Optimal Methodology to Generate Road Traffic Emissions for Air Quality Modeling: Application to Ho Chi Minh City

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Abstract

Growing population, consuming a large amount of energy such as combustion of fossil fuel, increasing pollutant emissions in the atmosphere are the threats to the sustainable development of our planet in general, and of the air quality in particular. According to the World Health Organization, air pollution causes the death of more than 2 million people per year in developing countries, and millions of people also suffer from various respiratory illnesses. Road traffic is the main source of air pollution in cities and there are large uncertainties associated to this source of pollution. Different models are available to quantify the amount of pollutants released by road traffic. However, these models always require a large amount of information and work, and thus their use results expensive. These limitations are difficult for the study and the management of air quality in cities from the developing world. Thus, it is extremely difficult to design efficient abatement strategies to reduce air pollution. For this reason, it is necessary to develop a new methodology for generating road traffic emissions to contribute to a better management of the urban air quality.

The first aim of this PhD thesis is to develop and to validate a new model for generating road traffic emissions in several steps with different levels of complexity. The developed model is called EMISENS. Its main specifications are: (i) EMISENS is able to compute a total amount of emissions and to distribute it in time and in space using a methodology which combines the top-down and the bottom-up approaches; (ii) the model is able to compute the emissions and the uncertainties within a reasonable computing time and (iii) the model formulation is based on well referenced methodology (COPERT IV).

The validation of EMISENS model was carried out by its application over Strasbourg, France. The results of EMISENS have been compared with the results of the more complete and complex model Circul'air which is currently used to manage the Strasbourg air quality. After comparing the results of the two models, it appeared that they are very close. This example of application illustrates the capacity of EMISENS to calculate road traffic emission inventory (EI) for cities in developed countries as well as in developing countries

Further on, a complete EI is carried out over Ho Chi Minh City (HCMC) by applying an innovative methodology based on the application of the EMISENS model. HCMC is the largest city in Vietnam, it had more than 6 million inhabitants in 2006. It has more than three million vehicles and 28,500 factories in the city. High levels of air pollution are thus very often detected. The purpose of this part of the research consists in applying the EMISENS model to generate road traffic emissions. For the other emission sources, the top-down approach is used for generating the EI. The results show that the road traffic is the main emission source in the city. The motorcycles are responsible of the traffic emissions (94 % of CO, 68% of Non-Methane Volatile Organic Compound (NMVOC), 61 % of SO_2 and 99 % of CH_4). Two scenarios for reducing traffic emissions are evaluated to reduce the HCMC emissions for the year 2015 and 2020. In addition, two other scenarios are the Business as Usual scenarios for the year 2015 and 2020 are also studied to evaluate the traffic emissions in HCMC.

The third part of this work consists in applying air quality models to the region of HCMC, the aim here is to study abatement strategies for emission reduction in the city. The results of the simulation show that the plume of O_3 is developed in the north-western part of the city. These results are in good agreement with the measurements. Among the four previous emission scenarios, we chose only two reduction emission scenarios to study the effective abatement strategies for the year 2015 and 2020 in using air quality model. These two affective abatement strategies are adopted to help the local government to take decision for managing air quality in HCMC. The 100 Monte Carlo (MC) simulations are run for estimating the uncertainty in the results of air quality simulations. The results of these two abatement strategies showed that if the local government follows the emission control plan:

- For 2015, the O_3 concentration in 2015 will be similar to the present O_3 concentration.

- For 2020, the O_3 concentration in 2020 will decrease of around 10% to 30% of O_3 in comparison to the actual level. However, the O_3 concentration in 2020 is still higher than standard limit.

The developed methodology for generating road traffic emissions offers several advantages. It is able to calculate a road traffic emission for both developing and developed countries. The calculation is divided in several steps with different level of complexity. Therefore, this methodology provides the new approach to manage air quality in cities.

Keywords: Urban air quality, emission inventory (EI), uncertainty analysis, Monte Carlo (MC), EMISENS model, Ho Chi Minh City (HCMC), photochemical modeling, effective abatement strategies.

Résumé

La croissance de la population mondiale induit une consommation élevée d'énergie issue des combustibles fossiles. La combustion de ces derniers augmente l'émission de polluants dans l'atmosphère, et celle-ci menace le développement durable de notre planète en général, et la qualité de l'air en particulier. D'après l'Organisation Mondiale de la Santé, la pollution atmosphérique dans les grandes villes cause la mort de plus de 2 millions de personnes par an dans les pays en voie développement. De plus, des millions de personnes souffrent de différentes maladies respiratoires. Parmi toutes les sources de pollution, le trafic routier est la principale source de pollution de l'air dans les villes. Malheureusement, les modèles disponibles actuellement pour quantifier ce type d'émissions exigent à la fois beaucoup d'efforts, d'argent et de temps. Ils font obstacles à l'étude et à la gestion de la qualité de l'air. Par conséquence, de nouvelles stratégies pour améliorer la qualité de l'air sont extrêmement difficiles à appliquer. Il est donc nécessaire de développer une nouvelle méthodologie pour quantifier les émissions du trafic routier afin de gérer la qualité de l'air d'une manière plus efficace.

Le premier objectif de cette thèse est de développer et valider un nouveau modèle (appelé EMISENS) pour estimer les émissions du trafic routier. Les principales caractéristiques du modèle sont: (i) EMSIENS est capable de calculer une somme totale d'émissions et de la distribuer dans le temps et l'espace en utilisant une méthodologie qui combine des approches top-down et bottom-up, (ii) le modèle calcule les émissions et les incertitudes avec un temps de calcul raisonnable, (iii) la formulation du modèle est base sur une méthodologie bien référencé (COPERT IV). La validation du modèle EMISENS a été réalisée en appliquant celui-ci, ainsi que le modèle complexe Circul'air, au cas d'étude de Strasbourg en France. Suite à la comparaison des résultats entre les deux modèles, il en résulte que ceux-ci sont très proches. Cet exemple d'application permet d'illustrer la capacité du modèle EMISENS, développé dans cette thèse, à calculer des émissions du trafic routier aussi bien pour les pays développés que pour les pays en voie développement.

Dans une deuxième phase, un complet de cadastre des émissions est réalisé sur Ho Chi Minh Ville (HCMV). HCMV est la plus grande ville du Vietnam. En 2006, sa population dépasse les 6 millions d'habitants. HCMV est l'une des 100 villes dont la croissance économique est la plus élevée dans le monde. Il a plus de trois millions de véhicules et 28,500 usines dans la ville. De haut niveau de pollution de l'air sont ainsi très souvent détectés. Le but de cette partie de la recherche consiste à appliquer le modèle EMISENS à HCMV afin de calculer les émissions du trafic routier. Pour les autres sources d'émission, une approche top-down est utilisée pour créer un cadastre d’émissions. Les résultats ont montré que le trafic routier est la principale source d'émissions dans la ville. Les motocycles sont les principaux responsables des émissions dues au trafic (respectivement 94% du CO, 68% des Composés Organiques Volatils Non Méthaniques (COVNM), 61% du SO_2 et 99% du CH_4). Afin de réduire les émissions dues au trafic, deux scénarios sont étudiés en utilisant un plan de réduction des émissions pour HCMV pour l’année de 2015 et 2020. En plus, deux scénarios «Business as Usual» pour l’année de 2015 et 2020 sont également étudiés pour évaluer les émissions dues au trafic à HCMV.

La troisième partie de ce travail présente l’application d’outils de modélisation de la qualité de l'air sur la région de HCMV, dans l’intention d’étudier l’impact des stratégies de réduction des émissions dans la ville sur la qualité de l’air. Les résultats, issus du modèle, ont montré que le panache d’O_3 se développe dans la partie nord-ouest de la ville. De plus, ces résultats sont similaires aux mesures effectuées sur le terrain. Parmi les quatre scénarios d’émissions précédentes, on a choisi deux scénarios de réduction des émissions pour étudier les stratégies de réduction en utilisant le modèle qualité de l’air. Ces deux stratégies de réduction sont adoptées dans ce travail pour aider le gouvernement local à prendre une décision concernant la gestion de qualité de l'air à HCMV. Les 100 Monte Carlo (MC) simulations sont utilisées pour l'estimation de l'incertitude dans les résultats de simulations qualité de l'air et dans les résultats de simulations des stratégies. Les résultats provenant des deux stratégies de réduction pour l’année de 2015 et 2020 ont montré que si le gouvernement suit le plan de contrôle des émissions tel que prévu :

- Pour 2015, la concentration en O_3 restera similaire à la concentration actuelle,
- Pour 2020, la concentration en O_3 diminuera d'environ 10% à 30% par rapport à la concentration actuelle. Cependant, la concentration O_3 en 2020 est toujours plus haute que la limite du Vietnam.

La méthodologie développée pour estimer les émissions du trafic routier a plusieurs avantages. Il est capable de calculer une émission de la circulation routière pour les pays développés et en voie développement. Le calcul est divisé en plusieurs étapes avec différents niveaux de complexité. Donc cette méthode ouvre une nouvelle approche pour gérer la qualité de l'air dans les villes.

Mot clés: Pollution de l’air, cadastre d’émission, analyse de l’incertitude, Monte Carlo (MC), EMISENS model, Ho Chi Minh Ville (HCMV), modélisation photochimique, stratégies de réduction.

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Chapter 1 Introduction

1.1 Motivation

Over the last 60 years, the urban population has increased at an incredible pace. According to the statistical documents of the United Nations Environment Program (UNEP, 2006), in 1900 the world only had 15 cities having a population of 1 million, whereas in 1950 the world had 83 cities having a population with more than 1 million and today there are more than 350 cities having a population more than 1 million. The population living in urban areas is about 50% of the world's population and the population living in urban areas will continue to increase rapidly in the future. In 2005, Asia had 50% of the most populous cities in the world. The urbanization process is a consequence of the explosion of the industrialization and automation process world-wide. People are attracted by high rates of economic growth in urban areas because there is more employment, educational opportunities and a better quality of life.

However, the urbanization process creates high density of street network, building, population and other activities (industry, etc.). These activities are relation with the high consumption of fossil fuel, such as people in urban areas uses more energy for cooking, air-conditioning, transportation, etc., and industry uses energy for production (Zarate, 2007). Consequently, these activities of high energy consumption emit a large amount of pollutants into the atmosphere which brings many environmental problems, for example, air, water and noise pollution as well as waste management. Among them, air pollution is one of the most serious environmental problems in urban areas. The World Health Organization (WHO) (WHO, 2005) has estimated that urban air pollution causes the death of more than 2 million people per year in developing countries, and millions of people are found to be suffering from various respiratory illnesses related to air pollution in large cities.

Therefore, the urban air quality management should be urgently considered in order to protect human health. Up to now, developed countries have made extensive efforts to improve the air quality through reducing emissions, such as: using cleaner energy, applying new air quality regulations, moving the industrial activities to the developing countries, etc. These efficient strategies at global scale are to move to developing countries. Air quality in developing countries has deteriorated considerably, thus exposing millions of people to harmful concentrations of pollutants because in developing countries the urban air quality management has not been adopted for a variety of difficulties.

1.2 Focus of research

With this PhD thesis we want to study methodologies for generating EI for road traffic source because of many reasons, such as: in cities, the main source of air pollution is the road traffic (Molina and Molina, 2002; Moussiopoulos, 2003; Vivanco and Andrade, 2006 and to cite a few) which produces emissions at ground level and in areas with high population density. This causes people to breathe the harmful pollutants more quickly than from other emission sources. Since the emission sources are also dominated by road traffic in HCMC. Therefore, study of abatement strategies for reduction of pollution in HCMC focuses on road traffic source.

However, study of abatement strategies for reduction of pollution is strongly dependent on emission inventory (EI) for different emission sources, especially for traffic source. Up to now, there have been many methods in existence to estimate the emissions from road traffic source but these methods require a big effort, finance and time. This is a restriction for air quality study and air quality management for developed countries. For developing countries, the application of these methods becomes more difficult or sometimes not even possible. Thus, it is extremely difficult to adopt abatement strategies to reduce air pollution. It appears necessary to develop a methodology which allows to generate as easily as possible and for the lowest cost.

1.3 Research objectives

General objective

The main objective of this PhD thesis is to develop a methodology to generate emission inventory (EI) for road traffic source for developing countries and to test the methodology to evaluate abatement strategies.

Specific objectives

- *First, we develop and validate a new road traffic EI model (called EMISENS) which can be used to generate a road traffic emission in several steps with different levels of complexity*. The validation of this model is being carried out in Strasbourg (France) because Strasbourg is a developed city where detailed EI data is available. The air quality of the Strasbourg region is studied by ASPA (Association for monitoring Air Pollution in Alsace); the ASPA studies air quality in Strasbourg by using the Circul'air model. This model is a complex and highly accurate model which was developed in Europe. The Circul'air and EMISENS models are applied in Strasbourg, with the same input parameters. Therefore Strasbourg is an optimal place to validate the EMISENS model.

- *Secondly, we apply this innovative model to study air quality in HCMC and to study some abatement strategies for air pollution reduction in HCMC.* HCMC is one of the largest cities in Vietnam in particular and Southeast Asia in general. HCMC is similar to every developing city in the world where the urbanization and industrialization process develops rapidly. These developments increase the demand of transport. However, in HCMC they use almost exclusively the motorcycle with out-of-date technology for circulation rather than public transport, which means that HCMC has a relatively high level of air pollution due to road traffic emission. Some research shows that air pollution from road traffic emission has a high impact on human health in HCMC (ADB, 2006).

1.4 Outline

This thesis is structured as follows:

Chapter 2: In this chapter, first it presents the problems of air pollution in urban areas. Second, it reviews and evaluates the state of research concerning the available methodologies for generating EI for road traffic emission sources and urban air quality management system. Lastly, it reviews the status of air quality in various cities around the world and the state of research concerning the study of air quality in Ho Chi Minh City (HCMC).

Chapter 3: The development of the EMISENS model for generating road traffic emission is firstly presented in this chapter. The EMISENS model is based on a well known and well referenced methodology of COPERT IV. The model combines top-down and bottom-up approaches for generating EI and uses Monte Carlo methodology for computing the uncertainties of emissions which are due to input parameters. Secondly, the validation of this EMISENS model is carried out by the application of the EMISENS model and a complex Circul'air model in the Strasbourg case. The results of the EMISENS model are compared with those of the Circul'air model. Lastly, the different simplifications which correspond with developing countries are tested to evaluate the impact of these different simplifications. The results of these simplifications are presented and discussed.

Chapter 4 of this work is devoted to generating the EI for road traffic source over HCMC by using the EMISENS model and estimating the EI for other sources by using the top-down approach. There were many campaigns which were organized in the framework of this research during the years 2007 and 2008 to obtain the input data for generating the EI for road traffic emissions. After, four scenarios for reducing the traffic emissions were designed and discussed in using the HCMC's plan for reduction of road traffic emissions.

Chapter 5 introduces the reader to the meteorological and air quality simulations over HCMC during a high pollution period of 3 days. This approach helps one understand the formation of pollution plumes over the city in order to provide a new possibility for managing air quality in HCMC based on scientific research. Lastly, two abatement strategies for emission reduction are studied by using a photochemical model. The probability estimate for the photochemical model is carried out in this research by using the traditional Monte Carlo (MC) approach. Analyses of the results of abatement strategies and their uncertainty are shown and discussed in this chapter. This is the first research of air quality in HCMC by using the numerical simulation methodology.

Chapter 6 presents the conclusion from this PhD thesis and proposes some recommendations for the further research work.

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Chapter 2 Urban air quality and tools for air quality assessment

Population and economic growth put pressure on transport systems. Road traffic is the main form of transportation in cities, and motor vehicles dominate road traffic. These motor vehicles release large amounts of hazardous substances into the atmosphere. Consequently, air quality is degrading rapidly.

First, this chapter presents the problems of air pollution in urban areas. Next, it evaluates the state of the art in the fields of road traffic emissions and urban air quality management. Lastly, it reviews the status of air quality in various cities around the world and the state of research concerning the study of air quality in Ho Chi Minh City (HCMC).

2.1 Urban air pollution

Population growth is a primary cause of environmental problems. Human activities require more energy such as fossil fuels for transportation systems, foods, etc. These human activities release a large amount of pollutant into our atmosphere. The primary pollutants are rejected directly to the atmosphere, such as: NO_x (emitted by road traffic and heating), volatile organic compounds (VOCs) (mainly emitted by industrial activities and road transport), CO_2, CO, etc. Among these emission sources, traffic is a very important emission source in urban areas because it is the main contributor to urban emissions (e.g., more than 98.5% of VOCs and 62% of NO_x in HCMC originated from the traffic source) and, moreover, traffic is the closest emission source to the population. After the primary pollutants are emitted into atmosphere, there are various processes which happen in atmosphere as shown in Figure 2.1. The three main factors which involve in urban air pollution are presented in Figure 2.1: (1) emissions; (2) dispersion of pollutants due to the meteorological condition and (3) transformation of pollutants due to chemical reactions. Among them, the formation of secondary pollutants due to the chemical transformation from primary pollutants is very important. The important secondary pollutant which is formed in atmosphere is Ozone (O_3) because O_3 is an

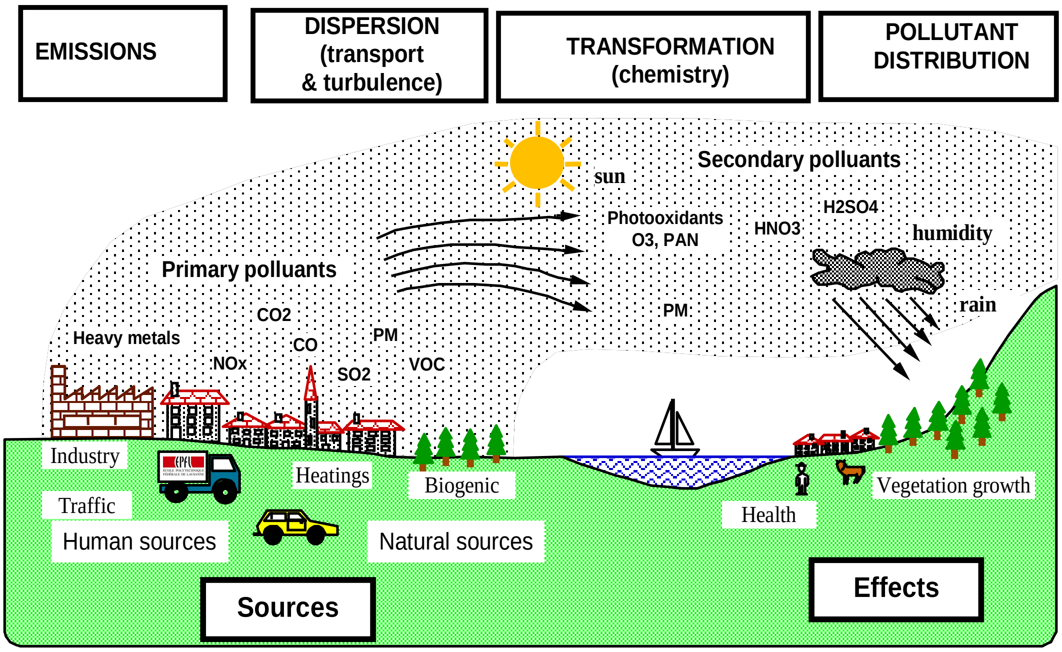

Figure 2.1: Interactions of pollutants in atmosphere (source: modified from Clappier, 2001)

oxidizing substance. Exposure to O_3 causes negative effects on health and the environment. Since the 1970s health standards for O_3 have been often violated in major metropolitan areas in Europe, especially in Southern Europe (e.g. Athens) (Moussiopoulos, 2003). In the short term, when the concentration of O_3 exceeds 0.1ppm, O_3 is responsible for sore of eyes, throat, etc (Kuentz Burchi, 1996). O_3 tends to reduce the mechanisms of photosynthesis of plants. The ozone formation depends on the concentration of NO_x, VOC, and the presence of solar energy. The problems of O_3 pollution become more complex because the production of O_3 is strongly non-linear depending on the absolute and relative quantities of VOC and NO_x. Because air pollution results from very complex and non-linear processes; we have to use modeling tools for managing air quality in urban areas.

2.2 Air quality management

The design of effective abatement strategies for reduction emission becomes very difficult if we take into account the socio-economical problems. The population growth

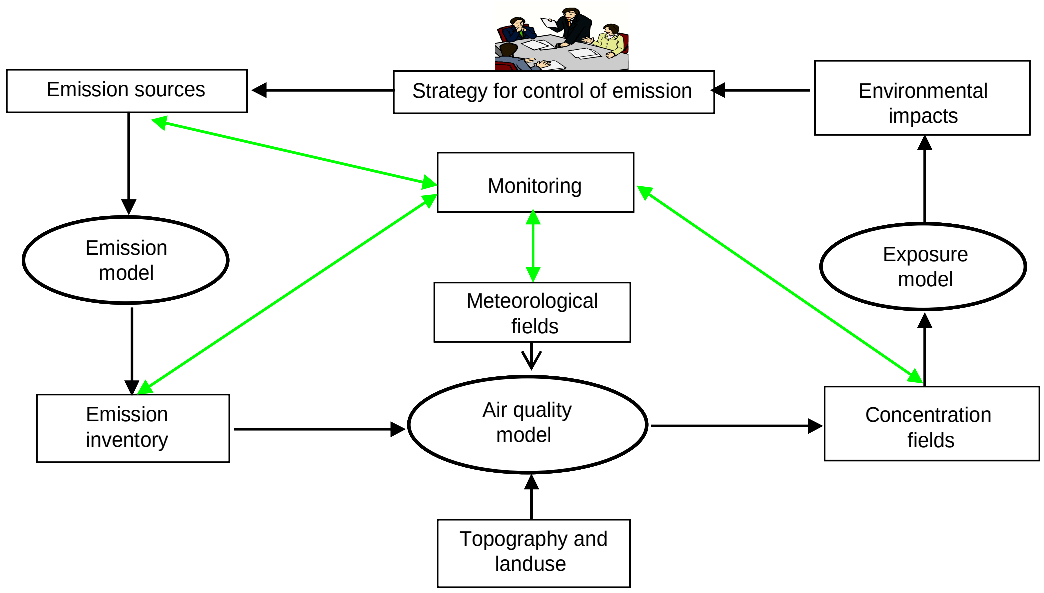

Figure 2.2: Air quality management system for urban areas.

leads to increase economical as well as industrial activities which can not be inhibited due to the development needs. These difficulties could be solved using an improved technology to reduce the pollution. However, the implementation of an improved technology is very costly. For example, it is quoted that it costs 7 billions US$ to install the catalytic converters in all new vehicles which are bought each year in United States (US) (Clappier, 2001).

The design of effective abatement strategies for reducing emission requires a good understanding of all factors related to air pollutions. Over the past 20 years, a multitude of different urban air quality management (AQM) systems have been developed by scientists and environmental authorities (Moussiopoulos, 2003). These tools have been well-used to study air pollution and to propose efficient abatement strategies. They include; monitoring of air pollution and meteorology, emission inventory (EI), air quality, meteorological, and exposure modeling (as shown in Figure 2.2).

The state of the art of these tools is presented in the next sections.

