedischen Road Administration, dem norwegischen Umweltbundesamt sowie ADEME (Agence de l'Environment et de la Maîtrise de l'Energie, Paris. INFRAS, Bern. www.hbefa.net [Accessed 15. June 2015].*

Matzer, C., Weller, K., Dippold, M., Lipp, S., Röck, M., Rexeis, M., Hausberger, S. 2019: *Update of Emission factors for HBEFA 4.1. Final report DRAFT-V1, I-05/19/CM EM-I-16/26/679 from 12.04.2019. Technische Universität (TU) Graz, Graz, Austria.*

Ntziachristos, L., Gkatzoflias, D., Kouridis, C., Samaras, Z. 2009: *"COPERT: A European Road Transport Emission Inventory Model" in I. N. Athanasiadis, A. E. Rizzoli, P. A. Mitkas, and J. M. Gómez (eds.), Information Technologies in Environmental Engineering. Springer Berlin Heidelberg, Berlin, Heidelberg, 491–504. http://link.springer.com/10.1007/978-3-540-88351-7_37 [Accessed 28. September 2015].*

Shenzhen Municipal Government 2018: *Shenzhen Blue Sustainable Action Plan 2018. http://www.sz.gov.cn/gkmlpt/content/7/7786/post_7786646.html#749*

Song, J. 2014: *Shenzhen Transport Emission Monitoring Platform and Application. Presentation at the Expert Panel Meeting of the Shenzhen Urban Transport Planning Centre on 2014-07-22. Shenzhen.*

State Council of P.R China 2018: *Three-Year Action Plan to Fight Air Pollution. http://www.gov.cn/zhengce/content/2018-07/03/content_5303158.htm*

Sun, S., Schmied, M., Bongardt, D., Wüthrich, P., Eichhorst, U. 2014: *Modelling Energy Consumption and GHG Emissions of Road Transport in China. Technical Paper on the CRTEM/HBEFA China Model. https://transition-china.org/wp-content/uploads/2021/02/81-Modelling-GHG-Emissions-of-Road-Transport-in-China_Final_WF-1.pdf [Accessed 30. March 2021].*

Zeng, Y., Cao, Y., Qiao, X., Seyler, B. C., Tang, Y. 2019: *Air pollution reduction in China: Recent success but great challenge for the future. Science of The Total Environment 663, 329–337.*

Zhang, F., Shi, Y., Fang, D., Ma, G., Nie, C., Krafft, T., He, L., Wang, Y. 2020: Monitoring history and change trends of ambient air quality in China during the past four decades. Journal of Environmental Management 260, 110031.

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Sitz der Gesellschaft
Bonn und Eschborn

Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Deutschland
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Deutschland
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de