2.2.1 Monitoring of air pollution

Monitoring of air pollution is one of the most important parts in AQM. It helps to evaluate the status of air pollution levels and the evolution of air pollution. Monitoring allows evaluation of emissions both at the roadside to assess traffic emissions and in industrial parks for measuring industrial emissions. Almost all large cities in the world have installed monitoring systems to inform their populations about air pollution levels. Monitoring of air pollution also helps validate the results of emission models and air quality models.

There are different methods in use to monitor the air pollution including: automatic, semi-automatic, and manual methods. Automatic methods use the equipments which can measure directly the pollution and can be moved anywhere for monitoring of air pollution. For example, the equipments manufactured by Environmental S.A, France, just to mention some, monitors automatically CO, NO_2, NO, O_3, PM10, etc. On the other hand, semi-automatic methods involve collecting air quality samples at the selected sites by placing the equipments there; samples are collected and then these samples are transported to laboratory for analysis. Such methods are used, for example in order to collect BTEX (benzene, toluene, and xylene) samples; they collect the samples for a continuous duration of 6h and then transporting the samples to laboratory for analysis by GC (Gas Chromatography). The third category of methods called manual methods involves collecting the samples manually as is done for the case of CO monitoring.

Among three methods, automatic method is the best one because this method allows monitoring real time air pollution. A lot of measurements are made which can be later used to study the evolution of pollution in different periods and throughout the year. However, this method is very costly because the equipments are expensive and need to maintain them regularly and to train technicians to operate these equipments (Molina and Molina, 2004).

Nowadays, automatic and manual air pollution measurement networks have been installed in the world. In Europe some 1450 measurement stations covering 350 cities all over Europe have been installed; in US over 1000 stations are operated throughout the country by the US Environmental Protection Agency (USEPA) (Baldasano et al., 2003);

in Latin America there are more than 4000 urban monitoring stations (Belalcazar, 2009); in Asia countries installed networks include China, Japan, Korea, India, Indonesia, Thailand, Vietnam, etc. In addition to these, WHO installed the monitoring networks over 100 cities around the world since 1990s.

In Vietnam, the information from air pollution measurement networks is used to improve air quality. Most of the cities in Vietnam before 1995 were polluted by lead from gasoline combustion of vehicles (several times higher than Vietnam air quality standard). Therefore, the import of leaded gasoline was banned by Vietnam government. Thus, the concentrations of lead in atmosphere have been reduced and are now lower than the local air quality standard.

2.2.2 Emission inventory

Development of EI database is very important to describe the emissions and to manage air quality (Moussiopoulos, 2003; Ranjeet et al., 2008). The information from EI helps us to understand the emission sources and also the emission fluxes in the study domain. The atmospheric pollutants needed for assessment and management are SO_2, NO_x, CO, VOCs, particle maters, etc. The emission sources are grouped in different categories: mobile source (such as road traffic), area sources (such as agriculture, natural), and point sources (such as industry). Resolution in space of EI depends on the scale of study domain and the availability of information for generating emission inventories (EI). In general, the smaller the region of interest, the finer is the required spatial resolution of the EI. Resolution in time of EI must follow the activity pattern of emission sources.

The principal equation for calculation of emissions is obtained from the combination of two variables:

$$E = e \times A \tag{2.1}$$

where, E is the total emission

e is the emission factor (EF)

A is the activity data of emitters

There are two main approaches currently used for generating emission inventories: top-down and bottom-up.

Top-down approach

A top-down approach starts to estimate the total emissions by using total activity for the whole domain and average emission factors. Then, it uses several assumptions to distribute these emissions in space and time (Friedrich and Reis, 2004).

Strengths: this approach is easy to apply because it needs few input information and the time to generate EI is rapid. It is better to use top-down for fuel use. This method is particularly appropriate to estimate the total emissions at large scale such as: national level.

Weaknesses: one of the main limitations of this approach is that the results of spatial EI are normally highly uncertain.

Examples of using top-down approach for generating EI from the literature are:

+ Streets et al., (2004) calculated emissions of Carbonaceous aerosols, black carbon, and organic carbon for the entire world by using total fuel consumption of the year and emission factors (g/kg of fuel burned).

+ Streets et al., (2003) calculated emission of gaseous and primary aerosol in Asia by using parameters such as: energy use, human activities, and biomass burning.

+ Generoso and Bey (2007) combined the results of a global chemistry and transport model and satellite data to evaluate the emission produced by the Russian fires in 2003. In this research, they used top-down approach to estimate the emissions, etc.

Bottom-up approach

The bottom-up approach is based on a source oriented inquiry of all activities and emission data needed for describing the behaviour of a single source. It starts to evaluate the spatial and temporal repartition of the parameters used to calculate the emissions (Friedrich and Reis, 2004).

Strengths: this approach is more accurate than the top-down approach to evaluate the spatial and temporal repartition. Bottom-up approach is more appropriate for the small scale (city scale and lower).

Weaknesses: The main limitation of this approach is that it needs a large amount of input data for generating EI. Sometime, the information can even not be collected in the cities of developing countries. The time of generating EI of this approach is longer than top-down approach

Examples of using bottom - up approach for generating EI from the literature are:

+ Schillinger et al., (2005) calculated road traffic emissions over Lorraine in France by using EFs per vehicles from CORINAIR methodology. They used Circul'air model which was developed at Association for monitoring Air Pollution in Alsace (ASPA).

+ Molina et al., (2002) measured emissions of industry and used GPS to locate the position of factory on the map to calculate the industrial emissions for Mexico City.

+ Mattai et al., (2002) calculated the EI for London, England.

The bottom-up approach is in general impossible due to lack of available information for generating EI, while top-down approach might lead to poor accuracy level for generating spatial EI. Therefore, several researchers used top-down approach to generate EI for point sources and area sources because data for these sources are not easy to access, while they used bottom-up approach to generate EI for road traffic sources. An example from the literature is: Sturm (2003) generated EI for urbanised triangle Antwerp-Brussels-Ghent which is located in Northwest Europe. He used the top-down approach for generating EI for point sources (based on statistic data and emission factors from literatures) and area sources (based on collective data per km^2). However, for road traffic emissions, he used bottom-up approach using road traffic emission measurements and an urban traffic flow model.

Some research has been done to evaluate capacity of the two approaches for generating EI in a specific case. For example: Zarate et al., (2007) generated the EI for traffic sources over the city of Bogotá, Colombia by using two different approaches. In the first version of EI (EI-1), the bottom-up approach was used to generate EI by using the traffic fluxes obtained from a traffic model and the emission factors (EFs) per vehicles from CORINAIR methodology. In the second version of EI (EI-2), the top-down approach was used to generate EI by using a real-world EFs calculated for Bogotá. These real-world EFs were obtained by means of in-situ measurements and inverse modeling. The results showed that EI-2 traffic emissions are 3-5 times higher than the values in EI-1. Then, the two versions of the EI were evaluated by using a mesoscale air quality model. The results showed that simulated concentrations using EI-2 are closer to the observed values. It means that using the top-down approach and real-world EFs for generating EI is better than using the bottom-up approach and unreal-world EFs. They also suggested that we should explore the possibility to better couple both bottom-up and top-down approaches in order to optimize EI.

In summarize, in the cities of developing countries, the data for generating EI for traffic sources are generally not available, so it is difficult or even impossible to use the bottom-up approach for generating EI. In addition, spatialisation of the EI obtained with a top-down approach is highly uncertain. Therefore, it is essential to use the top-down as well as bottom-up approach in a coherent way and to evaluate the uncertainty of both approaches to increase the accuracy of the results.

Uncertainty

The results of air quality model obtained depend on the accuracy of input and the emission inventory (EI). Therefore, it is necessary to calculate the uncertainties of EI due to the input parameters. Despite the fact that some people have studied uncertainties for emissions, no model integrates the calculation of uncertainties.

For calculating uncertainty, the most often used approach is the Monte-Carlo method (Hanna et al., 1998). The details of Monte-Carlo method are explained in the section 3.2.5.

Examples of Monte-Carlo application for estimating the uncertainties in EI and air quality model from the literature are:

+ Hanna et al., (2001) evaluated the effect of uncertainties in UAM-V input parameters (emissions, initial and boundary conditions, meteorological variables, and chemical reactions) on the uncertainties in UAM-V ozone predictions by using Monte-Carlo uncertainty method in framework of research: Uncertainties in predicted ozone concentrations due to input uncertainties for UAM-V photochemical grid model applied to July 1995 OTAG domain.

+ Kuhlwein et al., (2000) determined the uncertainties of input parameters of a road traffic emissions model (IER). The main uncertain parameters were the road gradient, traffic volume, driving pattern, and emission factors. The emission inventory was calculated by the working group "urban emission inventories" of GEMEMIS and the working group "Val.3 of Saturn" over West Germany.

+ Tarantola et al., (2004) used the Copert III model to generate transport emissions over Italy. Then, the Coppert III model was implemented for estimating the uncertainty by using the Monte-Carlo method. The main uncertain parameters depended on pollutant types, such as: uncertainty in VOC and PM emissions depended on fuel type used in passenger cars and light duty vehicles, emissions factors and average trip length. Uncertainty in NO_x depended on emission factors.

2.2.3 Modeling of air pollution

One of the most important functions of air quality modeling is to evaluate the effective of abatement strategies to reduce air pollution in cities. Because the processes in atmosphere are complex and nonlinear therefore modeling is the only tool which can take into account all these processes. The European Directive on evaluation of ambient air quality (EU-N°96/62/CE 1996) allows the use of modeling tools to define the zones of high pollutant concentrations. Modeling tools use mathematical formula to simulate all the atmospheric processes over various time and space scales. Concerning the space scales of modeling, there are many scales such as global scale, regional or continental scale, mesoscale (city or country) and microscale (street canyons). There are many mesoscale models that are used to simulate urban air quality, such as METPHOMOD, TVM-Chem, CIT, CHIMERE, CMAQ, TAPOM, etc. Input parameters of these air quality models are meteorological conditions, EI, land use, topography, boundary and initial conditions. In recent decades, computer technology has rapidly developed; therefore many new mesoscale models are developed. With the increased power of computer technology, the time scale of modeling more refined. The new models can now simulate air quality for long periods and on temporal resolution from few hours to few months.

Another function of modeling tools is used to study the impact of different activities on urban air quality and to evaluate the methodology for generating EI, such as Zarate et al., (2007) used TAPOM model to evaluate the accuracy of different methodology for generating EI for Bogotá city, Colombia.

As the air quality model takes into account all processes in atmosphere, so that the main input parameters of air quality model are meteorological fields and EI.

2.3 Status of the air quality in various cities around the world

2.3.1 Air pollution in large cities in the world

A vast majority of the urban and suburban areas in the world is exposed to conditions which exceed air quality standards set by WHO. Especially, the large cities in developing countries have the highest air pollution levels. Some researches show that the emissions from Asian cities will rise and this will continue to have an impact on hemispheric background ozone level as well as global climate (Gurjar et al., 2005). In general the cities in developed countries have the concentrations of air pollutants lower than the cities in developing countries. A lot of measurements of air pollutants (such as O_3, SO_2, NO_2, TSP, and PM10) in the world have been done; some of them are shown in the Table 2.1.

Table 2.1 Air quality in large cities of the world. Almost data reported correspond to the mean annual concentration in μ g.m^{-3} (only O_3 is reported in maximum 1-h concentration).

City	Population[a]	O_3	TSP[b]	PM10	SO_2	NO_2
Tokyo, JP	33.4		49		18	68
Seoul, KR	23.1		84		44	60
Mexico, MX	22.0	546	201	52	46	55
New York, US	21.8	272		24	26	70
Bombay, IN	21.1		240		33	39
Delhi, IN	20.8		415		24	41
Sao Paulo, BR	20.3	403	53		18	47
Shanghai, CN	18.6		246		53	73
Los Angeles, US	17.9	225		39	9	66
Jakarta, ID	16.9		271			
Osaka, JP	16.6		43		19	63
Cairo, EG	15.8				69	
Calcutta, IN	15.4		375		49	34
Manila, PH	15.2				32	
Buenos Aires, AR	13.5		185			20
Moscow, RU	13.4		100			80
Beijing, CN	12.4		377		90	122
Rio de Janeiro, BR	12.2		60		50	40
Bogota, CO	8.4	348		58	40	39
HCMC, VN	6.3	247	260	79.6	44	34
WHO standard[c]		160[d]	90	20	50	40

Sources: Baldasano et al., 2003; Zarate, 2007; ADB, 2006 and HEPA, 2006.

[a] Population expressed in millions, 2005.

[b] TSP = Total suspended particles.

[c] WHO standard for PM10 was manly issued in 2005, the rest in 2000. Sources: WHO, 2000 and WHO, 2005.

[d] WHO standard for O_3 (maximum 1-h concentration). Source: Molina and Molina, 2001

Data in Table 2.1 has been extracted for the period 1999 – 2000 (only the data of Bogotá and HCMC were for the year 2005). Data were not completed for all cities because measurements are not available for the same year. Data has been used from urban stations to represent the overall pollution levels of the city. In the case of NO_2 concentrations (standard limit =40 μg.m^{-3}, WHO), the high concentrations for both the developed and developing cities occurred where the main source of emission is road traffic. However, the road traffic emissions in developed countries are less dangerous than developing countries. This is because they use modern vehicular combustion and emission control technology, clean fuel and more public transport. While in developing countries, the out-dated vehicle technologies are used and few public transports are used. As a result, most cities in developing countries such as: Shanghai, Delhi, Jakarta, Beijing, HCMC, etc show a relatively high level of air pollution. The maximum NO_2 concentrations are found in several cities of China (over 100 μg.m^{-3}). In the case of total suspended particles concentrations (standard limit =90 μg.m^{-3}, WHO), particle are normally related to SO_2 concentrations because TSP and SO_2 are emitted from burning coal for industrial activities. In general, the highest concentrations of TSP and SO_2 are found in developing cities where industrialization rate is rapid. Particle matters (PM10) with diameters less than 10 μm are very dangerous for respiratory human system. PM10 is originated from industrial and traffic sources, the values of PM10 are normally highest in developing cities where they use much old vehicle and diesel fuel.

The guideline value for the average annual value of O_3 does not exist. In some countries they apply the guideline for the maximum daily hourly O_3 at ground-level (standard limit = 180μ g.m^{-3}, TCVN) to manage air quality. Therefore, Table 2.2 shows the maximum daily hourly O_3 concentrations. The highest O_3 concentrations are found in Mexico City (546 μg.m^{-3}), followed by Sao Paulo (403 μg.m^{-3}). The lowest maximum hourly concentrations of O_3 are found for the European cities where the lowest photochemical reaction occurs.

The highest pollution is found in developing countries. However, it is extremely difficult to adopt abatement strategies for reducing emissions in developing countries because developing countries have a low level of organization and a low level of living (less money).

2.3.2 Air pollution in HCMC, Vietnam

Pollution level in HCMC

HCMC is the largest city in Vietnam and is the most important economic center in Vietnam. HCMC became one of 100 rapid economic growth cities in the world (Gale, 2007). The population of city was 6.105 million (8% population of Vietnam). However, the city accounts for 20.2 % GDP, 28 % industrial output of Vietnam. HCMC had 28,500 factories and 2,895,381 motorcycles. They are the most important sources which contribute to air pollution in HCMC.

The HCMC government has been set-up a number of air quality monitoring stations around the city for monitoring air pollution due to road traffic and industrial activities. The results are shown as follows in Table 2.2.

Table 2.2: Air quality in HCMC from 2001 to 2006. Almost data reported correspond to the mean annual concentration in μ g.m^{-3} (only O_3 is reported in maximum 1- h concentration).

Pollutants	2001	2002	2003	2004	2005	2006	WHO standard
TSP	900.0	475.0	486.7	496.7	260.0	-	90
PM10	-	122.5	83.5	61.5	79.6	77.4	20
NO_2	-	-	-	-	34.0	32.1	40
SO_2	-	-	-	-	44.2	28.5	50
O_3	-	-	238	266	247	-	160[a]

Sources: HEPA, 2004; HEPA, 2005 and HEPA, 2006.

[a] WHO standard for O3 (maximum 1- h concentration). Source: Molina and Molina, 2001.

The measurement results show that air quality in HCMC are polluted by TSP, PM, and especially O_3. The highest TSP concentrations were found in 2001 about 900 μ g.m^{-3} (10 times higher than WHO standard). TSP concentrations reduced to the value of 260 μ g.m^{-3} in 2005. The high TSP concentrations in HCMC were related to the construction and traffic activities (Belalcazar et al., 2009). The constructions activities in 2001 were higher than recently years. Therefore, the TSP concentrations are decreased from 900 μg.m^{-3} (2001) to 260 μg.m^{-3} (2005). The mean annual concentration of NO_2 and SO_2 are lower than WHO standard, but their average daily/hourly values regularly exceed the WHO standards. PM10 and O_3 are the most critical pollutants in HCMC, because their concentrations are very high and almost exceeded the WHO standard during the period 2001- 2006. They have high toxic health effects. The measurements show that O_3 concentrations are highest during the midday where the highest photochemical processes happen. The high O_3 concentrations are related to high VOCs concentrations in HCMC. However, there is very few information on VOCs concentrations which are monitored in the Asian countries due to their complexity to measure. Until 2007, the first long-term study on the VOCs levels in HCMC was carried out by Belalcazar (Belalcazar, 2009). He measured continuously roadside levels of 17 VOCs species in range C2 - C6 during the dry season (from January to March) of 2007 in HCMC. Table 2.3 firstly shows VOCs concentrations in HCMC, then compare with available roadside VOCs concentrations of other Asian cities.

Table 2.3: VOCs levels in BTH street (HCMC) and comparison with the VOCs levels in other Asian cities (concentrations are in ppbv).

VOCs	HCMC Mean	Changchun Mean	Karachi Mean	HongKong Mean	Hanoi Mean
n-Propane	3.7				
Propene	19.5				
n-Butane	22.6				
Trans-2-Butene	5.2				
1-Butene	4				
Cis-2-butene	5.2				
i-Pentane	80.3	14.7	74		
n-Pentane	21.8				
Trans-2-Pentene	16.4				
1-Pentene	4.6				
2-methyl-2-butene	3.8				
Cis-2-Pentene	4.2				
2,3-Dimethylbutane	8.6				
2-Methylpentane	7.7	6.1	39		
3-Methylpentane	43.5				
n-Hexane	91	1.7	71	4.4	
Benzene	14.2	11.9	19.7	8.2	40
total	356.3				

Source: Belalcazar, 2009.

Unfortunately, the air quality standard for all VOCs compounds does not exist. Only some individual VOCs standard limits are defined by WHO based on health effects. Among those, benzene is one of the very toxic VOCs. The measurements of benzene in HCMC show a very high concentration of 14.2 ppbv (annual mean WHO standard - 6ppbv). The VOCs concentrations in HCMC are generally higher than other Asian cities. The benzene concentrations in Hanoi are higher than in HCMC, because benzene in

Hanoi is measured at peak hours (short time) when the highest benzene concentration happens during the year.

Current state of research concerning the air quality study in HCMC

Thus far, very few research attempts have been made for improving air quality in HCMC. The focus of these research attempts is on air pollution status, dispersion of air pollution and effective abatement strategies.

- Research on air pollution status

The researches on status of air pollution analysed the data from the monitoring networks to evaluate air pollution status of the city. Over the last 15 years, the Vietnamese government has funded for environmental monitoring and research to estimate the status of air quality in HCMC. The main studies are as follows:

- Project: Monitoring air pollution by traffic in HCMC, from 1996 up to now – by Huynh T,M,H and Nguyen D,T – Institute of Environment and Resources in HCMC (Huynh et al., 1996).
- Project: Energy – air pollution in HCMC, conducted by Department of Science, Technology and Environment of HCMC (DOSTE) and French Environment and Energy Management Agency (ADEME), 2000 (DOST, 2000).

All of their work supply data on the status of air pollution in HCMC. This data also helps the government in proposing solutions to reduce air pollution today and in the future.

- Research on dispersion of air pollution

Different researches on dispersion of air pollution have been performed in the framework of master and PhD thesis. They were funded by Vietnamese and overseas scientific projects. Several researches were carried out by using simple models which often did not include chemical reactions, emission factors, etc. Most of them did not consider adaptations necessary for special situations of Vietnam:

- Ho et al., 2005: Air quality simulation over HCMC. This research is the first study of dispersion of air pollution over HCMC. The input data for air quality simulations was limited, such as he estimated EI for all emission sources over HCMC by using the top-down approach. As the result of EI was highly uncertain. Therefore, the results of air quality simulations were high uncertain.

- Bui et al., 2006: Developing an air quality forecasting model in HCMC. This model is a Lagrangian model and does not include chemical reactions.
- Ngo, 2004: Study and select the methods to calculate the loading and concentration dispersion of pollutants caused by transport traffic in Ho Chi Minh city. Based on that, a computer based calculation program is built, a master thesis.
- Nguyen, T, 2004: Project: Asian Regional Research Program in Energy, Environment and Climate (ARRPEEC) - Phase III, supported by SIDA organization, from 2002 to 2004. In framework of this project, they used a regional model to simulate the dispersion of air pollution over Asia.
- Nguyen, P, 2004: Building a database management system of air quality in HCMC. It is also a project at master thesis scale.
- Project: Management of monitored emission data using GIS combined with modeling air pollutants (diffusing and distributing) in HCMC, supported by the Norwegian Institute for Air Research - Air Quality Information and Management System (AirQuis) (2002 – 2005). This project was collaborated with HEPA. This project was finished and at the moment all activities have closed.

- Research for proposing solutions to reduce air pollution

Nowadays, in Vietnam, especially in HCMC, research for proposing solutions to reduce air pollution consists mainly of master theses which were carried out at Institute of Environment and Resources in HCMC (IER). The main studies are:

- Nguyen, (2000) proposed some methods to reduce air pollution which is caused by traffic in HCMC: such as, developing public transportation system and using unleaded gasoline.

- Another study proposed technical solutions for reducing air pollution level which is caused by traffic activities (Duong, 2004).

As discussed above, the concentrations of air pollutants in HCMC are regularly higher than Vietnamese standards. Therefore, it is urgent to study abatement strategies to reduce air pollution in HCMC.

In summarize, both the developed and developing cities have air pollution problem, especially in the developing countries where it is related to high level of air pollution. It is urgent to find solution for improving the air quality in these cities.

2.4 Conclusions

This chapter reviewed and discussed the state of the art in the fields of road traffic and urban air pollution research. Road traffic is a very important source of pollution in urban areas because it is the main contributor to urban emissions and traffic is the closest emission source to the population.

Air pollution processes in urban areas are very complex and non-linear. This is because after primary pollutants are emitted to the atmosphere, these pollutants are transformed into secondary pollutants. For managing air quality in such cases, we have to use air quality management (AQM) systems which include air quality modeling tools. This chapter has discussed available air quality management systems.

The problems of air pollution in developing countries deserve greater attention because the air in developing countries is more polluted and there is less research for reducing emissions as compared to developed countries. For studying abatement strategies to reduce pollution levels in such cities, we have to use air quality models because there is less real monitoring data available. The emission inventory (EI) is the most important input for air quality models. However, generating EIs is difficult due to limitations on data, finances, and time. EIs can be generated from a top-down or a bottom-up approaches; each approach has several strengths and weaknesses. The main weaknesses of the bottom-up approach is that it requires a large amount of information and it produces uncertainty in total emissions; while the main weakness of the top-down approach is that the spatialisation of the EI is normally highly uncertain. Therefore, it is necessary find a way to combine the two approaches and to estimate the uncertainties to develop an optimal emission inventory at the lowest cost. This method is indispensable to study air quality in developing countries; however it could be also very useful for developed countries.

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Chapter 3 Fast and efficient methodology to generate road traffic emission inventories: Application to developing cities

Abstract

Road traffic emissions are one of the main sources of air pollution in the cities. They are also the main sources of uncertainties in the air quality numerical models used to forecast and define abatement strategies. Until now, the available models for generating road traffic emission always required a big effort, money and time. This inhibits decisions to preserve air quality, especially in the cities in developing countries where road traffic emissions are changing very fast. In this research, we developed a new model (called EMISENS) design to produce road traffic emission inventories fastly. The rapidity of the model is mainly due to the possibility to use several simplifications concerning the description of the fleet and the street network. EMISENS combines the well-known top-down and bottom-up approaches to force them to be coherent. A Monte Carlo methodology is included for computing emission uncertainties and the uncertainty rate due to each input parameters.

The validation of this EMISENS model was carried out by the comparison of EMISENS outputs with the results of the Circul'air model (using bottom-up approach) which is used for many years to forecast and study air pollution over Strasbourg region, France, by the air quality agency, ASPA. After comparing the result of the two models, the results of EMISENS model are very close to the results of Circul'air model. This example of application illustrates the capacity of EMISENS to calculate road traffic emission inventory (EI) for cities in developed countries as well as in developing countries

In order to evaluate EMISENS results over the cities where few input data are available, the impact of several simplifications are tested using the full EMISENS simulation, closest to Circul'air, as a reference. It means that if we make simplification of an input parameter for road traffic EI, the results of EMISENS model show that how many percentage of error in total results which originated from this simplification, is produced. The results of simplifications help us to understand the impact of each simplification, such as, we can use the same average fraction of mileage driven with a cold engine ($\overline{\beta}$)

for all the cells of the study domain in stead of using each value of β_i for each cells of the study domain. Or, only one emission factor could replace both cold and hot emission factors.

3.1 Introduction

Urban agglomerations are major sources of atmospheric pollution and road traffic is the main source of air pollution in cities (Molina and Molina, 2002; Moussiopoulos, 2003; Vivanco and Andrade, 2006). Over the last 20 years, air quality models have been developed in order to forecast air pollution and define abatement strategies (Skold and Holmberg, 2000; Metcalfe et al, 2002; Martilli et all, 2003; and others). The quality of their results depends on the air pollutant emission inventories (EIs). Traffic emissions are usually estimate using two types of approaches called as bottom-up or top-down. In the bottom-up approach the emissions are directly calculated in time and space using parameters as well as road traffic, the number of cars, etc., which are distributed in time and space. The top-down method calculates the total amount of aggregated emission (for example fuel consumption for the whole city or the whole country during a full year). This total is then distributed in time and space using the distribution of the parameters linked with the activity responsible of the emissions (like the population, the road network, etc.). The two approaches applied on the same region usually do not give the same results and the causes of these differences are very difficult to identify. The main advantage of the bottom-up method approach is that it is able to produce disaggregated emission inventories but it required a large amount of input information. The main advantage of the top-down approach is that is requires less input information but it only produces aggregated EIs. The problem is to relate the choice of good approach with the effective precision needed: “The level of detail of the emission census depends on the nature of the problem at hand. It is futile to expect emission calculations to achieve results which are superior in accuracy to that of the original survey data. The right model has to be chosen to meet the task at hand. It is not always necessary, sometimes not even possible, to work with the most detailed model. On the other hand, using a simple model in a complex environment can easily lead to spurious conclusions”: (Sturm P, 1996). Many authors recommended a combination of both approaches for urban emission estimates (Friedich and Reis, 2004; Vivanco and Andrade, 2006; Parrish, 2006).

Air quality agencies follow this recommendation. They usually use first bottom-up approach (Acri, 2000 use AirEMIS model; EPA, 2003 use Mobile6; ASPA, 2005 use

Circul'Air; Slordal et al., 2008 use AIRQUIS). Secondly, they correct their first results using a top-down approach and comparisons between air quality modeling and measurements. The methodologies are very efficient in developed countries but show limits in developing countries: (1) they need a lot of input parameters; (2) they use equations to calculate emission factors which are specific to certain types of fuels and vehicles and may not be applied abroad. Indeed, in developing countries the economy is changing very fast, the information needed to generate EIs are changing rapidly. There are lower levels of administrative organizations that are not fully capable to record and manage the data. Due to poor economies and lower standard of living in most of developing countries, they do not have enough money to generate EIs.

The objective of this article is to present a new road traffic emission inventory model, EMISENS. This model has been designed to keep coherent the bottom-up and the top-down approaches. It has also been decided to fast generate EIs from reduced input information and adapted to existing conditions in developing countries.

In the present work, we also show the results of a comparison of the EMISENS model to the Circul'air model used since several years by the French air quality agency, ASPA, in charge of the air quality monitoring in the Alsacian region (North East of France). Circul'air is based on the well known COPERT methodology and is representative of the most famous road traffic emission models. The comparison is done on the limited area of Strasbourg. The objective of this comparison is first to evaluate the ability of EMISENS to generate an EI in a city from the developed world where detailed input information is available. The second is to define a reference to evaluate the performance of the EMISENS model when several simplifications are done. These simplifications are done in order to represent typical situations encountered in developing countries where data are often missing.

One important advantage of EMISENS is that it includes a Monte Carlo methodology. This allows the user to compute the emission uncertainties and the uncertainty rate due to each input parameters. This step is essential to identify the most influencing parameters on the total emission result. The identification of these parameters drives the user to significantly improve the quality of his emission inventory

3.2 Description of the EMISENS model

3.2.1 Main specifications of the EMISENS model

The goal of the EMISENS project was to design a model able to calculate road traffic emissions in several steps with different levels of complexity. The idea was to develop a model able (1) to generate an emission inventory using a minimum of input parameters, but also using any well known and complete referenced database such as COPERT IV (2) to compute the total uncertainties on the emission inventories and the uncertainty rates due to each input parameters. This last requirement has been decided to help to identify which parameters have the greatest impact on the emissions and should be improved. Another specification was to give to the user the possibility to produce space and time distributed emissions if his input parameters are distributed in space and time. To fulfil this option, EMISENS computes the total emission (first step) using a top-down approach, while the time and space distribution (second step) is obtained using a bottom-up method. Both methods are kept to be coherent

3.2.2 Coherence between top-down and bottom-up approach

In the top-down and bottom-up methods, the calculation of the emissions is based on the use of emission factors which depend on different sources of pollutants. Methods are coherent if the calculation of the total emission gives the same result.

With the bottom-up approach the emission $E_{ip,ie}$ (in g.veh^{-1}.h^{-1}) of the pollutant *ip* (NO_x, CO, CH_4, etc) and the emitters *ie* (emitters are pollutants sources like a specific vehicle on specific street) are calculated using time and space distributed parameters

$$E_{ip,ie}(x,y,t) = e_{ip,ie}(x,y,t)A_{ie}(x,y,t) \tag{3.1}$$

Where x and y are the position of each domain's cell; t is the time (in hour); A_{ie} is the activity of the emitters *ie* (it can be the volume of fuel burned, the number of kilometre travelled by the vehicles, etc.; in km.veh.h^{-1}); $e_{ip,ie}$ is the emission factors (g.km^{-1}.veh^{-1})

depending of the emitters and the pollutant. The total emission can be obtained calculating:

$$\overline{E}_{ip,ie} = \int_t \int_s e_{ip,ie}(x,y,t) A_{ie}(x,y,t) dsdt \qquad (3.2)$$

where *s* is the surface of the area on which the emissions are estimated.
With the top-down methods the total amount of emissions is obtained with:

$$\overline{E}_{ip,ie} = e_{ip,ie} \overline{A}_{ie} \qquad (3.3)$$

where $\overline{A}_{ie}$ is the total activity for the whole domain.

The results of the top-down and bottom-up methods are coherent when the total emissions $\overline{E}_{ip,ie}$ computed with the two methods, (3.2) and (3.3), are the same. This condition is fulfilled when the emission factors $e_{ip,ie}\left(x,y,t\right)$ are constant in time and space, (i.e. $e_{ip,ie}(x,y,t) = e_{ip,ie}$) and when $\overline{A}_{ie}$, the total activity for the whole domain is obtained calculating: $\overline{A}_{ie} = \int_t \int_s A_{ie}(x,y,t) dsdt$. (3.4)

All the input parameters of EMISENS can be distributed in space and time. Nevertheless, in this work, in order to keep the coherence between the different computations steps the emission factors are calculated are used without any dependence on time and space.

3.2.3 Reduction of computational time: use of category of vehicles

For a specific pollutant, the sum of emissions considering all emitters can be computed as:

$$E_{ip}(x,y,t) = \sum_{ie=1}^{ne} E_{ip,ie}(x,y,t) = \sum_{ie}^{ne} e_{ip,ie} A_{ie}(x,y,t) \qquad (3.5)$$

where *ne* is the number of emitters.
Concerning traffic emissions, these emitters can be divided into different vehicle categories such as heavy truck, light truck, car, motorcycle, etc. In the motorcycle category, we can find vehicle types as 2-strokes engine motorcycle or 4-strokes engine motorcycle. In the car category, we can find recent car or old car, etc. Generally the

proportion of vehicle types inside a category can be considered as a constant in space and time. For example, the proportion of 2 strokes and 4 strokes engine will always be the same in the whole city. However, as the emission factors can vary a lot from one vehicle type to another, a factor is usually computed for every kind of vehicle types.
The activity does not depend on the pollutant but depends on the number of vehicles. The activity A_{Ie} of a category Ie can be written as follows:

$$A_{Ie}(x,y,t) = \alpha_{ie} A_{ie}\left(x,y,t\right)$$

where α_{ie} is the proportion of each type of vehicle in each category (e.g. 20% of 2 strokes and 80% of 4 strokes engine in the category motorcycle) and nIe, the number of vehicle in the category Ie.

Using such definition, equation (3.5) can be rewritten as:

$$E_{ip}(x,y,t) = \sum_{Ie}^{NIe}\left[\sum_{ie}^{nIe} e_{ip,ie}\alpha_{ie}A_{Ie}(x,y,t)\right]$$

where NIe is the total number of vehicle categories.

With these considerations, we can define the $\bar{e}_{Ie}$ is the weighted averaged emission factor for a vehicle category Ie as follows:

$$\bar{e}_{Ie} = \sum_{ie}^{nIe} \alpha_{ie} e_{ie}$$

Consequently, the calculation of the emission can be done by using an average emission factor per category and a weighted average activity for each category:

$$E_{ip}(x,y,t) = \sum_{Ie}^{NIe} \bar{e}_{ip,Ie} A_{Ie}\left(x,y,t\right) \tag{3.6}$$

Using vehicle categories instead of vehicle types does not affect the accuracy of the results as long as the proportion of vehicle type inside a category keeps constant in space and time. Generally, 5 to 10 categories are able to describe a fleet of 150 vehicle types which lead to an important reduction of computation time. In this case, the reduction of computation time is more than 10 times.

3.2.4 Different choices for calculating emissions

a) COPERT IV methodology

The COPERT IV methodology (Ntziachristos et al., 2007) is based on CORINAIR (Eggleston et al., 1993). This is a classical methodology developed in Europe to develop EIs. The emissions are splitted into three types: hot emissions, cold emissions and evaporation emissions: $E = E_{hot} + E_{cold} + E_{evap}$

Each of these emission types is calculated based on the same equation as EMISENS

$$E_{ip,ie} = e_{ip,ie} A_{ie}$$

- Hot Emissions

Hot emissions (E_{hot}) are the emissions occurring when all the vehicles travelled with a thermally stabilised engine and exhaust after treatment conditions. The hot emission factors $e_{ip,ie} = e_{ip,iv}^{hot}$ (in g. km^{-1}.veh^{-1}) are given for each type of vehicle defined by European classification considering the vehicle technology (EURO I, II, III, IV, etc). They are assumed to depend on the vehicle speed, *V*, as follows: $e^{hot} = aV^2 + bV + c$, where a,b and c are constants depending on the type of vehicles.

A_{ie} is the number of kilometres travelled by all vehicles computed using the mileage of a vehicle (M_{iv}) and the total number of vehicle (N_{iv}):

$A_{ie} = M_{iv} N_{iv}$

- Cold emission

Cold emission (E_{cold}) is the additional emissions due to the fact that a number of vehicles are driven with cold engine. The cold emission factors are written as : $e_{ip,ie} = e_{ip,iv}^{hot} \left(\frac{e_{ip,iv}^{cold}}{e_{ip,iv}^{hot}} - 1 \right)$ (in g.km^{-1}.veh^{-1}). They depend on the vehicle speed and the atmospheric temperature $\frac{e^{cold}}{e^{hot}} = AV + BT + C$, where V (km.h^{-1}) is the speed and T (°C) is the temperature. A, B and C are constants.

A_{ie} is written $A_{ie} = \beta_{iv} M_{iv} N_{iv}$, where the β_{iv} is the fraction of mileage driven with cold engines or the catalyst operated below the light-off temperature for vehicle iv.

- Evaporative emission

Evaporative emission (E_{evap}) are estimated only for NMVOCs (Non Methane Volatile Organic Compounds) emissions and for gasoline vehicles. The evaporation emissions are divided into 3 types: running losses (due to the warm of motor), hot soak (due to the motor is turned off) and diurnal emissions (due to the daily variation in ambient temperature).

<u>(i) Evaporation due to running losses</u>:

The running losses emissions are calculated as follows:

$$E_{rulo} = Nx\left\{c\left[pe_{r,hot,c} + (1-p)e_{r,warm,c}\right] + (1-c)e_{r,hot,fi}\right\} \tag{3.7}$$

where *N* is the total number of gasoline vehicle, *x is* the mean number of trip per vehicle per day and c is the fraction of gasoline powered vehicles equipped with carburettor, *p* is the fraction of trips finished with hot engine and $e_{r,hot,c}$, $e_{r,warm,c}$, $e_{r,hot,fi}$ (in g.trip^{-1}) are the emission factors.

<u>(ii) Evaporation due to hot soak</u>:

The running losses emissions are calculated as follows:

$$E_{hoso} = Nx\left\{c\left[pe_{s,hot,c} + (1-p)e_{s,warm,c}\right] + (1-c)e_{s,hot,fi}\right\} \tag{3.8}$$

where $e_{s,hot,c}$, $e_{s,warm,c}$ and $e_{s,hot,fi}$ (in g.procedure^{-1}) are the emission factors.

<u>(iii) Evaporation due to diurnal losses</u>:

$$E_{dilo} = Ne_{d,j} \tag{3.9}$$

where e_d (in g.day^{-1}) is the average diurnal losses

b) Computation of emissions in EMISENS

- Computation of the activity:

In the COPERT IV methodology the activity is estimated as the product of the mileage of a vehicle (M_{iv}) by the total number of vehicle (N_{iv}): $A_{ie} = M_{iv} N_{iv}$. This formulation is easy to use to estimate the total emissions but gives any information to distribute the activities in space and time. In order to be distributed in time and space, the activities should be calculated using the vehicle flow on a specific street segment ($F_{is,iv}$ in veh.h^{-1}) times the length of this street segment (L_{is} in km): $A_{ie} = F_{is,iv} L_{is}$. If the vehicle flows are known each hour in each street of the city, the activities are easily distributed on a grid using the fraction of street length in each grid cells.

- Definition of the street category:

The COPERT IV equations show the emission factors for hot and cold emissions depend on the vehicle speed for each street (eventually it can also depend on the street slope). However, it is very costly for collecting the data of vehicle speed on each street. Therefore, in EMISENS we group the streets (is) into street categories (Is) in which the vehicle speed is the same, and where we can consider constant emission factors per street category. A street category is a group of streets with the same emission factors (i.e. same speed and eventually the same slope).

- Computation of the average emission factors:

When the emission factors are calculated using the COPERT IV methodology, the averaged emission factors are calculated for a certain number of vehicle categories (e.g. car, light truck, heavy truck, bus, motorcycle) using the associated fleet composition.

Hot emission factors are calculated as follows: $\bar{e}^{hot}_{Iv,is} = \sum_{iv}^{nIv} \alpha_{iv} e^{hot}_{iv,is}$

where α_{iv} is the proportion of each type of vehicle in each category.

Cold emission factors are written as: $e^{hot}_{iv,is} \left(\frac{e^{cold}_{iv,is}}{e^{hot}_{iv,is}} - 1 \right)$ with $\frac{e^{cold}_{iv,is}}{e^{hot}_{iv,is}} = A_{iv} V + B_{iv} T + C_{iv}$

A, *B* and *C* constants depending on the vehicle type; *V* and *T* are the cold speed (km/h) and atmospheric temperature (°C).

$$\bar{e}^{cold}_{Iv,is} = \sum_{iv}^{nIv} e^{hot}_{iv,is}\left(\frac{e^{cold}_{iv,is}}{e^{hot}_{iv,is}} - 1\right) = \sum_{iv}^{nIv} e^{hot}_{iv,is}\left(A_{iv}V + B_{iv}T + C - 1\right)$$

$$\bar{e}^{cold}_{Iv,is} = \left(\overline{e^{hot}A}\right)_{Iv,is} V_{is} + \left(\overline{e^{hot}B}\right)_{Iv,is} T + \left(\overline{e^{hot}C_1}\right)_{Iv,is} \qquad (3.10)$$

where $\bar{e}^{cold}_{Iv,is}$ is the averaged cold emission factor for the vehicle category Iv and nIv is the number of vehicle in the category Iv.

- Calculation of the emission:

The emissions are computed on each cell per hour:

$$E^{hot}(x,y,t) = \bar{e}^{hot}_{Iv,Is}\left[FL\right]_{Iv,Is}(x,y,t) \qquad (3.11)$$

$$E^{cold}(x,y,t) = \left(\overline{e^{hot}_{Iv,Is}A}V_{Is} + \overline{e^{hot}_{Iv,Is}B}T + \overline{e^{hot}_{Iv,Is}C_1}\right)\left[\beta FL\right]_{Iv,Is}(x,y,t) \qquad (3.12)$$

We can note that the emission factors can also been estimated through measurement campaigns (Belalcazar et al. 2010).

c) Differences of EMISENS with Circul'Air model

ASPA is using a home made emission model called Circul'air. This model is based on a bottom-up approach. It computes the emission factors for hot, cold and evaporation emissions using the COPERT IV methodology.

The street network of the city and its surrounding is divided in segments where the traffic flow is constant. It means that every point on one segment has the same traffic flow. The vehicle flows (*F* in veh.h^{-1}) are estimated in each street using traffic count data. The length (*L* in km) of each segment is calculated using the Arcmap software.

The Circul'air and EMISENS models use two different approaches for calculation the emission factors: The Circul'air model uses the "exact" speed to compute the emission factors. While in the EMISENS model, the average emission factors are computed using an average speed range

3.2.5 Calculation of the uncertainties in EMISENS using Monte Carlo methodology

The Monte Carlo methodology has been used to evaluate the uncertainties in previous air quality studies (Hanna et al., 1998; Sathya., 2000; Hanna et al., 2001; Abdel-Aziz and Christopher Frey., 2004). In EMISENS, the EIs are generated as the combination of different input parameters:

$$E = f(H_1, ...H_n) \tag{3.13}$$

where H_i are the input parameters (i=1, n). H_i can change due to the uncertainties. Each parameter H_i is distributed around an average $\overline{H}_i$ and a standard deviation σ_i.

The Monte Carlo method (Ermakov, 1977) generates for each input parameters a pseudorandom normally distributed numbers η^H ($\sigma = 1$ and mean= 0) which can be used to compute several values of H_i:

$$H_i^k = \overline{H}_i + \eta^H \sigma_i \tag{3.14}$$

The percentage of standard deviation σ_i could be calculated as: $\tilde{\sigma}_{Hi} = \dfrac{\sigma_i \times 100}{\overline{H}_i}$

The equation (3.14) becomes: $H_i^k = \overline{H}_i \left(1 + \dfrac{\tilde{\sigma}_{Hi} \eta^H}{100} \right)$

These parameters H_i^k are used to calculate several values of E^k: $E^k = f(H_1^k, ...H_n^k)$. The average value $\overline{E}$ and the standard deviation σ_E are deduced from the distribution of E^k.

The percentage of standard deviation σ_E could be calculated as: $\tilde{\sigma}_E = \dfrac{\sigma_E \times 100}{\overline{E}}$

The classification of standard deviation $\tilde{\sigma}_E$ is based on the standard deviation of the input parameters $\tilde{\sigma}_{Hi}$:

If $\tilde{\sigma}_{Hi}$ is the standard deviation of input parameters due to spatial and temporal repartition, the values $\tilde{\sigma}_E(x, y, t)$ are the standard deviation of emission for all input parameters but in space and time.

If $\widetilde{\sigma}_{Hi}$ (the standard deviation of each input parameters) is constant in the entire domain, then the values of $\widetilde{\sigma}_{E_{Hi}}$ are the standard deviations of emission for all the domain but for each input parameter.

3.3 Use and validation of EMISENS model

3.3.1 Application of Circul'air and EMISENS over Strasbourg

Strasbourg in the Alsace region is a city located in north-eastern France (Figure 1). Strasbourg's metropolitan area is the ninth largest city of France. Its urban community had 467,376 inhabitants in 2006. Tram and private cars are the main mode of transport in the city, the private cars are also the main sources of pollution (Schillinger et al. 2005).
The air quality of the Alsace region is monitored by the air quality agency, ASPA, which is also in charge to study and propose strategies to reduce air pollution. For this purpose, ASPA is using different types of air quality forecast models (ADMS-urban model; CHIMERE model). These models use emission inventory as input. These emission inventories are issued from the Circul'air model.
To fulfil the objective of the present paper, ASPA provides the emission inventory issued form a simulation of Circul'air for year 2006 on Strasbourg. The domain of study (Figure 3.1.b) stretches 10 km east-to-west and 8 km north-to-south with a resolution of 500 x 500 m (Figure 3.1.b). The lower left corner of domain is 48.55 ° N and 7.67 °E. It covers a part of the Urban Community of Strasbourg (UCS). The fraction of the street segment included in each cell is used to assign the fraction of the emission that corresponds to that cell

3.3.2 Comparison between the results of the Circul'air and the EMISENS models

In order to validate and evaluate the capacity of EMISENS model, EMISENS and Circul'Air models are applied over Strasbourg as a reference case. Both models use the same input parameters.

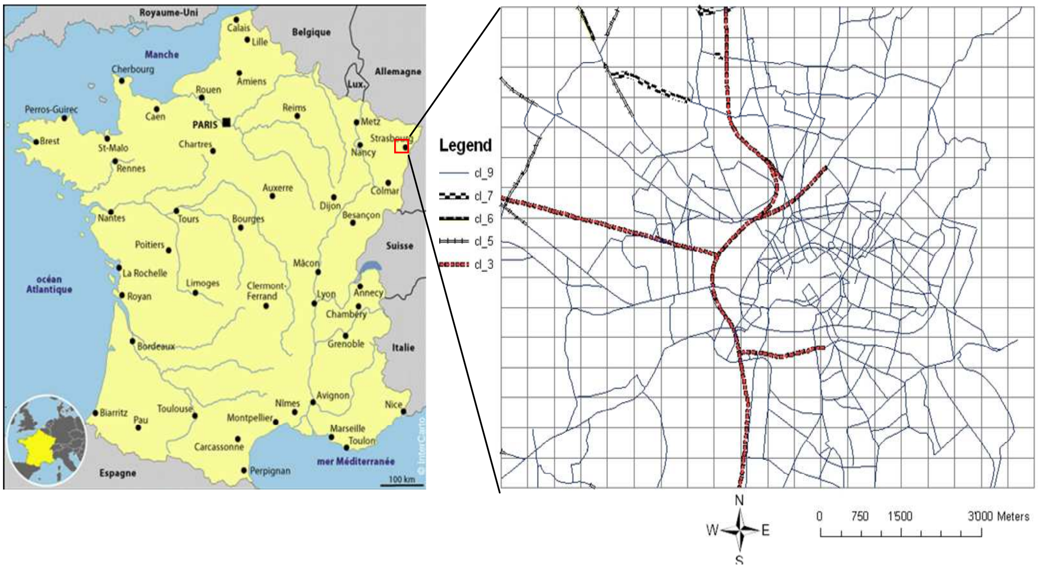

Figure 3.1: The national map of France (left, Figure 3.1a) and the road network of the domain chosen for generating the road traffic EI (right, Figure 3.1.b), cl_3 corresponds to the highways (speed maximum of 110 km/h), cl_5 corresponds to the street network over the structuring flat terrain (85 km/h), cl_6 corresponds to the network over the mountains (60 km/h), cl_7 corresponds the secondary network over the flat terrain (75 km/h) and cl_9 are urban streets (50 km/h).

In the following Tables, the total emissions for the different pollutants are compared. The Tables are divided in 4 columns: total emission, hot emission, cold emission and evaporation.

The results shown are the total annual hourly average emissions (in gram per hour) for the domain and in a normal working day. The atmospheric temperature used in both models for the cold emissions calculation is 10°C.

Evaporative emissions are calculated only for NMVOC and the gasoline vehicle because the gasoline only evaporates NMVOC (Ntziachristos et al., 2007).

Table 3.1: Results of EMISENS model are generated for road traffic emissions over Strasbourg

Pollutants	Total (g/h)	Hot emission (%)	Cold emission (%)	Evaporation (%)
CO	662093.6	45.66	54.34	0.00
NO_x	216534.9	94.46	5.54	0.00
CH_4	5093.1	80.11	19.89	0.00
NMVOC	68496.7	61.97	30.05	7.97

Table 3.2: Results of Circul'air model are generated for road traffic emissions over Strasbourg

Pollutants	Total (g/h)	Hot emission (%)	Cold emission (%)	Evaporation (%)
CO	538860.2	51.65	48.35	0.00
NO_x	218643.8	94.85	5.15	0.00
CH_4	4613.7	75.75	24.25	0.00
NMVOC	67002.7	55.48	36.34	8.18

Table 3.3: Comparison the two models in percentage (%).

Pollutants	Total emission	Hot emission	Cold emission	Evaporation
CO	20.52	8.27	31.99	-
NOx	-0.97	-1.38	6.37	-
CH4	9.88	15.45	-9.91	-
NMVOC	2.21	13.26	-16.77	-0.35

The percentage values in Table 3.3 are calculated as:

$$Percentage(\%) = \frac{(EMISENS - Circul'Air)\times 100}{\dfrac{(EMISENS + Circul'Air)}{2}} \tag{3.15}$$

Table 3.1 and Table 3.2 show that: 1) hot emissions are more important (more than 50% of total emission). However, it depends on pollutant type, e.g. more than 94% of hot emission in the case of NO_x and more than 80% of hot emission in case of CH_4. 2) Cold emissions are less important; except for the case of CO, cold emission of CO is around 54% of total emission. 3) NMVOC evaporation is calculated only for the case of "running losses" because the Circul'air model only calculates this kind of emissions. This kind of evaporative emissions is only 8% of the total NMVOCs emissions.

An uncertainty of 10% for each input parameter is used to evaluate a sensitivity analysis with the EMISENS model. The results of sensitivity analysis are described as follows:

- Carbon monoxide (CO):

There is very high percentage of cold emission (around 54%). The result of sensitivity analysis shows that the parameters for cold emission have more impact in case of CO. The parameters $\overline{e^{hot}_{Iv,Is}A}$ for the car, average speed, atmospheric temperature and the cold hourly street mileage ($[\beta FL]_{Iv,Is}$) for the car have uncertainty on total emission of CO about 3.1%, 2.3%, 2.0% and 1.81%, respectively. Table 3.3 shows that the CO cold emission of two models is different around 30% because the cold emission factors of CO in two models are used differently:

In Circul'air model the cold emission factor which is calculated, depends directly on the real speed of each segment of the street. However, in EMISENS model the cold emission factor calculated depends on the average speed range.

The car on highway and urban street has the most impact on the cold emission

- Nitrogen oxide (NO_x):

There is very low percentage of cold emission (around 5%). The parameters which are used to compute hot emission are most sensitive. The parameters hourly street mileage for the car, hot emission factor for the car have uncertainty on total emission of NO_x about 2.04% and 2.03%, respectively. The comparison results of two models are very similar.

The car on highway and urban street has a main impact on hot emission.

- NMVOC:

There is high percentage of cold emission (around 30%). The parameters which are used to compute hot and cold emissions are most sensitive. The parameters hourly street mileage for the car, hot emission factor for the car, cold hourly street mileage for the car and atmospheric temperature have uncertainty on total emission of NMVOC about 1.91%, 1.91%, 1.52% and 1.42%, respectively.

The comparison results of two models (Table 3.3) have shown that the difference is 16.75% in the results of cold emission; the explanation of this difference is the same the explanation in the case of CO that there are differences in cold emission factors between two models.

The car on urban street has a main impact on hot and cold emission.

- Methane (CH_4):

There is "medium" the percentage of cold emission (around 20%). The parameters which are used to compute hot and cold emissions are most sensitive. The parameters hourly street mileage for the car, hot emission factor for the car, cold hourly street mileage for the car and $\overline{e^{hot}_{Iv,Is}C_1}$ have uncertainty on total emission of CH_4 about 3.19%, 3.19%, 1.54% and 1.54%, respectively. The comparing results of the two models are similar.

The car and light truck on urban street have most impact on hot and cold emission.

Through the above comparison, we can see that a produced result of EMISENS model is similar to Circul'air model. So, EMISENS model could be used to calculate the road traffic emissions. The EMISENS model will be used to test different scenarios presented in next section.

3.4 Scenarios in the EMISENS over Strasbourg

As we mentioned in previous section, in this part the EMISENS model will be used to run 4 principal scenarios. Scenario is started with the most data needed (scenario 1) to the less data needed (scenario 4).

3.4.1 Scenario 1: Constant cold engine driving in space

The cold emissions are an important part in the total emission, for some pollutants the cold emissions are more than 50% of the total emission. The fraction of mileage driven with the cold engine ($\beta_{(x,y)}$) is one of the most important parameters on the calculation of the cold emissions. But this parameter is not easy to estimate for each street because it is costly. Here we evaluate this parameter.

In this scenario, we use the same methodology and the data we used in the reference case. However, we replaced the value $\beta_{(x,y)}$ which is variable in each street by a constant average value of $\overline{\beta}$ for the hold domain. It means that fraction of mileage driven with cold engine are constant in all the cell of the domain.

Table 3.4: Results of reference case (in g/h)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	662093.6	302294.9	359798.7	0.0
NO_x	216534.9	204538.3	11996.6	0.0
CH_4	5093.1	4079.9	1013.2	0.0
NMVOC	68496.7	42450.2	20584.4	5462.0

Table 3.5: Results of scenario 1 (in g/h)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	650516.8	302294.9	348221.9	0.0
NO_x	216166.5	204538.3	11628.2	0.0
CH_4	5097.0	4079.9	1017.1	0.0
NMVOC	68115.2	42450.2	20203.0	5462.0

Table 3.6: Compare the reference case and scenario 1 in percentage (%)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	1.76	0.00	3.27	-
NO_x	0.17	0.00	3.12	-
CH_4	-0.08	0.00	-0.38	-
NMVOC	0.56	0.00	1.87	0.00

The scenario 1 was performed. The results shown in Table 3.4 and Table 3.5 are almost the same. We can see that their difference is created by the cold emission calculation, the differences between the two cases (Table 3.6) are from -0.38% to 3.27% depending on the pollutant.

Table 3.6 shows a comparison of the total in whole domain. However, as we know that in this scenario, we changed the parameter $\beta_{(x,y)}$ which is variable in space by another constant parameter ($\overline{\beta}$=0.3762) in space.

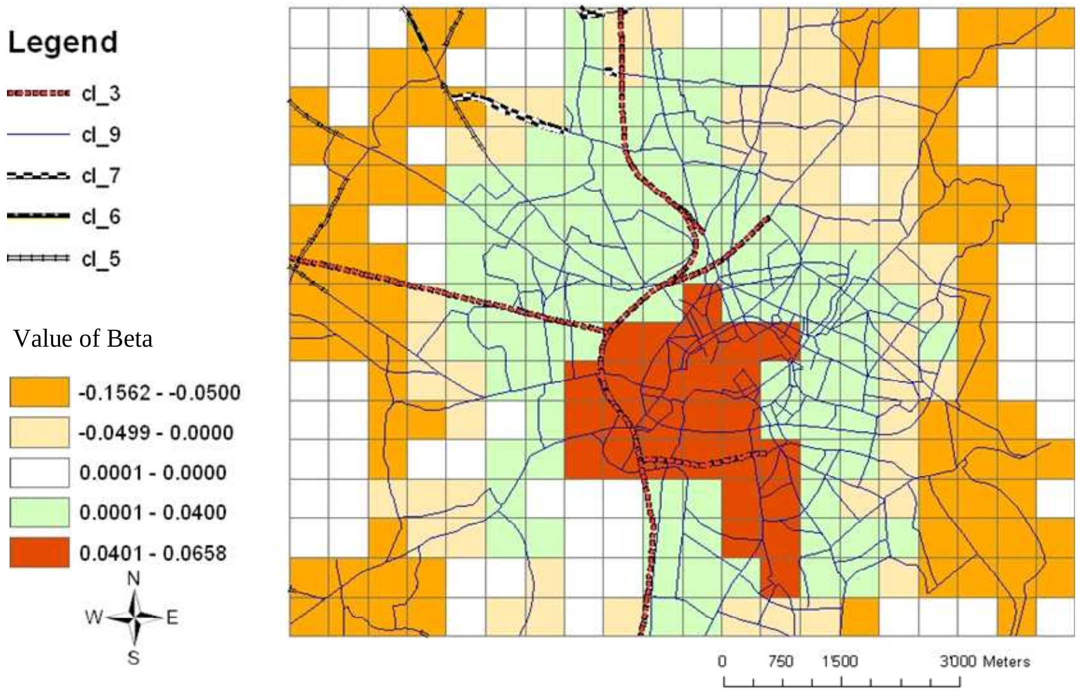

Figure 3.2: The difference of value $\beta\,(\beta = 0 \div 1)$ between reference case and scenario 1 on study domain. Different street categories are already defined in Figure .3.1

The value shown in Figure 3.2 are calculated in each cell as: $\beta_{reference\ case} - \overline{\beta}_{senario\_1}$. The cold emissions seem to be most likely for urban driving (Ntziachristos et al., 2007), therefore the value β in center is higher than around the city. So in this scenario the emissions will tend to be overestimated in the center and underestimated around the city. The following map (Figure 3.3) shows the difference between the base case and the scenario 1 for each cell of the domain, this difference is calculated as follow:

$$Diffrence(\%) = \frac{(reference\ case - scenario) \times 100}{\frac{(reference\ case + scenario)}{2}} \tag{3.16}$$

Figure 3.3 shows that the highest difference in space between reference case and scenario 1 is in the case of CO (from 9% to -21%). However, only one cell has this highest difference (occupied 0.3% total of cell).

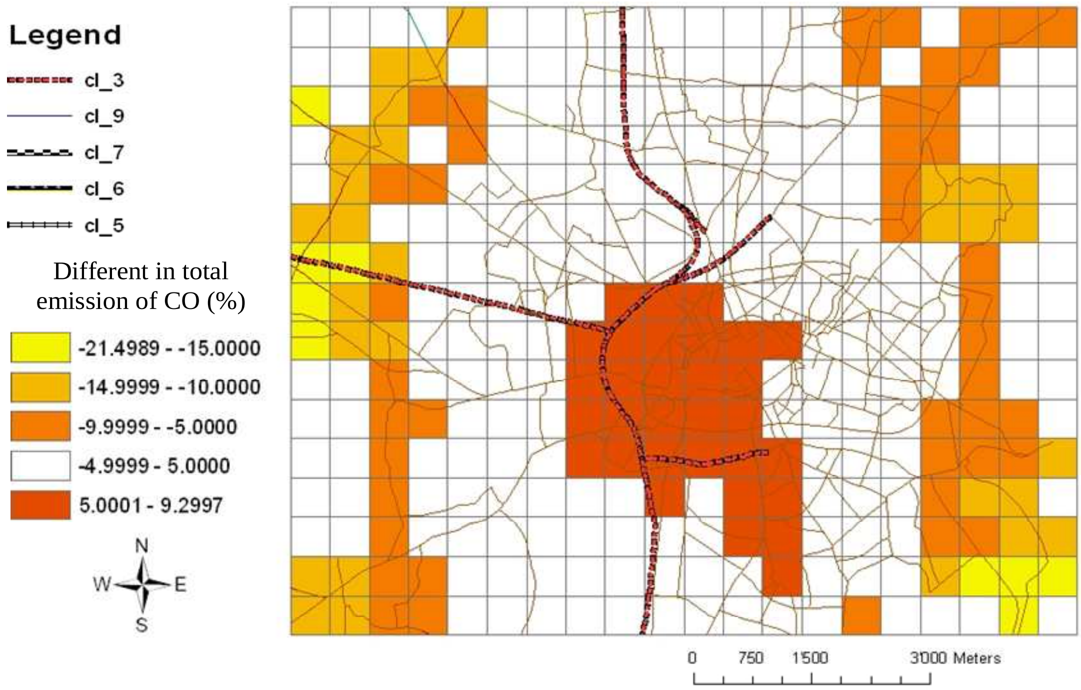

Figure 3.3: The different emission of CO (in %) between reference case – scenario 1 on study domain. Different street categories are already defined in Figure .3.1

There is almost no difference in space for NO_x emissions (from 1.1% to -2.2%) and the number of cells which has great difference is very small, only 5% cells in the case of NO_x has difference higher than 1% (annex A.3.1 b).

The difference is not too much in case of NMVOC and CH_4. Their differences are from 5.6% to -10.9% and from 4.8% to -10.5%, respectively (see annex A.3.1 a, c)

We can see that the emission map (Figure 3.3) follows the map of β (Figure 3.2). These map show that in the center of city where we overestimated the β value, consequently the emission also overestimated in this zone and vice versa for another zone.

The patterns of comparison maps between two cases are similar to all the pollutants. However, the magnitude of comparison values is difference from pollutant to pollutant.

3.4.2 Scenario 2: average traffic flow

The road traffic flow is one of the most important parameter for generating EI and it changes in time and space. It results difficult to estimate the real flows. In the sensibility analysis (section 3.3.2) the traffic flow created the greatest impact on total emission.

In this scenario we evaluated the impact of using the average value of traffic flow ($\overline{F}_{(t,Is)}$) and street length ($\overline{L}_{(x,y)}$) on the EI. All the input parameters of this scenario are the same to the reference case, but we replaced the values of $FL_{(t,x,y)}$ by the value of $\overline{F}_{(t,Is)}$ (the temporal profile of the traffic flow is the same in each street category) and $\overline{L}_{(x,y)}$ (average street length in each cell).

Table 3.7: Results of scenario 2 (in gram/hour)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	661910.2	302265.7	359644.4	0.0
NO_x	216513.5	204522.1	11991.4	0.0
CH_4	5092.1	4079.5	1012.6	0.0
NMVOC	68482.3	42446.1	20574.3	5462.0

Table 3.8: Compare the reference case and scenario 2 in percentage (%)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	0.03	0.01	0.04	-
NO_x	0.01	0.01	0.04	-
CH_4	0.02	0.01	0.06	-
NMVOC	0.02	0.01	0.05	0.00

The scenario 2 was performed and the obtained results are shown in Table 3.7. This result was compared with the reference case, the difference between two cases is mainly created by cold emission calculation; their differences (Table 3.8) are from 0.04% to 0.06% depending on pollutant type. However, the emissions of two cases are different in space because the profile temporal of traffic flow now is constant in the street category.

The value of each cell on Figure 3.4 is calculated by formula: $F_{(t,x,y)} - \overline{F}_{(t,Is)}$. The traffic flows of street cl_3 (highway) have the highest impact. The difference in traffic flow is

Figure 3.4: The difference of traffic flows (vehicle number/hour) between $F_{(x,y,t)}$ case and $\overline{F}_{(t,Is)}$ case on study domain. Different street categories are already defined in Figure 3.1.

from -65% to 69% of average traffic flow in street category 3. The following Figure 3.5 shows the impact of traffic flow on EI in space.

The highest difference in values of EI in two cases vary from -123% to 146% in case of NMVOC emission. However, the highest values focus on street category 3 and occupy only in some cell (4.06% of total cell). The patterns of difference emission between two cases are similar to others pollutants, such as from -145% to 160%, -166% to 160% and -155% to 168% for CH_4, NO_x, and CO, respectively (annex A.3.2.a, b, c). Especially, the highest values of CH_4 case occupy only in 4 cells of study domain (1.25% of total cell).

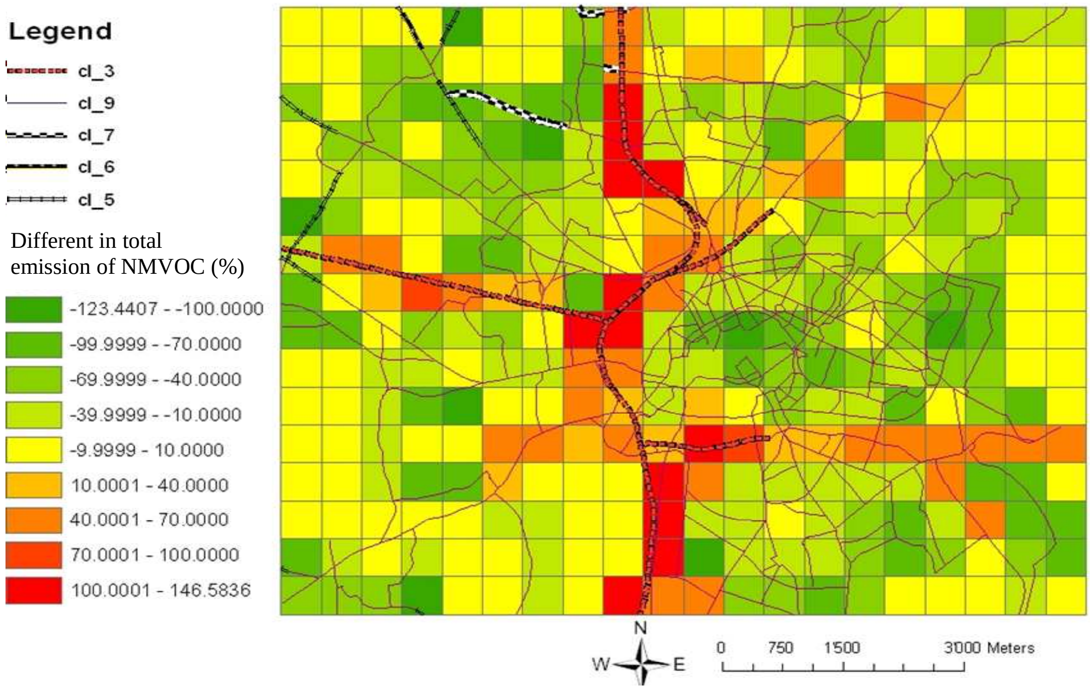

Figure 3.5: The difference in emission of NMVOC (in %) between reference case – scenario 2 on the study domain. Different street categories are already defined in Figure 3.1.

Scenario 3: including scenario 1 and scenario 2

The scenario 3 includes the simplification of scenario 1 and 2, so this is a simple scenario. It means that we replaced the value of $\beta_{(x,y)}$ by average value of $\overline{\beta}$ and replaced the value of $FL_{(t,x,y)}$ by the average value of $\overline{F}_{(t,Is)}$ and $\overline{L}_{(x,y)}$.

Table 3.9: Results of scenario 3 (in gram/hour)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	650466.9	302260.3	348206.7	0.0
NO_x	216153.0	204524.7	11628.3	0.0
CH_4	5096.3	4079.4	1016.9	0.0
NMVOC	68107.5	42445.9	20199.6	5462.0

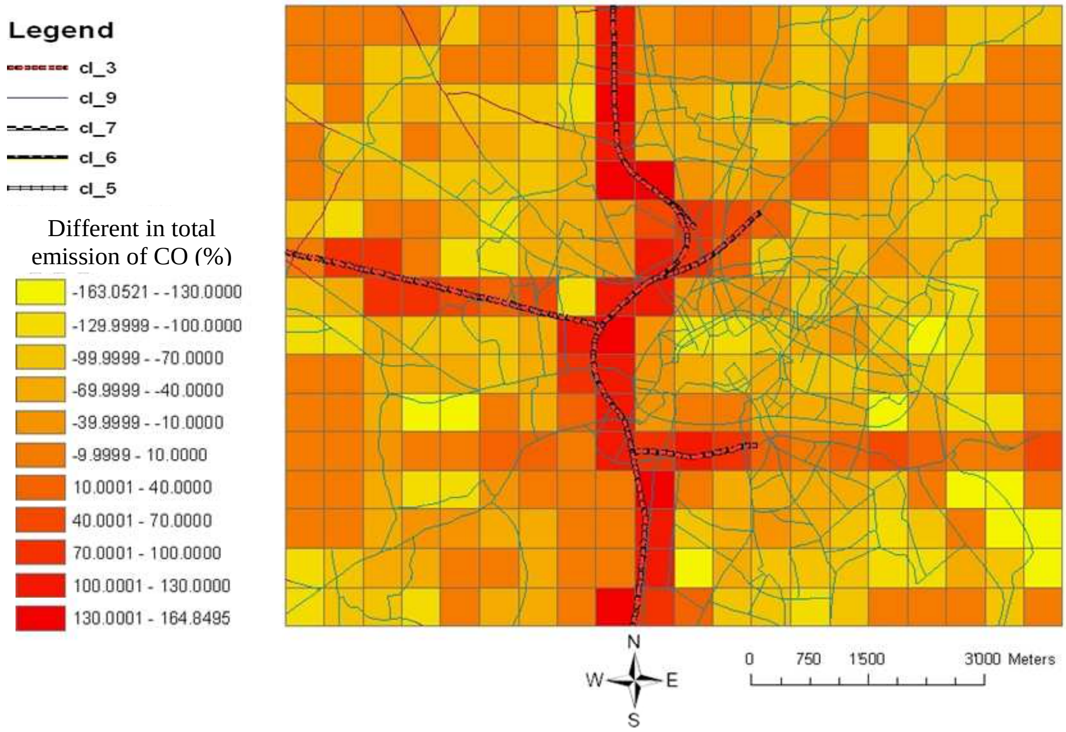

Figure 3.6: The difference in emission of CO (in %) between reference case – scenario 3 on the study domain. Different street categories are already defined in Figure 3.1.

Table 3.10: Compare the reference case and scenario 3 in percentage (%)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	1.77	0.01	3.27	-
NO_x	0.18	0.01	3.12	-
CH_4	-0.06	0.01	-0.36	-
NMVOC	0.57	0.01	1.89	0.00

The scenario 3 was performed and the obtained results in total are shown in Table 3.9 and it was compared with reference case in Table 3.10. The difference between the reference case and scenario 3 looks like the sum of difference of scenario 1 and scenario 2. Their difference is mainly created by cold emission calculation and the different percentage is from -0.36% to 3.27% depending on pollutant type. Figure 3.6 shows simultaneously the impact of traffic flow and fraction of mileage driven with cold engine on EI in space.

In this scenario, the results in space are similar to the scenario 2. The greatest difference in space between this scenario and reference case is higher than the greatest difference in space between the scenario 2 and reference case around 7%. Because of the simplifications in scenario 3 include the simplification of scenario 2 and simplification of scenario 1, so that the errors of simplifications in scenario 3 are accumulated from scenario 2 and scenario 1.

However, especially for the CH_4 (annex A.3.3 c) the difference in space between reference case and scenario 3 is from -21% to 98% and the highest value occupies only 3 cells in study domain. This can be explained by annulment the differences from simplifications of $\beta_{(x,y)}$ (negative differences) and $FL_{(t,x,y)}$ (positive differences).

The patterns of comparison map (Figure 3.6) between reference case and scenario 3 are similar to CO, NO_x and NMVOC such as from -163 to 164%, -167% to 162% and -130% to 147 for CO, NO_x, and NMVOC, respectively (annex A.3.3.a, b, c).

3.4.3 Scenario 4: simplest scenario

This is the simplest scenario. The input parameters are grouped as: Only 1 street category (urban street), 5 vehicle categories, the temporal profile of the traffic flow is the same in the domain (repartition in time), the distribution of the emission in space is using the street density (repartition in space) and the average value of $\overline{\beta}$=0.3762 constant in the domain.

The input parameters that are used in this scenario are the most used in cities from the developing world.

We considered only one urban street category because:

- The highway and other streets have less than 10% of total street length in the city
- In a previous research the average emission factors were calculated only for one urban street category (Belalcazar et al., 2009).

Table 3.11: Results of scenario 4 (in gram/hour)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	723587.2	376031.7	347555.5	0.0
NO_x	239679.9	228097.5	11582.5	0.0
CH_4	7836.3	5702.9	2133.4	0.0
NMVOC	85607.0	50217.1	29927.9	5462.0

Table 3.12: Compare the reference case and scenario 4 in percentage (%)

Pollutants	Total	Hot emission	Cold emission	Evaporation
CO	-8.88	-21.74	3.46	-
NO_x	-10.15	-10.89	3.51	-
CH_4	-42.43	-33.18	-71.20	-
NMVOC	-22.21	-16.76	-36.99	0.00

This is a rough scenario where we need less input parameters. The results of the total emission for each pollutant are shown in Table 3.11 and Table 3.12: There are just around 10% difference in total emission between reference case and scenario 4 for CO and NO_x. However, for NMVOC results, the difference in total emission between reference case and scenario 4 is around 22%. And especially for CH_4, the scenario 4 is higher than reference case up to 42%.

The results of hot emission: In this scenario we replaced others street categories by urban street and the hot emission factors of some pollutants in urban street category are 2 times higher than the others street categories. The resulting hot emissions of CO and CH_4 are higher than reference case around 20% and 30%, respectively.

The results of cold emission: The cold emission for CH_4 and NMVOC is very high in urban street (cl_9). Especially for CH_4 the difference is more than 2 times than the reference case, this can be explained that there is no cold emission in highway street (Ntziachristos et al., 2007). However, in this scenario 4, we considered the cold emissions of highway street are similar to urban street. So the cold emission of NMVOC and CH4

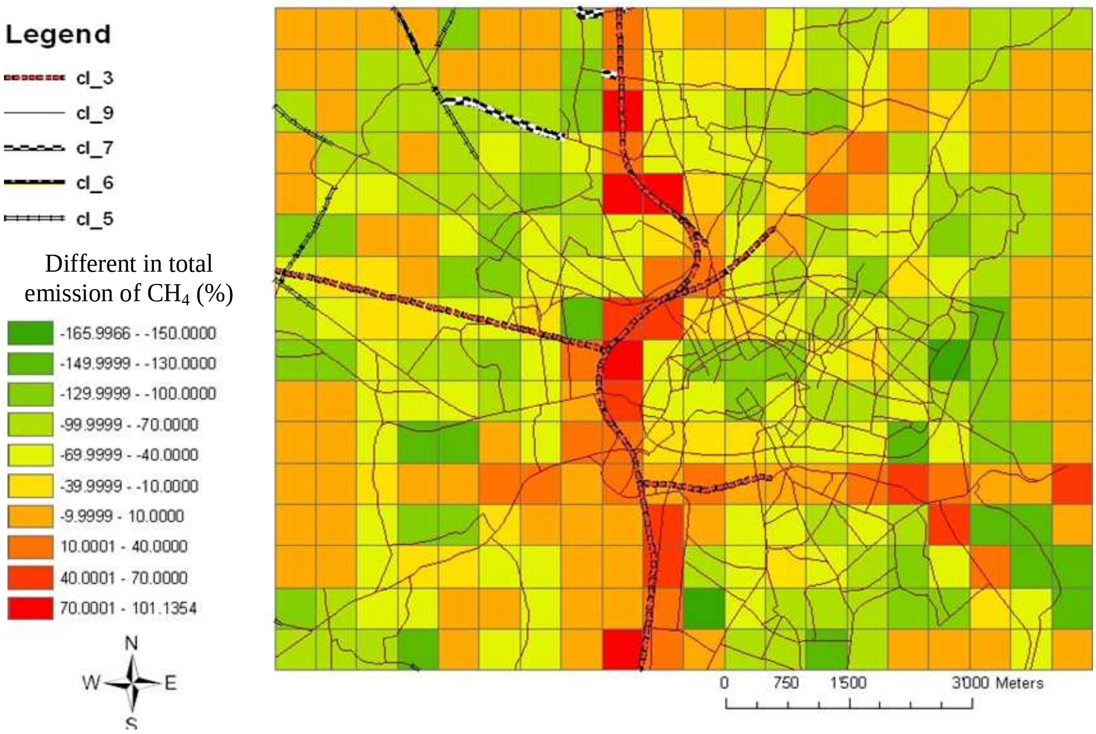

Figure 3.7: The difference in emission of CH4 (in %) between reference case and scenario 4 on the study domain. Different street categories are already defined in Figure 3.1.

are higher than reference case around 45% and 100%, respectively. For others pollutants like CO and NOx, the cold emission of scenario 4 are similar to reference case.

The comparison in space between reference case and scenario 4 is shown in Figure 3.7. As we saw in Figure 3.7 that the greatest difference in space between the reference case and the scenario 4 in case of CH_4 is -165% (occupied only 1 cell of study domain). The underestimated emission is computed on the highway category and the overestimated emission in the urban street. The underestimated and overestimated are easily explained that because of we used the same average traffic flow for all street category, while the traffic flow of highway is 10 times higher than the traffic flow of the urban streets.

The patterns of comparative map in space between two cases of others pollutants is similar to CH_4 case (annex A.3.4. a, b, c). The difference in space between reference case and the scenario 4 for NMVOC, CO and NO_x are from -146% to 137%, -166% to 161% and -170% to 159%, respectively.

In general, if we validate the EMISENS model by its application to calculate the road traffic emissions for other cities than Strasbourg, the magnitude of results of validation and the simplification scenarios can be changed. However, the example of application EMISENS over Strasbourg shows that: (1) EMISENS mode is able to calculate the road traffic emissions in several steps with different levels of complexity of input parameters; (2) It helps us to determine the most sensitive input parameters and the hierarchy sensitive of input parameters; (3) It is ready for using to generate road traffic emissions.

3.5 Conclusions

In this study we developed and tested the model EMISENS for generating the road traffic emissions. The model is developed by combining two approaches, top-down and bottom-up, for generating EI. The top-down method calculates the total amount of emission for the whole city during a full year and this total is then distributed in time and space using the distributed parameters. While the bottom-up approach, the emissions are directly calculated in time and space using spatial parameters which are distributed in time and space.

With this new methodology, the EMISENS model allows us to calculate the uncertainties in EI and reduces the computational time. The Monte Carlo methodology was used to generate the uncertainties in EI which are created by input parameters. The computational time is reduced by grouping the vehicle types to vehicle categories; the resulting 5 to 10 vehicle categories are able to describe a fleet of 150 vehicle types.

The basic formulas used in the EMISENS model were based on COPERT IV. The COPERT IV methodology is a classical methodology in Europe. So EMISENS is a unique and useful model for computing the EI and their uncertainties for not only developing countries but also the developed countries.

In order to validate and evaluate the capacity of our new model EMISENS, the EMISENS model was applied over Strasbourg as the reference case. The results of the EMISENS model were compared with the results of ASPA.

The ASPA was using a home made emission model called Circul'air. This model is based on a bottom-up approach. It computes emission factors for hot, cold and evaporation emissions using the COPERT IV methodology.

The obtained results of EMISENS are very close to the results of Circul'air model; the difference between the two models range from -1% to 20% depending on each pollutant. A preliminary uncertainties study with uncertainty of 10% an each input parameter of EMISENS model was also carried out to evaluate the most sensitive input parameters. The obtained results show that the parameters for cold emission calculating have more of an impact in case of CO (e.g the parameters $\overline{e^{hot}_{Iv,Is}A}$ for the car, average speed and atmospheric temperature for the car have uncertainty on total emission of CO about 3.1%, 2.3%, 2.0% and 1.81%, respectively). Contrary to the case of CO, the parameters for hot emission calculating have most sensitive in case of NO_x (e.g the parameters hourly street mileage for the car, hot emission factor for the car have uncertainty on total emission of NO_x about 2.04% and 2.03%, respectively). While the parameters which are used to compute hot and cold emissions are most sensitive in case of NMVOC and CH_4. The EMISENS model showed its capacity very well when generating road traffic EI.

We used the EMISENS model to run the different simplifications of input parameters which correspond with developing countries situation to evaluate the level of errors created when we have a limit of input parameters for generating EI. Four simulations with different simplifications from most needed data to less needed input data were tested. The obtained results of the simulations were compared with the reference case and their results show that:

+ We can use the same average fraction of mileage driven with cold engine ($\overline{\beta}$) for all the cells of the study domain.

+ The results show that only one emission factor for both cold and hot emission could be used because the $\overline{\beta}$ value has no impact on space. There was some research for creating emission factors for vehicle category; they created only one emission factors for both emissions.

+ There were no differences in total emission for all domain when we used the same average traffic flow, average temporal profile and divided the streets into 5 different street categories. While, the results of emissions in space are different, such as the difference between simplifications cases with reference case in some cell up to 150% in case of NMVOC.

+ However, if we consider only one street category in the study domain, the EI are underestimated in total emission and the EI are differences in space in comparing with reference case.

In conclusion, the EMISENS model is able to calculate road traffic emissions for cities in developed countries as well as in developing countries.

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Chapter 4 Emission inventories over Ho Chi Minh City and their uncertainties

Abstract

A complete Emission Inventory (EI) is generated for Ho Chi Minh City (HCMC), Vietnam. For generating the EI for road traffic sources, we used the new Emisens model which combines the top-down and bottom-up approaches described in chapter 3. The bulk emission factors of traffic stem from another study which estimated the emission factors for HCMC by using an inverse air quality model method (Ho et al., 2008). The method is based on top-down approach. To compute the EI for others emission sources, the top-down approach is used. The results show that the road traffic is the main emission source in the city (contributing 78% of NO_x, 90% of CO and 89% of Non Methane Volatile Organic Compounds (NMVOC)). The motorcycles are responsible for the bulk of traffic emissions (occupied 94 % of CO, 68% of NMVOC, 61 % of SO_2 and 99 % of CH_4). Two scenarios for reducing traffic emissions are designed using the HCMC's plan for reduction of emissions for the year 2015 and for the year 2020. Two other scenarios are the Business as Usual scenarios for the year 2015 and for the year 2020. The results show that if the local government does not have any plan for reduction of emissions (Business as Usual), the emissions will increase rapidly. If the HCMC government follows the planning as set out by the local managers, the emissions of some pollutants will decrease. However, the emissions of NO_x, NMVOC and SO_2 will increase slowly because in 2015 more than 10 % of motorcycles will be replaced by diesel buses. In order to evaluate the replacement of the diesel buses by buses using Compressed Natural Gas (CNG), a new scenario has been tested. The results show that in this case all the pollutants will decrease in 2015.

4.1 Introduction

The strong demographic growth and the fast development of the economy in HCMC lead to a massive increase of the population in the city. According to HCMC's General Statistics Office (HCMC statistics, 2006), the population density in the inner area in 2004 was 1.6 times higher than in 1979, the population of HCMC was 6.105 million people in 2006 and the HCMC government forecasted that the population of HCMC in 2020 will be 10 million inhabitants. In parallel to the increase of the population, HCMC becomes one of 100 rapid economic growth cities in the world (Gale, 2007). According to the HCMC Institute for Development Studies (HIDS), HCMC's economic growth rate is estimated at 11.0% per year during period of 2001 – 2005, and 12.0%-12.5% per year during period of 2006-2010 (HIDS, 2007).

The main visible consequence of the population increase and the economical growth is a rapid increase of vehicles and industries. The annual increase in vehicles in HCMC is estimated at 14.5% for automobiles and at 5.4% for motorcycles (HEPA, 2005). In 2006 it has reached a total of 3'340'964 vehicles (2'895'831 motorcycles, 347'242 cars, 45'116 light trucks, 28'442 buses and 24'333 heavy trucks). According to the HCMC's General Statistics Office (HCMC statistics, 2003), there are about 28'500 factories in the city (including 700 medium to large–scale enterprises), distributed in ten industrial zones and two export processing zones. In HCMC, the top polluters of industry are the industries of textile and dyeing, concrete, thermo-electricity and food-processing, as well as cement plants, steel mills, fertilizer plants, chemical factories, rubber processing plants and the tobacco industry. In addition, the infrastructure of HCMC can not keep pace with the rapid urbanization and its economic growth. For example, traffic jams are omnipresent on the week-ends. The results are environmental problems such as air and noise pollution.

For over 10 years, air quality in HCMC has deteriorated considerably thus exposing millions of people to harmful concentrations of pollutants. A recent study on the relation between air pollution and health showed that more than 90% of children under 5 years old were found to be suffering from different respiratory illnesses in HCMC (Le et al., 2008).

It is urgent to find the solution for controlling air pollution in HCMC. Up to now,

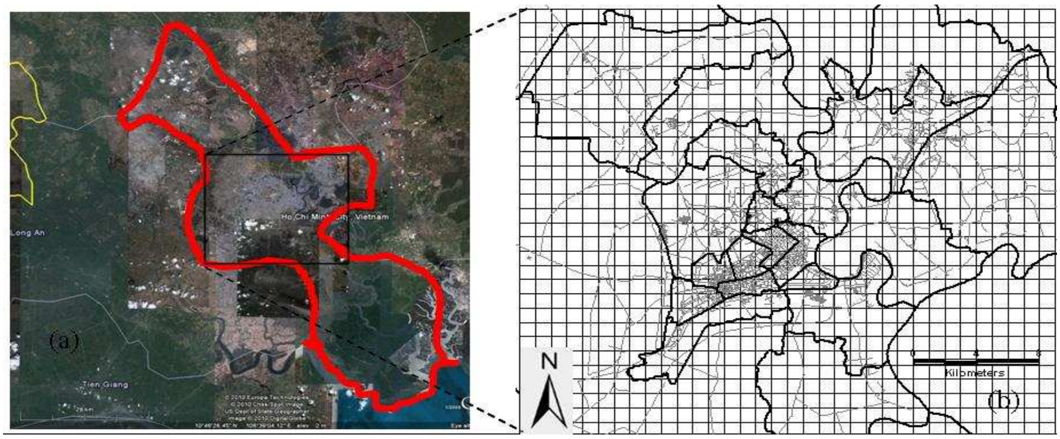

Figure 4.1: (a) HCMC's urban perimeter from Google earth. (b) Domain chosen for the emission inventory (34 km x 30 km, lower left corner 10.656 N and 106.539), the contour of the districts (black colour) and the street network (grey colour). (Source: (a) Google earth, (b) Triet et al, 2003).

numerical air quality model is only tool which is used to evaluate strategies for reducing emissions and study air pollution. This can be explained that after the emissions are ejected into the atmosphere, the emissions will be transformed by a series of complex processes (atmospheric dynamics, chemistry, solar radiation, etc.) (Clappier, 2001). Only numerical air quality models are able to account for all these processes. However, the numerical air quality models in turn depend on emission inventories (EI). In order to provide a good decision for reducing emission by using air quality model, we must first calculate the emissions of all the emission sources in order to identify which pollutants and emission sources are the most important. Up to now, no EI existed for HCMC. The present chapter is devoted to the generation of an EI for HCMC and the discussion of some emission abatement strategies. For generating the EI for road traffic sources, we use the new methodology that we developed in chapter 3 of this study. Due to time and financial restrictions of this study, we will use the top-down approach for the other emission sources (industry, residential and biogenic). The year 2006 is chosen as the base for the EI and the chosen domain for this study shown in Figure 4.1.

4.2 Status of emission inventory in HCMC

Previous studies have shown that the main sources of atmospheric pollution in HCMC are vehicles (ADB, 2006; Ho et al., 2006; Trinh, 2007). In HCMC, there are only 3% of people who use public transport (Dana et al 2009) and the rest of the people use private vehicles such as motorcycles.

Table 4.1: Emission sources in HCMC in 2000 (values in %)

Pollutant	Industry	Transport	Residential	Biogenic	Total
NO_x	38	61	1	-	100
CO	15	84	1	-	100
SO_2	92	5	3	-	100
HC	5	94	-	1	100
CO_2	77	12	10	-	100

Source: Thang, 2004

SO_2 = Sulphur dioxide, NO_x = Nitrogen dioxide, CO = Carbon monoxide, CO_2 = Carbon dioxide, HC = hydrocarbons, - = insignificant or zero contribution.

Table 4.1 shows the distribution of emission sources in HCMC. This estimation is based on an ad hoc estimation for the year 2000. For the traffic source, they used bottom-up approach for generating total traffic emissions in HCMC without distributing in space. For other sources, they used top-down approach for estimating emissions.

Traffic is the main emissions sources of Nitrogen oxide (NO_x: 61%), Carbon monoxide (CO: 84%), and Hydrocarbons (HC: 94%), while industries are the main emission sources of Sulphur dioxide (SO_2: 92%) and Carbon dioxide (CO_2: 77%). Among all emissions sources of transportation, the motorcycles are the dominant source. Motorcycles contribute with 70% of the total road traffic emissions in case of CO (ADB, 2006), 73 % of HC and 92 % of volatile organic compounds (VOC).

As with the preliminary estimation of the EI in Table 4.1, the main source of emissions in HCMC is traffic. Since the emission sources are dominate by traffic, in this chapter we focus on generating the EI for road traffic sources.

4.3 Road emission sources

As a first step towards estimating the traffic emissions, we organized several campaigns for collecting vehicle data. A second step, we used our new EI model EMISENS (in chapter 3) to generate an EI for HCMC

As the road traffic is the main emission source in HCMC. In the framework of this section 4.3 we generated EI for only road traffic.

4.3.1 Methodology

The following Figure 4.2 shows an outline of the process of generating an EI for HCMC where the input data is limited and using the EMISENS model. The EMISENS model was presented in chapter 3.

This process can also be applied for other cities than HCMC.

(I) We collected the necessary data: minimum information to compute emission, estimation of the variability of the parameters (use the literature, other EI, existing data from HCMC, etc.).

(II) We run the EMISENS model with variable parameters in one cell.

(III) Results of model are a list hierarchy of standard deviation (σ_{E_j}) due to input uncertainties, for example:

Input parameters	σ_{E_Unc}
H_1: emission factors	-
H_2: vehicle number	-
H_3: temperature	-
H_n : ...	-

Then, we analyse the results to identify the parameters which generate the maximum of variability in the EI.

(IV) After the determination of the most sensitive parameters, we try to find more information of these parameters and will conduct additional campaigns to reduce the level of uncertainties of these parameters. We rerun the EMISENS model to revaluate the standard deviation of the emissions.

(V) Identification of the parameters that generate significant standard deviation in space and in time and generate a spatial and temporal distribution of these parameters.

(VI) We run the EMISENS model for each cell (run the model with parameters variable in all cells of the grid).

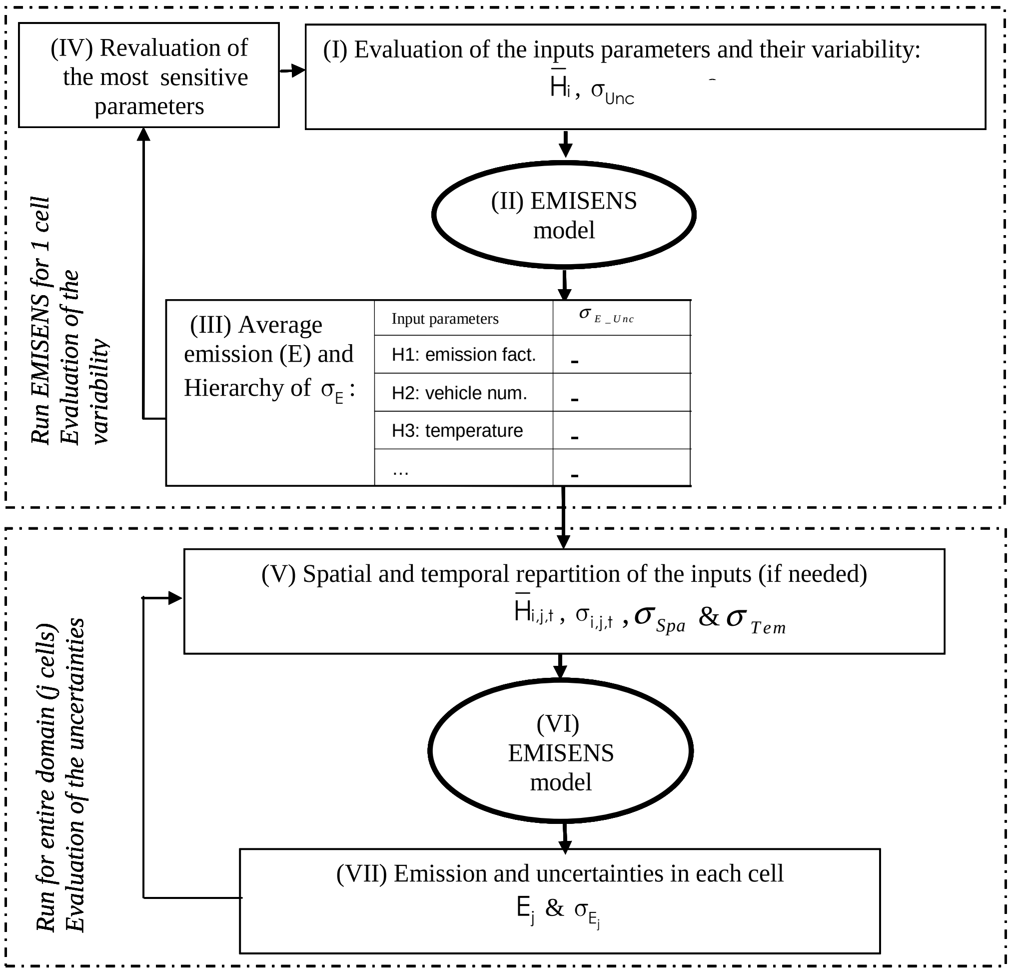

Figure 4.2: Research process outline ($\overline{H}_i$ is the average value of input parameters. σ_{Unc}, σ_{Spa} and σ_{Tem} are the standard deviation of the input parameters due to the uncertainties, the spatial and temporal variability, respectively. The σ_{E_Unc}, σ_{E_Spa} and σ_{E_Tem} are the standard deviation of the emissions due to variability of the input parameters. The E_j & σ_{E_j} are the emission and their standard deviation for each cell.

(VII) Results of model are the emissions of each pollutant for each cell including its uncertainties (E_j and σ_{E_j}).

4.3.2 Input data

The air quality of HCMC is controlled by Ho Chi Minh environmental protection agency (HEPA). However, the research on air quality for HCMC is mainly studied by Institute of Environment and Resources (IER), Vietnam national university in Ho Chi Minh City (VNU-HCM). The database for air quality studies in HCMC is still limited because there have not been a lot of research conducted for this city. The only available source of data or other information about this city are the reports on air quality from monitoring activities and some research conducted by master student of VNU-HCM.
Within the framework of this study, several campaigns were organized which focused mainly on the on-road traffic activities (vehicle fleet, traffic flow, etc.) using different methods.

Traffic counts

As there were not have enough cameras available for traffic counting, the traffic flow was manually counted by students in different streets. For the counting of traffic flow, we could not divide the vehicles into vehicle legislations (Car_Euro I, Car Euro_II...) so we have grouped the vehicles by vehicle category for counting.
- *Definition of vehicle categories*: the vehicles were grouped into 5 categories, namely car (all the passenger car and private car), light truck (less than of equal to 2.5 ton), heavy truck (greater than 2.5 ton), bus (urban buses and coaches) and motorcycle (including 2 strokes and 4 strokes)
The street network in HCMC has more than 1350 segments and the total street length is 3047km (HEPA, 2006). We could not count the traffic flow for of all the streets in HCMC because the street situation changed very quickly and we did not have enough funding for it. Our solution was to group the streets into different street categories.
- *Definition of street categories*: the streets were grouped in 3 main street categories (highway, rural and urban street) based on the speed and function of the street. For the

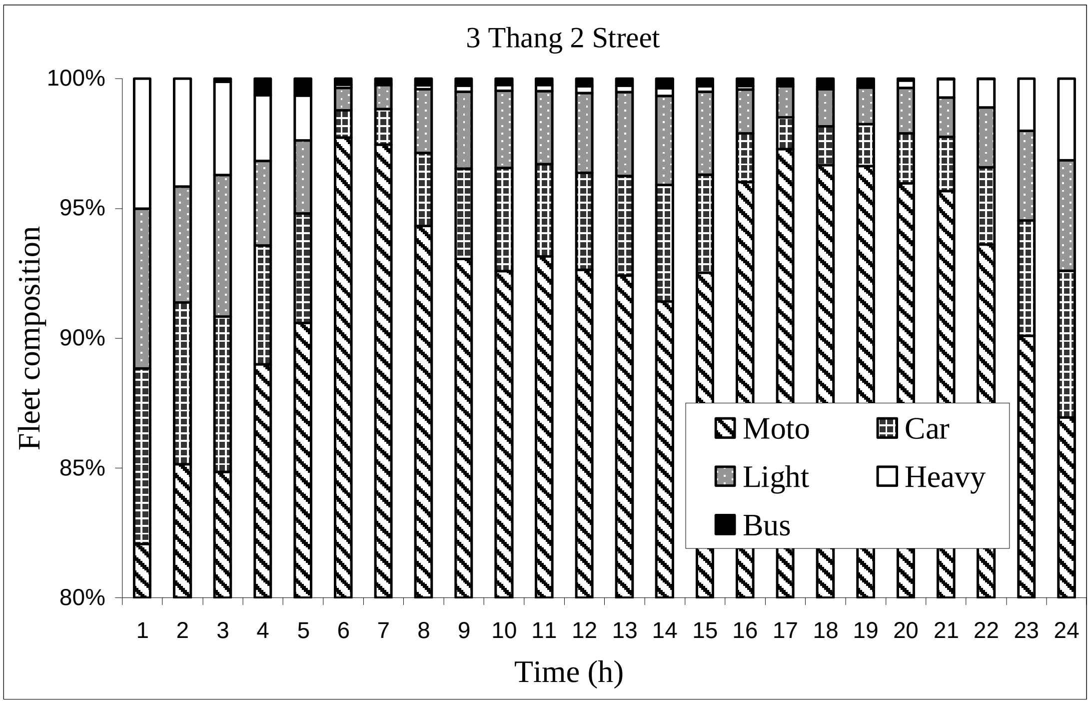

Figure 4.3: Daily variations of the fleet composition at 3 Thang 2 street (urban street category).

urban streets we subdivided the urban streets into 3 types based on the street function as main urban streets, sub urban streets and streets in industrial zones.

To count the vehicle flow, we collected the data such as traffic flow, street name, street length, vehicle speed and street width for the workdays. The traffic flow on 170 streets which are spread throughout all the districts in HCMC was counted. Traffic counts were performed for each interval of 30 minutes during each hour (e.g. 6:00 to 6:30, 7:00 to 7:30, etc.) from 1:00 to 24:00 for each street.

Figure 4.3 shows the daily average variation of the fleet composition (in %) at 3 Thang 2 street (urban street category).

The fleet is almost dominated by light gasoline vehicles (motorcycles: 92%, cars: 3.46%, light trucks: 2.8% and buses 0.1%). Only 1.1% of the fleet is made of heavy truck diesel vehicles. The fleet distribution can be assumed the same for all streets in HCMC in the urban category. The fleet composition we have determined is also similar to the fleet of

HOUTRANS project which was counted for the whole city of HCMC (HOUTRANS, 2004).

Survey for the characterization of the vehicles (on road)

We prepared a questionnaire and organized several groups of students to interview the vehicle drivers at different sites in HCMC (in parking, at seaport, in streets etc). The interviews for motorcycles and buses were mainly made in parking. However, for other vehicles the main campaign was in the street where the vehicle stopped because there is not parking for these vehicles in HCMC.

The following information was asked for in the questionnaire:

- Vehicle age
- Vehicle category: Motorcycles (moto), cars (car), buses (bus), light trucks (light), heavy trucks (heavy).
- Fuel type: gasoline, diesel, LPG and compressed natural gas
- Engine size (c.c.) or loading capacity (ton or number of people)
- Mileage of vehicle
- Number of trips per day

The campaign was organized during the year of 2007 and 2008. The number of interviews for each type of vehicle is shown in Table 4.2.

Table 4.2: Number of questionnaires during campaign

Vehicle category	Total vehicle	Number of interview	% (Interview)
Heavy	24333	498	2.05
Light	45116	605	1.34
Bus	28442	565	1.99
Car	347242	989	0.28
Moto	2895831	1438	0.05

Some results of the campaign are shown in the Figure 4.4. This Figure describes the distribution motorcycle age. We can conclude that motorcycles currently used in HCMC have been produced in recent years (more than 32% of motorcycles are produced less than 1 year and about 94% of motorcycle are produced less than 10 years) and more than 98% are the 4 strokes motorcycles. The main fuel used by motorcycles is gasoline. In spite of the fact, that most of motorcycles used in HCMC are not very old, they are a

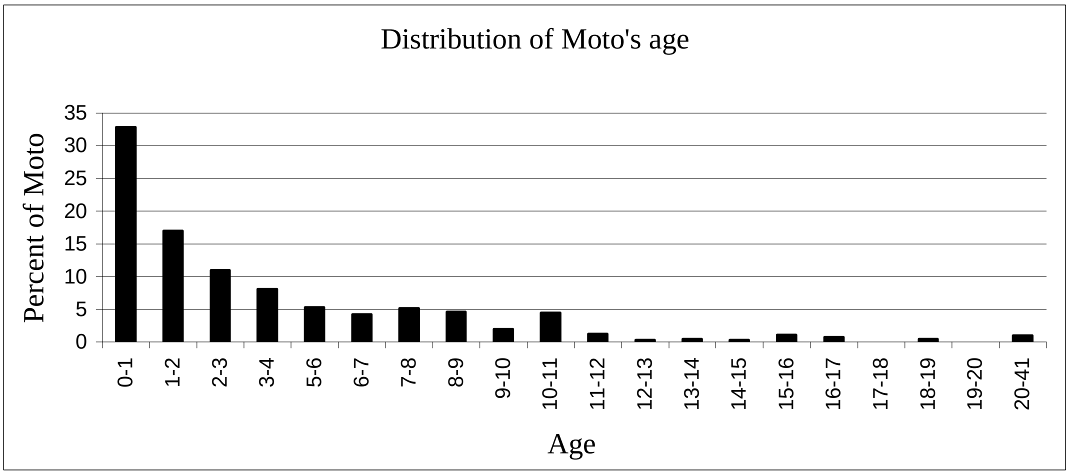

Figure 4.4: Distribution of Moto’s age in HCMC.

major producer of pollution. The reason is that they are manufactured by low standard technology (older than EURO II standard). The largest fraction of the motorcycles are imported from China and Taiwan which are very cheap in price and easily meet the requirement of the local people according to their purchasing power.

The survey further revealed that there are more than 25% cars which are less than 1 year old and more than 70% cars which are less than 4 years old. More than 98% cars use the gasoline for fuel and the rest of cars use the diesel oil.

Figure 4.5 shows the distribution of gasoline car legislation to which the cars in HCMC adhere. It shows that about 97% of the cars in HCMC adhere to the EURO IV and EURO III legislation. The cars contrast the findings concerning the motorcycles in terms of pollution. The main reason is that car manufacturers have to follow global standards for manufacturing. Thus, if most of the cars are of recent manufacture, there will be less pollution.

Concerning the light trucks and the buses, half of these vehicles use gasoline and the rest use the diesel fuel. The heavy trucks use only diesel fuel. The survey results indicate that

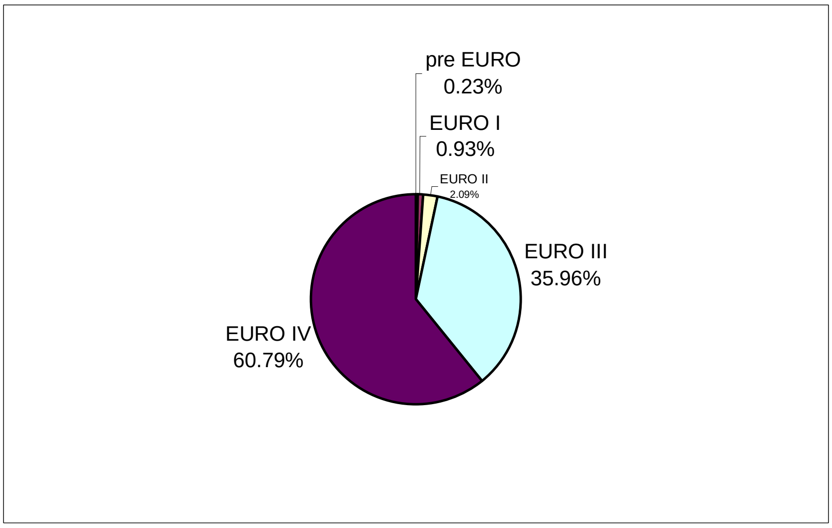

Figure 4.5: Distribution of the gasoline car legislation.

in general the light trucks, buses and heavy trucks used in HCMC are produced in recent years.

Emission factors (EFs)

The three sources of road traffic EFs considered in this study are given below:

- The EFs calculated by an inverse estimation from in-street measurements of pollution in HCMC (Belalcazar et al., 2009; Ho et al., 2008).
- The EFs of China (DOSTE, 2001).
- The EFs calculated for HCMC using the Copert IV methodology.

Table 4.3: The EFs (in $g.km^{-1}.vehicle^{-1}$) from three sources (China, HCMC and Copert IV)

Pollutant	Source	Moto	Car	Light	Bus	Heavy
NO_x	Copert IV	0.155	0.116	0.677	3.16	8.81
	China	0.23	0.3	0.69	6.1	20.29
	HCMC	0.05	1.9	1.9	19.7	19.7
CO	Copert IV	9.18	0.372	4.50	13.57	2.17
	China	17	3.8	16.09	2.51	14.96
	HCMC	21.85	34.8	34.8	11.1	11.1
SO_2	Copert IV	-	-	-	-	-
	China	0.03	0.18	0.05	1.86	1.86
	HCMC	-	-	-	-	-
NMVOC	Copert IV	0.999	0.0239	0.305	1.60	0.689
	China	11.8	0.4	0.5	1.12	6.69
	HCMC	2.34	15.02	15.02	89.92	89.92
CH_4	Copert IV	0.115	0.0031	0.0176	0.077	0.0619
	China	-	-	-	-	-
	HCMC	-	-	-	-	-

Note: - = value not reported

Table 4.3 shows the road traffic EFs for 5 vehicle categories (motorcycle, car, light truck, bus and heavy truck). The EFs of China give no value for CH_4. The EFs of Copert IV give no value for SO_2. While the EFs of HCMC give no value for SO_2 and CH_4. So it is not possible to use only one source of EFs for this research. The selected of EFs used for this study are explained in section 4.3.3.

In general, the EFs are different among three sources. The EFs of China are close to the EFs of HCMC. The EFs of HCMC are in general larger than the EFs of Copert IV (e.g. 100 times in case of CO for heavy truck), except for the case of NO_x (HCMC's EFs for motorcycle are lower than Copert IV by factor of 3.0). Detailed information on EFs and possible explications for the differences among the three sources are given in section 4.3.3.

4.3.3 Calculation of the total emission

a) Three street categories

Following the methodology outlined in Figure 4.2, we first run the EMISENS model for the whole city as one cell. As it is the first study on generating emission of road traffic source, the available data for this study is limited (as discussion in section 4.3.2). We made the following hypotheses for applying the EMISENS model:

Hypotheses

- The EFs are based on 5 vehicle categories. We grouped all kind of vehicles into 5 vehicle categories (heavy truck, light truck, bus, car and motorcycle). The composition of each vehicle category is constant for the whole region considered.
- The activity is based on 3 street categories. The categories are highway, rural street and urban street.
- As the EFs are a function of the velocity of the vehicle, we consider that the velocity is constant on each street category and constant in time. Therfore the EFs are constant in each street category and also constant in time.

Emission factors

Three sources we have been used for the computation of the EFs, they are the following:

<u>Copert IV database:</u>

The vehicle fleet compositions which were collected in a previous survey were used to calculate the EFs in using the Copert IV methodology (section 3.2.4 of chapter 3). The average EFs are calculated for 5 vehicle categories and for different speed ranges (each speed range corresponding to a street category). The EFs were calculated for NO_x, CO, NMVOC and CH_4, but not for SO_2 (since SO_2 is not mentioned in the Copert IV methodology). It is important to note that the Copert IV methodology is normally used to calculate the EFs for European countries.

<u>Measurement in laboratory:</u>

Average EFs of China were calculated for 5 vehicle categories in another study (DOSTE, 2001). These EFs were directly calculated by laboratory measurements. The EFs were calculated for NO_x, CO, NMVOC and SO_2, but not for $CH_{4.}$

<u>Experiment study in a street canyon:</u>

Another study computed EFs for HCMC (Belalcazar et al., 2009; Ho et al., 2008) by using the new method which is based on a long term tracer experiment. The authors used the inverse application of a dispersion model within a street canyon with a high traffic density, which is representative of general driving conditions and fleet circulating in

HCMC. This methodology allows us to estimate hot emissions within the street canyon for 3 pollutants (NO_x, NMVOC and CO). EFs were computed for three main vehicle categories: motorcycle, light vehicle (car and light trucks) and heavy vehicle (heavy truck and bus).

The EFs from the three different sources are shown in Table 4.3. The differences of emissions factors from three sources can partly be explained by the different quality of fuel and the maintenance of vehicles. The motorcycle's engines are not regularly maintained in Vietnam and more than 60% of the motorcycles in Hanoi and in HCMC exceeded the emissions standard (Trinh, 2007).

We evaluated the EFs from the 3 different sources. The main EFs which were used in this study are the EFs from "experiment study in a street canyon" (NO_x, NMVOC and CO). However, there is no data available for the EFs of SO_2 and CH_4 for HCMC. So we used the emission factor of SO_2 from China because the characterizations of China's vehicles are similar to HCMC. For the emission factor of CH_4, we unfortunately had to use the emission factor of CH_4 from Copert IV. The EFs and their uncertainties which were used in this study are shown in Table 4.4.

Table 4.4: EFs (in $g.km^{-1}.vehicle^{-1}$) and their uncertainty

Vehicle	NO_x [a]	CO [a]	SO_2 [b]	NMVOC [a]	CH_4 [c]
Motorcycle	0.05±0.02	21.8±8.67	0.03±0.015	2.34±1.17	0.115±0.121
Bus	19.7±5.2	11.1±5.3	1.86±1.08	89.9±33.01	0.077±0.051
Light	1.9±0.9	34.8±15.5	0.05±0.029	15.02±7.36	0.017±0.018
Heavy	19.7±5.2	11.1±5.3	1.86±1.08	89.9±33.01	0.062±0.041
Car	1.9±0.9	34.8±15.5	0.18±0.105	15.02±7.36	0.0031±0.0032

Source:

[a]: the EFs were calculated for HCMC (Belalcazar et al., 2009; Ho et al., 2008)

[b]: the EFs of China (DOSTE, 2001)

[c]: the EFs were calculated from Copert IV.

Uncertainty of the input parameters

In order to estimate the uncertainty of the resulting EI due to input parameters, the uncertainty of each of the input parameters is estimated, computed or collected from different sources. For some parameters the uncertainty has been pre-calculated since the input parameters differ from the data we have available. For example, in the EMISENS model, the input parameter requested is hourly street mileage rather than the vehicle flow, so we have pre-calculated the uncertainty for hourly street mileage (Δ_{FL}):

$$(F+\Delta_F)(L+\Delta_L) = FL + F\Delta_L + L\Delta_F + \Delta_F\Delta_L \tag{4.1}$$

$$\Delta_{FL} = F\Delta_L + L\Delta_F + \Delta_F\Delta_L$$

where: F and L are the vehicle flow and street length, respectively.

Δ_F and Δ_L are the uncertainties of vehicle flow and street length, respectively.

Results

The results of the EMISENS model are shown in Table 4.5. The total emission for each pollutant is in ton per hour. The total relative uncertainty is given in the rightmost column of the Table.

Table 4.5: The average of emission and their total uncertainties of all parameters

Pollutants	Total emissions [ton h^{-1}]	Total uncertainties (%)
NO_x	6.44	31.00
CO	494.0	47.22
SO_2	1.40	42.67
NMVOC	74.20	43.76
CH_4	2.95	77.27

The relative uncertainties range from 31% for NO_x to 77% for CH_4. The uncertainty of the computed emissions is very high. Other studies have estimated the uncertainties of NMVOC and NO_x were around 40% and 37% of total emission in West Germany, respectively (Kühlwein and Friedrich, 1999). For improving the accuracy of EI, we need to reduce the level of uncertainties of the input parameters. In order to do this efficiently, we first have to find out which parameters contribute most to the uncertainty. The results of the EMISENS model also give the hierarchy of uncertainty as shown in Table 4.6.

Table 4.6: The percentage of uncertainties of each input parameter (with the greatest uncertainties) on total emission

NO_x		CO		NMVOC		CH_4	
Parameters	%	Parameters	%	Parameters	%	Parameters	%
FL_Heavy_Urban	16.66	FL_Moto_Urban	44.42	FL_Moto_Urban	28.08	EF_Moto_Urban	59.89
FL_Car_Urban	10.75	EF_Moto_Urban	29.42	EF _Moto_Urban	26.25	FL_Moto_Urban	47.98
FL_Moto_Urban	10.72	ColdFL_Moto_Urban	10.3	beC1_Car_Urban	7.36	ColdFL_Moto_Urban	25.53
FL_Bus_Urban	9.99	FL_Moto_Rural	6.08	FL_Heavy_Urban	6.56	FL_Moto_Rural	6.47
FL_Light_Urban	9.63	beB_Moto_Urban	4.07	FL_Car_Urban	6.52	EF_Moto_Rural	4.74

Note:

- *FL_Heavy_Urban: is the hourly street mileage* $[Flow \times Street\_length]$ *for the heavy trucks on urban street category.*
- *EF_Moto_Urban: is the hot emission factor for the motorcycles on urban street category.*
- *ColdFL_Moto_Urban: is cold hourly street mileage* $[\beta eta \times Flow \times Street\_length]$ *for the motorcycles on urban street category*
- *beB_Moto_urban and beC1_Car_Urban: are the parameters for calculating the cold emissions for the motorcycles and the cars, respectively, on the urban street category.*

Table 4.6 shows that the most sensitive parameter is the hourly street mileage for the urban street category. The motorcycles have the largest impact on the uncertainty. In the case of NO_x, the most sensitive parameter is the hourly street mileage of the urban street category. For example, the uncertainties of hourly street mileage for heavy truck, car and motorcycle are 16.66%, 10.75% and 10.72% of the total emissions, respectively.

For CO, NMVOC, CH_4 and SO_2, the hourly street mileage of motorcycles on urban streets is also the most important parameter for the uncertainty (e.g. the uncertainty of hourly street mileage of motorcycle on urban street is 59.89% of total emission of CH_4).

b) Five street categories

In order to improve the previous result, we analyse and reorganize the data of hourly street mileage of the urban street category.

We sub-divide the urban street category into 3 urban street categories according to the street function (i) urban main street (Urban_main); (ii) urban secondary street (Urban_sub) and (iii) urban street in industrial zone (Urban_ind). The rural and highway street categories are kept the same as in the previous calculation. Figure 4.6 shows the repartition of the motorcycle flow to the 3 urban street categories.

The repartition in Figure 4.6 shows that there are three zones separately for 3 urban street categories. Their averages are also quiet different for 3 urban street categories.
From Figure 4.6, we deduce that if we divide the original urban street category into 3 urban street categories, the uncertainty of vehicle flow in each urban street category will be reduced. For example, the uncertainty of motorcycle flow using only one urban street category is 48% of the motorcycle flow. But the uncertainties of motorcycle flow for urban_main, urban_sub and urban_ind categories are 32.5%, 31.7% and 4.73%, respectively.
We assume that the EFs of the 3 urban streets categories are the same to the EFs of the urban street category in section 4.3.3 (a).

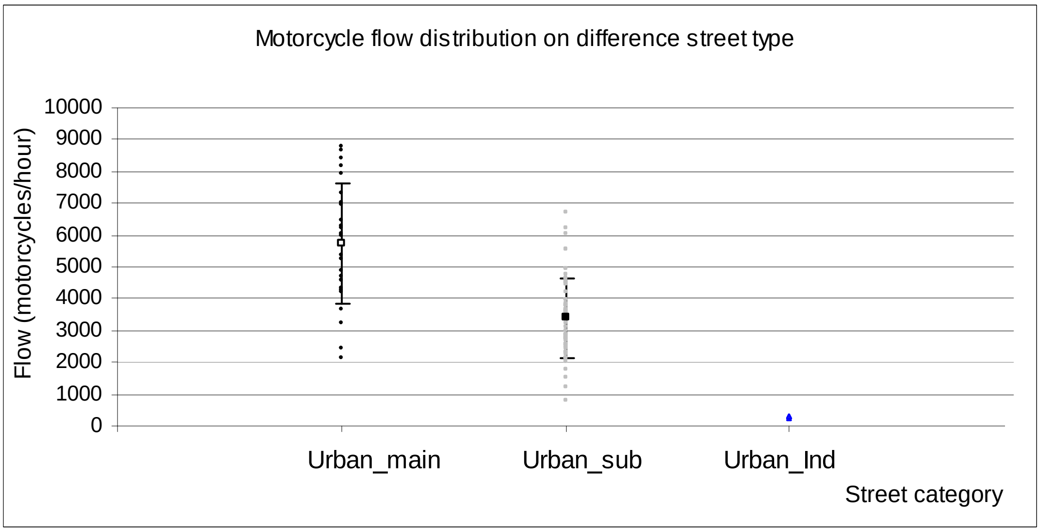

Figure 4.6: Repartition of motorcycle flow on 3 urban street categories: urban main street (Urban_man), urban secondary street (Urban_sub) and urban street in industrial zone (Urban_Ind). Each point presents motorcycle flow on each street.

The EMISENS model was rerun to re-evaluate the attribution of uncertainties of the input parameters, especially concerning the three newly introduced urban street categories. Other input parameters are kept the same as in the previous calculation. Results are shown in Table 4.7.

Table 4.7: The average of emission and their total uncertainties of all parameters

Pollutants	Total emissions [ton h^{-1}]	Total uncertainties (%)
NO_x	3.44	19.56
CO	331.4	33.77
SO_2	0.733	27.09
NMVOC	46.24	27.55
CH_4	2.04	49.66

We found that when we divided the urban street category into 3 urban street categories, the total uncertainties on total emission reduced significantly as shown in Table 4.5 and Table 4.7. The levels of uncertainty are reduced by 30% to 40% depending on the pollutant type.

Table 4.8 shows the percentage of uncertainties of each input parameters on the total emissions.

Table 4.8: The percentage of uncertainty of each input parameters (with the greatest uncertainties) on total emission

NO_x		CO		NMVOC		CH_4	
Parameters	%	Parameters	%	Parameters	%	Parameters	%
FL_Heavy_Highway	6.48	FL_Moto_M_U	15.9	EF_ Moto_M_U	14.13	EF_ Moto_M_U	29.06
FL_Heavy_M_U	5.93	FL_Moto_S_U	14.97	EF_ Moto_S_U	13.61	EF_Moto_S_U	27.98
FL_Moto_M_U	4.82	EF_ Moto_M_U	14.72	FL_Moto_M_U	10.81	FL_Moto_M_U	16.66
ColdFL_Moto_M_U	4.55	EF_ Moto_S_U	14.17	FL_Moto_S_U	10.18	FL_Moto_S_U	15.68
FL_Moto_S_U	4.53	FL_Moto_Rural	9.06	FL_Moto_Rural	6.15	ColdFL_Moto_M	12.39

Note:

- *FL_Heavy_Highway: is the hourly street mileage* $[Flow \times Street\_length]$ *for the heavy trucks on highway category.*
- *FL_Heavy_M_U: is the hourly street mileage* $[Flow \times Street\_length]$ *for the heavy trucks on main urban street category.*
- *FL_Moto_M_U: is the hourly street mileage* $[Flow \times Street\_length]$ *for the motorcycles on main urban street category.*
- *FL_Moto_S_U: is the hourly street mileage* $[Flow \times Street\_length]$ *for the motorcycles on secondary urban street category.*
- *ColdFL_Moto_M_U: is cold hourly street mileage* $[\beta eta \times Flow \times Street\_length]$ *for the motorcycles on main urban street category*
- *EF_Moto_M_U: is the hot emission factor for the motorcycles on main urban street category.*

Table 4.8 showed that the uncertainties of the most sensitive parameters are reduced significantly compared to the Table 4.6, especially the hourly street mileage of motorcycle on urban street reduced up to 16%.

Comparing the results from Table 4.6 and Table 4.8 we deduce that there is a clear benefit of sub-dividing the street network in 5 street categories rather than 3 street categories.

4.3.4 Temporal and spatial distribution

In this section, we identify of the parameters which generate significant uncertainty for spatial and temporal distribution.

Identification of the input parameters for spatial and temporal distribution

The results show that the hourly street mileage and the EFs are the parameters which are responsible for the largest part of the uncertainty in the resulting EI.

In this study we assume that the EFs are constant in each street category and that they are also constant in time.

Consequently, the parameters which have to be distributed on space and time are:

- The hourly street mileages (temporal and spatial distribution)
- The number of vehicles which are used to generate the evaporation emissions (spatial distribution)
- The number of trips per vehicle category which are used to generate the evaporation emissions (spatial distribution).

The main equation to calculate the road traffic emissions is presented in section 3.2.4 of chapter 3. The emissions ($E_{Iv,Is}$) depend on the EFs ($e_{Iv,Is}$) and the activities ($A_{Iv,Is}$) of the vehicle category (Iv) of the street category (Is): $E_{Iv,Is} = e_{Iv,Is} A_{Iv,Is}$. The EFs are assumed constant in same street category (spatial) and constant in time.

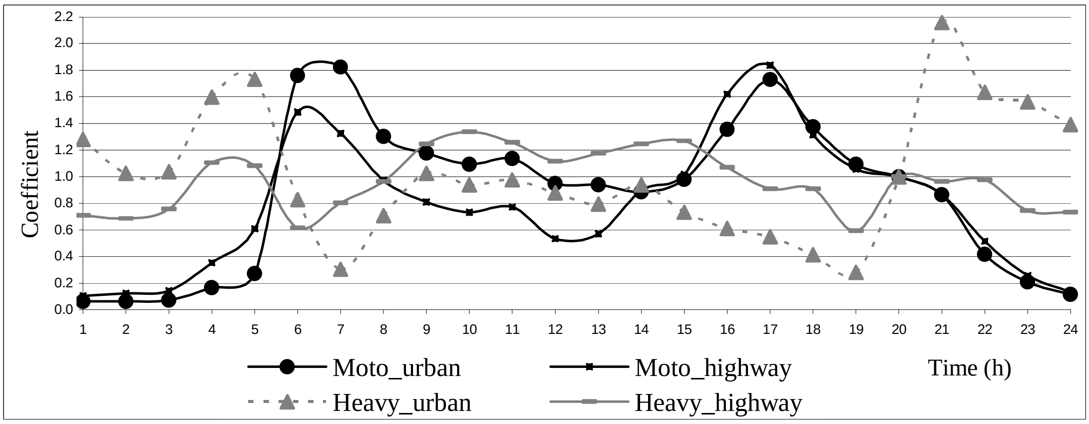

Figure 4.7: Normalized hourly distribution of Motorcycles (Moto) and Heavy trucks, per urban and highway street category. A factor of 1.0 is attributed to the hour between 1900LT and 2000LT to both categories of streets, for a working day.

The activities ($A_{Iv,Is}$) depend on vehicle flow in specific street categories ($F_{Iv,Is}$) and the length of those street categories (L_{Is}): $A_{Iv,Is} = F_{Iv,Is} L_{Is}$

The main parameters for temporal and spatial distribution are the activities of traffic ($A_{Iv,Is}$).

Temporal distribution

The vehicle flows from existing traffic counts were analysed to derive the temporal distribution. We compute the hourly coefficients of traffic circulation for each street and vehicle category. We choose the coefficient for the hour between 1900LT and 2000LT to have a factor of 1. As for example, the temporally distributed factors for heavy trucks and motorcycles during 24 hours in the urban street category are shown in Figure 4.7.

Figure 4.7 shows that the peak of motorcycle flow occurs around 600LT to 800LT in the morning and at 1600LT to 1800LT in the evening. These correspond to the rush hours in the morning and evening when people go to their work place in morning and return to their homes after finishing their work in the evening. The peak of heavy truck flow is measured at 400LT to 500LT in the morning and at 2000 LT to 2200LT in the evening because the heavy trucks are not allowed to circulate in the center of the city during the morning (from 600LT to 830LT) and the evening rush hours (from 1600LT to 2000LT).

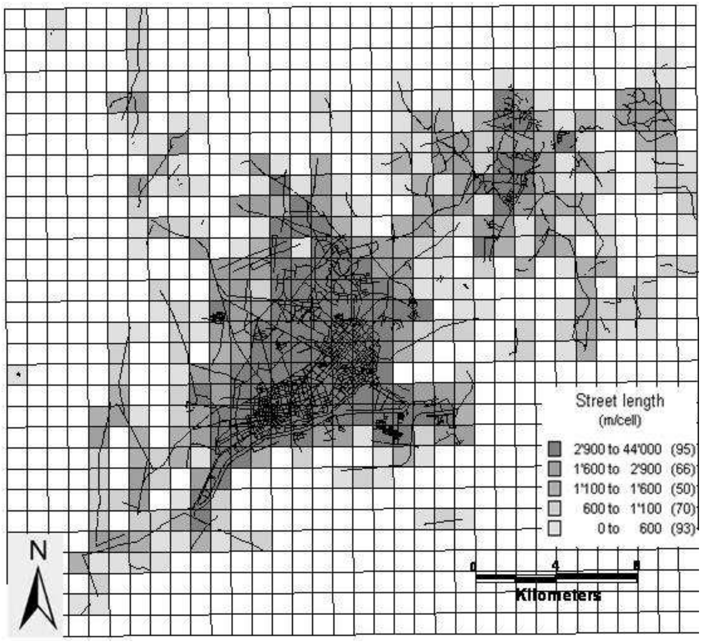

Figure 4.8: The network of urban streets category in the study domain. The different colour is the number of kilometres of street length per cell. The numbers in parentheses is the number of cells.

Spatial distribution

The spatial distributions are based on the length of each street category (L_{Is}) in each cell of study domain. The MapInfo software is used to distribute the parameters spatially.
Firstly, we extract the road network map into different maps. Each map corresponds to a street category. Then, we compute the street length in each cell of the study domain. An example for calculating the street length in the case of urban street category is shown in the Figure 4.8.
As expected, Figure 4.8 shows that most of the urban streets are concentrated in the districts of central HCMC.

Results

Finally, we run the EMISENS model for all cells of study domain. The outputs of the model are the emissions and their uncertainties in each cell (Figure 4.9, Figure 4.10,

Figure 4.11 and Figure 4.12). For each pollutant, the emissions are calculated for each cell per hour. The results of CO in Figure 4.9 show that most of the emissions occur in the center of the city where we can see the highest of street density of urban streets. In contrast, in the uncertainty map (Figure 4.10) the lowest uncertainties occur in urban streets in the city center. Because we sub-divided the urban streets into three urban street categories, the uncertainty for urban streets considerably is reduced. However, we get high uncertainty in main road (high way and rural street categories) because the vehicle flow of these street categories is high uncertainty.

The results of NMVOC are shown in Figure 4.11 and Figure 4.12. The patterns of the emissions and uncertainty map for NMVOC and other pollutants are similar to the one of CO. However, the magnitude of values is different from pollutant to pollutant.

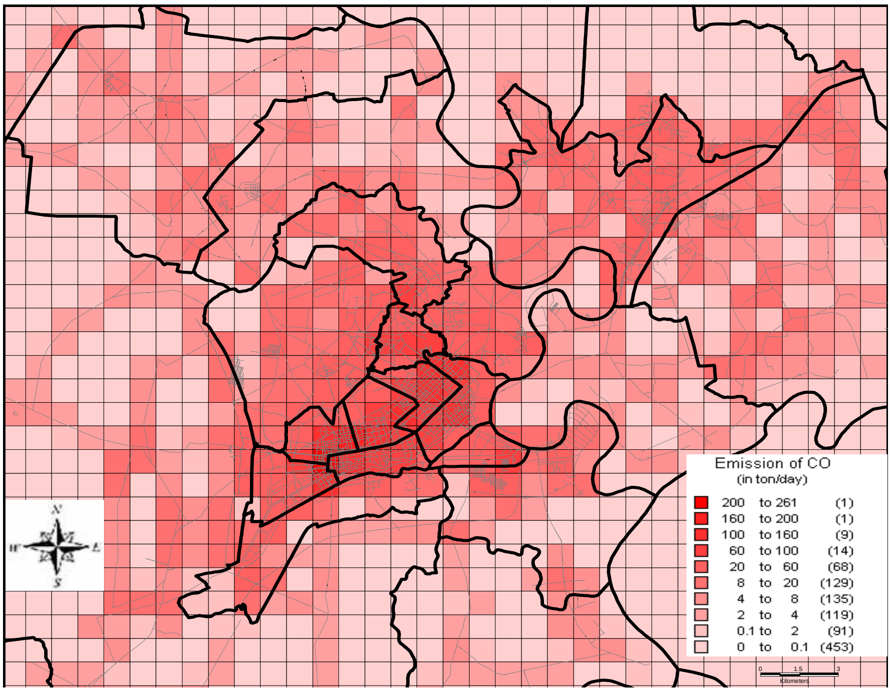

Figure 4.9: The traffic emission map of CO. The contour of the districts (black colour) and the street network (grey colour). The numbers in parentheses are the number of cells.

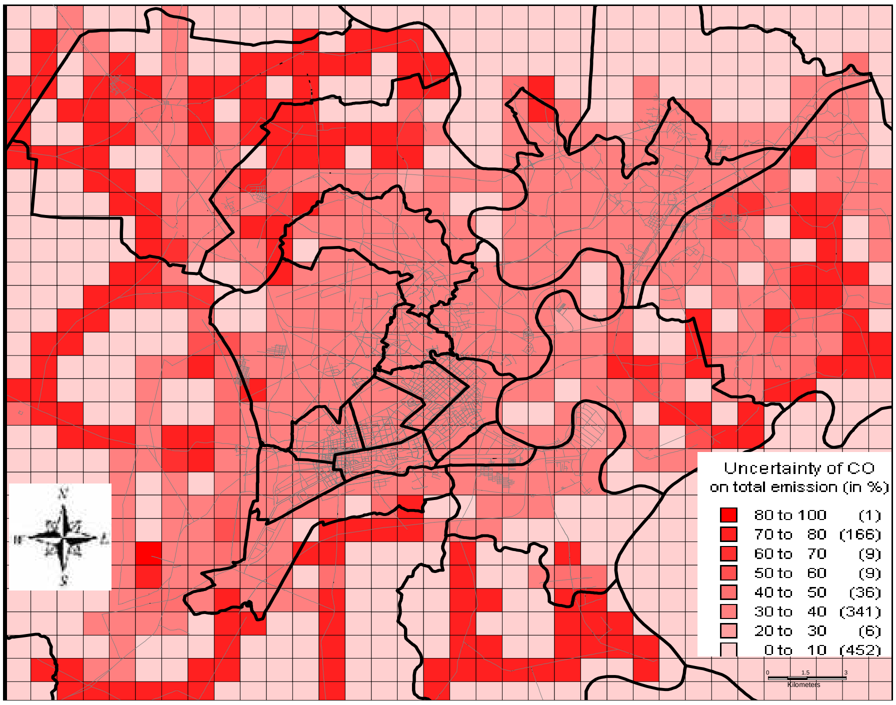

Figure 4.10: The uncertainty map of CO. The contour of the districts (black colour) and the street network (grey colour). The numbers in parentheses are the number of cells.

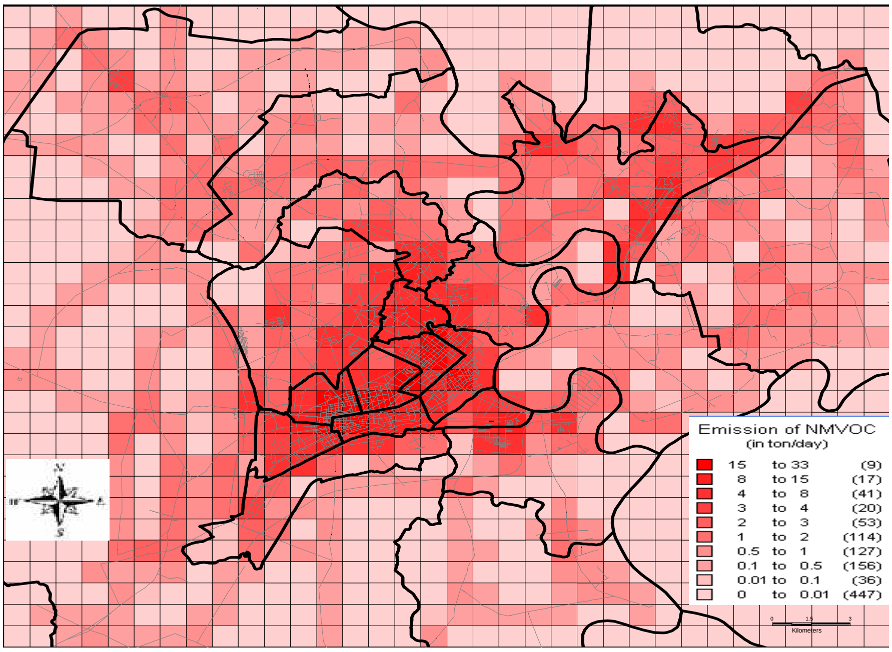

Figure 4.11: The traffic emission map of NMVOC. The contour of the districts (black colour) and the street network (grey colour). The numbers in parentheses are the number of cells.

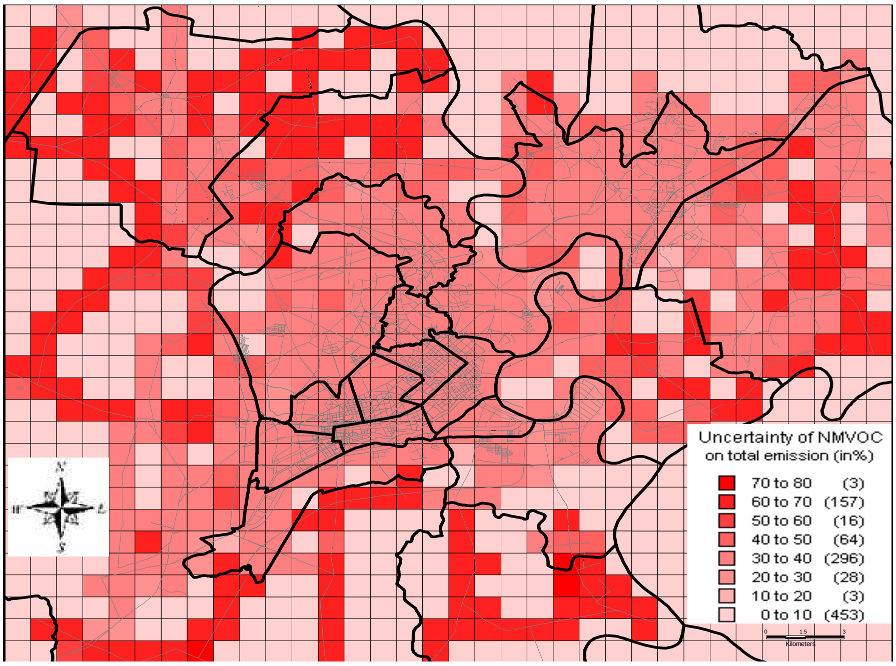

Figure 4.12: The uncertainty map of NMVOC in space. The contour of the districts (black colour) and the street network (grey colour). The numbers in parentheses are the number of cells.

4.4 Other sources

4.4.1 Industrial sources

The industry is second most important source of atmospheric pollution in HCMC (Ho et al., 2006; Nguyen et al., 2002). The city spans only 0.6% of the whole country's area but more than 20% industrial producing capacity and 40% industrial output of whole country (Nguyen, 2002) is located in HCMC. The main industries in HCMC are thermo-electricity, cement production, steel lamination and refinement, weaving and dying, food processing and chemistry. The existing information for industries is very poor and an official detailed database does not exist. Most of the industries in HCMC have the following characteristics:

- The factories are old and their operation times are over 20 years.
- They have old technology which is imported from Soviet Union.
- The engines consume much energy and fuel due to old and poor quality engines. The fuel used is of a low quality.

The above list mentions the major characteristics of a majority of the industries in HCMC. In this study, the emissions from industrial sources are calculated by using a top-down approach. Starting from the total emissions in Vietnam (Table 4.9) and the percentage of distribution of pollutants in different sectors in Vietnam (Figure 4.13), we estimate the yearly industrial emissions for Vietnam. The industry of HCMC accounts for 20.2% of the total industrial emissions of Vietnam (HCMC statistics, 2003).

Table 4.9: Total emission in Vietnam

Pollutants	Total Emission (Tg/year)
SO_2	0.193
NO_x	0.283
CO_2	169.200
CO	9.248
CH_4	2.907
BIO NMVOC	1.037
ANT NMVOC	1.168
COVNM total	2.205

Sources: Mics-Asia, 2000 (1 Tg = 10^6 ton).

Note:
- BIO NMVOC: NMVOC Biogenic
- ANT NMVOC: NMVOC Anthropogenic

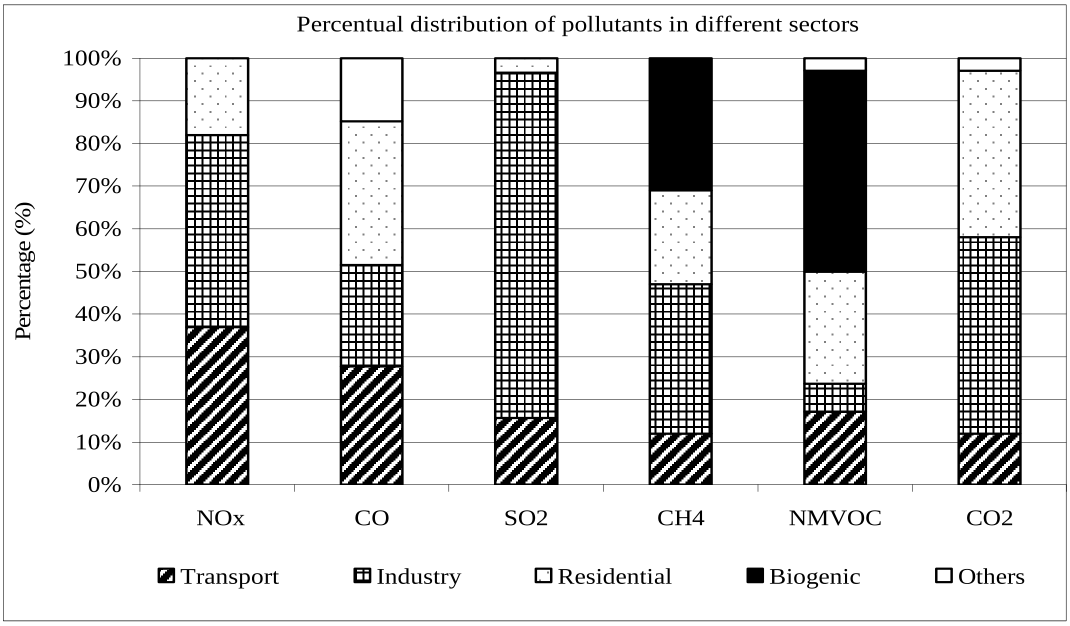

Figure 4.13: Percentage of distributions of pollutants in different sources in Vietnam.

The total emissions of Vietnam are shown in Table 4.9. These values were estimated by Mic-Asia project from all sources of emission in Vietnam. The project also estimated the contribution of different emission sources (Figure 4.13)

Figure 4.13 shows that the main emission sources in Vietnam are transport and industries depending on the pollutant type.

Temporal distribution

The results of the air quality monitoring program in south of Vietnam conducted by the Institute of Environment and Resources (IER, 2006) were used to estimate the monthly, daily and hourly coefficient distribution of industrial emissions in HCMC (Figure B.4.1, B.4.2 and B.4.3 in the annex). The results show that November is the most polluted month because it is the post-rainy season in HCMC. During this time period, all the companies want to complete their already planned targets of products for the specific year. So the companies utilize the maximum of the available resources and run their industries at full capacity to meet their targets. On a weekly basis, Friday is the day of the week with largest emissions as it suffers maxima of pollution at 0900LT in morning and 1400LT in afternoon.

Spatial distribution

The spatial distribution of industrial emission sources is estimated by using the population density in each cell because in HCMC the industry is mainly located in residential area. We also used the GIS software for distributing the emissions spatially.

4.4.2 Residential sources

The main emission sources of residential areas are anthropogenic, which are mainly caused from the gastronomic activity at the residences and restaurants in HCMC. Natural gas is the major source of domestic fuel and is mainly used for cooking purposes. However, there are many small restaurants in HCMC which still use the fossil coal. The pollutants such as SO_2 and CO are mainly produced by the burning of this fossil fuel (Dinh, 2003).

Temporal distribution

We estimated the monthly, daily and hourly coefficients for the temporal distribution of residential emissions in HCMC by using the data of the air quality monitoring program in south of Vietnam conducted by the IER (IER, 2006). Figure B.4.1, B.4.2 and B.4.3 of the annex show that December is the most polluted month of the year. This is because December is the start of hot season in HCMC. Saturday is the most polluted day of the week because of the weekend. Normally people cook more dishes on weekend than normal days of the week. The maximum pollution is measured at 1100LT on Saturday which is corresponds to lunch time in HCMC.

Spatial distribution

The spatial distribution of residential emission sources on each cell of study domain is also estimated using the population density in each cell.

4.4.3 Biogenic sources

Only volatile organic compounds (VOCs) are calculated for biogenic emission sources. The biogenic EI are very important for air quality modeling because biogenic VOCs contribute significantly to the formation of ozone (Varinou et al., 1999; Rappenglück et al., 2000, Moussiopoulos, 2003). The largest contribution through biogenic emissions is caused by trees, which emit 10 times more biogenic VOCs as compared to smaller plants. The biogenic VOCs are mainly divided in 3 major pollutants: Isoprenoids, Terpenes and other VOCs (EEA, 1999).

Temporal distribution

The emissions of biogenic VOCs depend on the air temperature and the intensity of solar radiation (EEA, 1999; Rappenglück et al., 2000; Moussiopoulos, 2003). So, the estimation of monthly, daily and hourly coefficient for biogenic source in HCMC is based on the results of solar-radiation measurements (from the urban air quality monitoring of Ho Chi Minh environmental protection agency (HEPA, 2006)). Figure B.4.1, B.4.2 and B.4.3 of the annex show that the highest intensity of solar radiation is in the month of April because the April is in the middle of the hot season in HCMC. Midday is the time when the maximum of radiation intensity is observed.

Spatial distribution

In this study, we estimate the emission for the districts in center of HCMC. We assume that the percentage of green space is similar every where in the domain. The spatial distribution of biogenic emission sources to each cell of study domain is estimated by using the area of each cell.

4.5 Results and discussions

4.5.1 Results of total EI

Table 4.10 presents the results of total EI for all emissions sources in HCMC and the percentage of contribution of each emission source towards the total emissions in HCMC. The column “total emissions” represents the total emissions (in ton per day). The last four columns correspond to the percentage of contribution of each emission source on total EI.

Table 4.10: Total emissions in HCMC [ton day^{-1}] and the contribution of each emission source on the total emissions in HCMC (in %)

Pollutant	Total emissions	Industry (%)	Residential + other (%)	Biogenic (%)	Traffic (%)
NO_x	106.27	15.79	6.46	-	77.75
CO	8860.25	5.45	4.78	-	89.77
SO_2	1603.37	80.42	18.49	-	1.10
NMVOC	1241.45	1.90	8.33	0.38	89.39
CH_4	214.81	27.02	33.19	16.98	22.80

Table 4.10 shows that the emissions of SO_2 (80.42%) from industrial sources are very important. Because the industry in HCMC uses a lot of diesel oil, mazut oil and fossil coal which contain high percentage of sulphur as fuel (Dinh, 2003).

The traffic sources contribute with a high percentage of total emissions (NO_x 77.75%; CO 89.77%; and NMVOC 89.39%). These pollutants play an important role in the production of the secondary pollutant as ozone in HCMC (a further discussion of these secondary pollutants will be presented in chapter 5).

Figure B.4.4 in the annex shows the spatial distribution of the total emissions of NMVOC. The patterns of the total emissions of NMVOC are similar to the emissions of NMVOC by traffic sources (Figure 4.11) because the emissions of traffic occupy more than 89% of total emission in case of NMVOC. The highest emissions are in the city center where we find the highest density streets.

As discussed above, traffic is the most important source of emissions in HCMC and, consequently, will play a central role in any pollution abatement strategy. In order to understand the importance of individual vehicle categories in the road emissions in HCMC, we generated EI for each vehicle category. The results of these EI will be used to design scenarios for reducing the emission in HCMC.

Figure 4.14 shows that the emissions of CH_4, CO, NMVOC, SO_2 and NO_x from the motorcycle category occupy more than 99%, 94%, 68%, 61% and 29%, respectively of total road traffic emissions. The motorcycle category is the most important source of emissions from traffic (except NO_x because the heavy truck category is the most important source of NO_x emissions). The main reason for this is because motorcycles constitute more than 86% of the total vehicles in HCMC. A large number of motorcycles

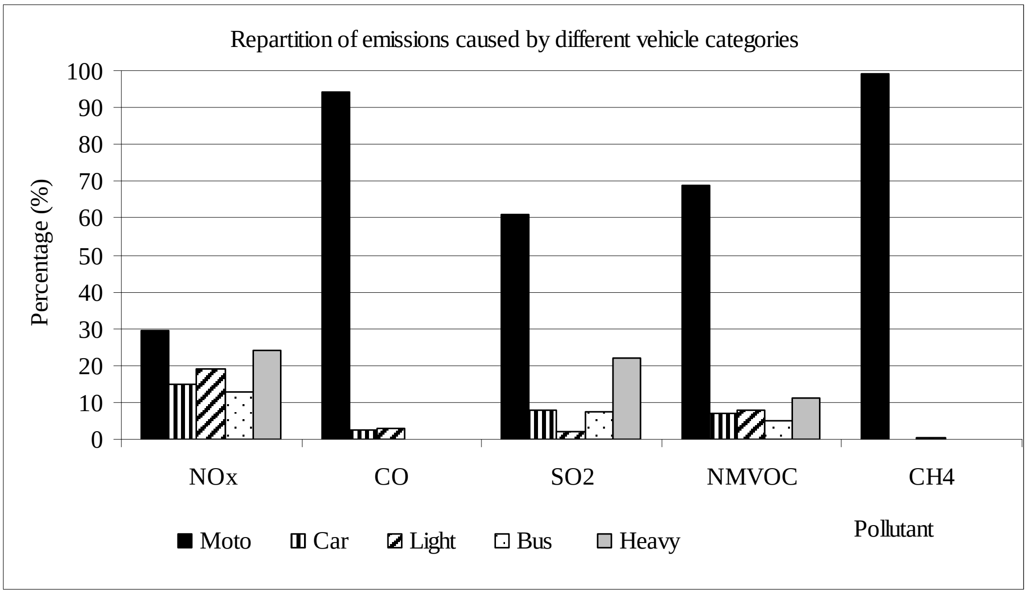

Figure 4.14: The repartition of emissions caused by different vehicle categories.

have low quality engine and are not maintenanced properly and regularly. These values are taken into account in the emissions factors of Ho et al., (2008).

The design of abatement strategies for reducing the emissions in the section 4.5.2 will be focused on the use of motorcycle. For the case of NO_x (mainly from heavy truck source), in the abatement strategies we also included the activity for reducing emission from heavy truck category (such as: control emission of all heavy trucks, etc.)

4.5.2 Abatement strategies of emission

In this section, two emission reduction scenarios were devised for the year 2015 and 2020. The proposed scenarios take into account all changes (the details are shown in each scenario) related to the traffic activities in HCMC.

Emission reduction scenario for 2015

In 2015, the HCMC government will have put into place several measures for controlling air pollution due to road traffic sources (Trinh, 2007). The specific scenario here includes the following measures:

- Control of the emission of all vehicles. The vehicles that do not meet the emissions standards must be upgraded or replaced. This measure will reduce motorcycle emissions by 30%, car emissions by 20% and bus and truck emissions by 19% (Thang, 2004).
- The first metro line will be finished by the end of 2014. In 2015 the metro system will replace 25% of the total number of motorcycles (Bao du lich, 2008).
- The automobiles increase 14.5% per year and the motorcycle increase 5.4% per year, HCMC government will add 3000 buses for the period of 2006-2015 (Tuong, 2005).

Table 4.11: The comparison of emissions between the year of 2006 and 2015

Pollutants	2006 [ton h^{-1}]	2015 [ton h^{-1}]
NO_x	3.443	3.726
CO	331.4	294.5
SO_2	0.733	0.735
NMVOC	46.24	46.27
CH_4	2.041	1.770

Generally, we obtain that the emissions in 2015 will be reduced by an average value of 3.3 % as compared to the emissions of 2006. This means that if HCMC government follows all the above mentioned proposed activities, the emissions in 2015 will be then decrease by 3.3% as compared to the emissions of 2006.

Nevertheless, the emissions of NO_x will increase by around 8% in 2015 as compared to the emissions of 2006. This can be explained by the fact that the EFs of NO_x for the buses are higher than the EFs of the motorcycles by a factor of 394 (Table 4.4). The number of buses in 2015 will increase by 100% as compared to 2006, while the number of motorcycles will increase more slowly than the buses and the number of cars in HCMC is negligible in comparing to motorcycles number. A detailed explanation is given in the discussion of Figure 4.15.

Emission reduction scenario for 2020

This scenario is designed for the year 2020 because in 2020 all of the four metro lines will be finished. In 2020 the metro system will replace 50% of the total motorcycles (Bao du lich, 2008). The other measures are similar to the scenario of 2015 (the automobiles increase 14.5% per year and the motorcycles increase 5.4% per year (Tuong, 2005)) and the number of buses increase by 4500 for period 2006-2020.

If the HCMC government controls the emissions of 2020 as planned, the road traffic emissions in HCMC in 2020 will increase to an average value of 2.5%. The comparison of emissions in the Table 4.12 is divided into two groups. The first group shows the increase of emission up to 2020 (NO_x, SO_2 and NMVOC) and the second group shows the decrease of emission up to 2020 (CO and CH_4).

Table 4.12: The comparison of emissions between the year of 2006 and 2020

Pollutants	2006 [ton h^{-1}]	2020 [ton h^{-1}]
NO_x	3.443	4.213
CO	331.4	303.8
SO_2	0.733	0.791
NMVOC	46.24	49.21
CH_4	2.041	1.801

We can see that although HCMC government is following the plans to reduce the emissions as set out, the emissions of NO_x, SO_2 and NMVOC will most probably still increase. In the next section we present two more scenarios which are called scenarios of Business as Usual to evaluate the emissions in the case that the HCMC government does not have implemented any pollution abatement measures or fails to reduce the emissions. These emissions scenarios are compared with previous scenarios. In these scenarios, we also evaluated the influence of public transport on emissions and their role in reduction of emissions.

Comparison of the reduction scenarios and Business as Usual scenarios to the emissions of 2006.

The two Business as Usual scenarios were also made for the years of 2015 and 2020:

- The Business as Usual scenario for 2015: The per year increase of automobiles is predicted 14.5% and of motorcycles 5.4%. For the period 2006-2015, the city will add 3000 buses (Tuong, 2005).

- The Business as Usual scenario for 2020: the increase of automobiles and motorcycles are predicted similar to the scenario of 2015 but for the period 2006-2020 the city will add more 4500 buses.

The emissions of each case are calculated by changing the percentage of transport done by vehicle mode. This means that we replaced the private vehicle (motorcycles and car) by the public transportation (buses). Figure 4.15 shows the different emissions of CO between scenarios and reference case (2006) as a function of percentage of transport done by buses (PTDB).

where PTDB is: $PTDB = \frac{Number\ of\ kilometers\ traveled\ by\ buses}{Total\ of\ kilometers\ traveled} \times 100\%$

As mentioned in Tables 4.11 and 4.12 the change of emissions between the year of 2006 and the fours scenarios is divided into two groups: the first group corresponds to the pollutants with decreasing emissions (CO and CH_4), the second group corresponds to the pollutants with increasing emissions (NO_x, SO_2 and NMVOC).

The changing of emissions of CH_4 between emissions in 2006 and the four scenarios has a profile similar to the case of CO; results are shown in the Figure B.4.5 of the annex.

Figure 4.15 shows the decrease of emissions of CO depending on the percentage of transport done by buses and for the pollutant of CH_4 the changing of emission is similar to the case of CO. Their results are shown in the Figure B.4.5 of the annex. For the year 2006, we can see that if we increase the number of buses, the emission of CO reduces. Point A is the real emission of CO in 2006. At this point the percentage of transport done by motorcycle and car (private vehicle) is 99.91% and the percentage of transport done by buses is only 0.09%.

If we follow the reduction scenario of 2015, the emission of CO will reduce from A to D. Then the emission of CO in 2020 will increase from D to E. However the emission of CO in 2020 is still less than 2006.

If we let the number of vehicles increasing as Business as Usual scenarios without any reduction solution, the emission of CO in 2015 will increase from A to B (increasing more than 30% from the emission in 2006). Then the emission of CO continuously and

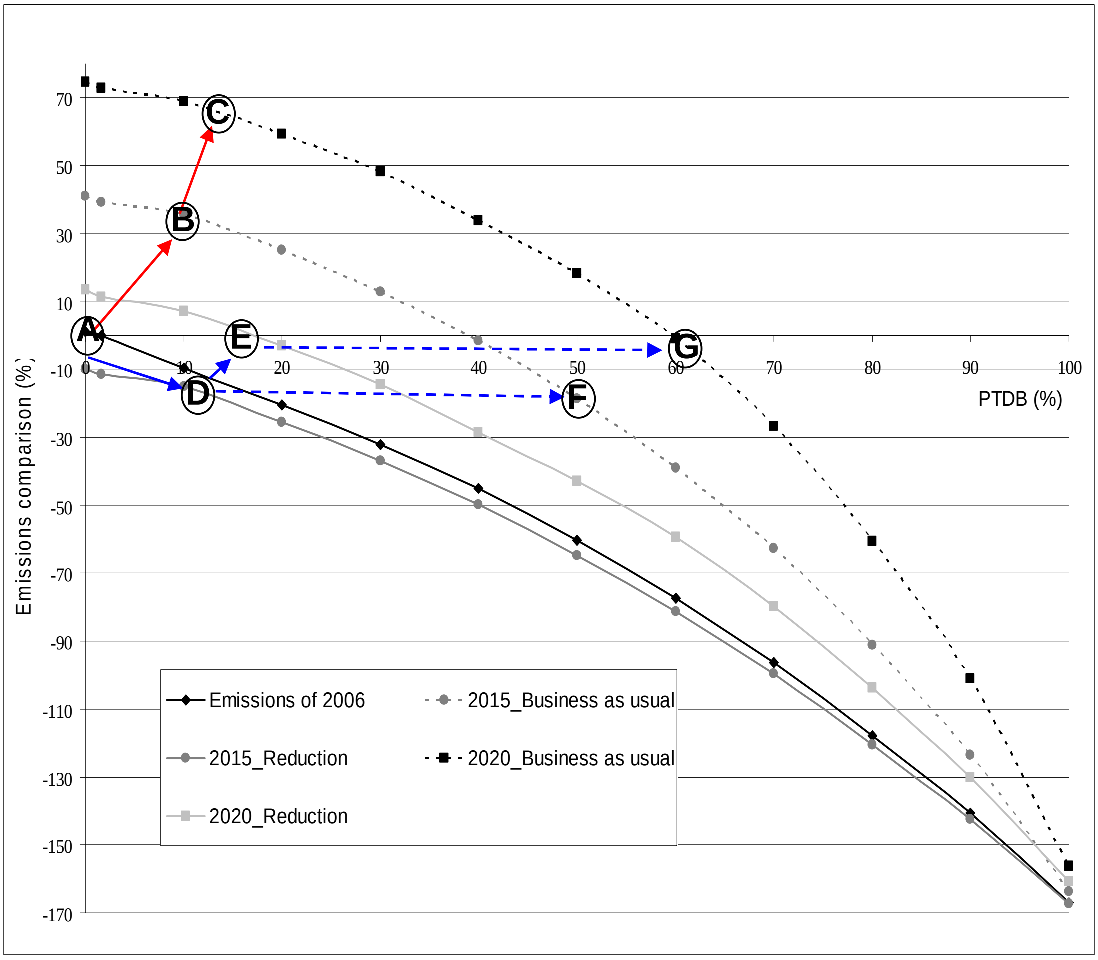

Figure 4.15: Percentage difference between the emissions of CO of 2006 according to percentage of transport done by buses (PTDB) (solid black line) with 4 scenarios: 2015_Reduction (solid grey line with a circle), 2020_Reduction (solid grey line with a square), 2015_Business as Usual (dash grey line with a circle), 2020_Business as Usual (dash grey line with a square). A, B, C, D and E are the real emissions of each scenario. F & G are the emissions in 2015 and 2020 (respectively) in the case that we do not have the metro but we want to keep the emissions same in the case we have metro (D& E).

rapidly increases (from B to C) until 2020 (increasing more than 60% than the emission in 2006).

For the CO emission in 2015, the Figure 4.15 also showed that if we want to keep the emission of Business as Usual scenario similar to the emission of reduction scenario (from B to F), we have to replace more than 40% of the private vehicles by buses.

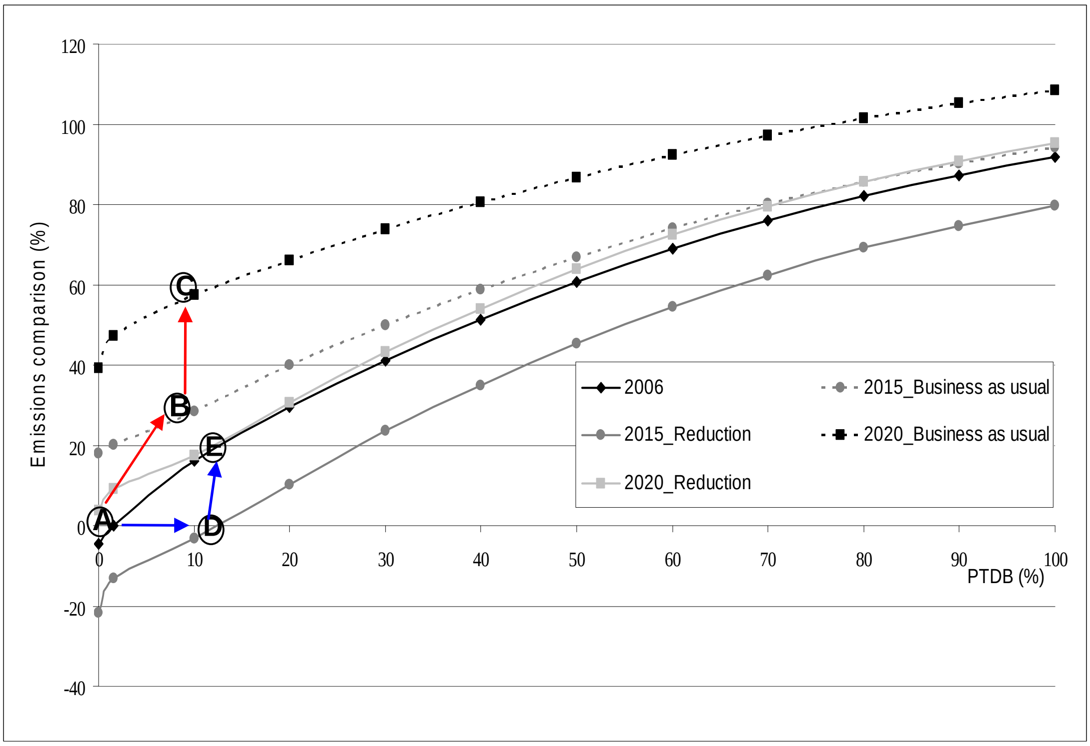

Figure 4.16: Percentage difference between the emissions of NMVOC of 2006 according to percentage of transport done by buses (PTDB) (solid black line) with 4 scenarios: 2015_Reduction (solid grey line with a circle), 2020_Reduction (solid grey line with a square), 2015_Business as Usual (dash grey line with a circle), 2020_Business as Usual (dash grey line with a square).

For the CO emission in 2020, if we want to keep the emission of Business as Usual scenario similar to the emission of reduction scenario (from C to G), we have to replace more than 45% of the private vehicles by buses.

Figure 4.16 showed the increase in emissions of NMVOC depending on the percentage of transport done by buses. For other pollutants (SO_2 and NO_x) the change in emissions is similar to the case of NMVOC. Their results are shown in the Figure B.4.6 and B.4.7 of the annex. In 2006, we can see that if the numbers of bus increase the emission of NMVOC also increase. Point A is the real emission of NMVOC in 2006.

If we follow the reduction scenario of 2015, the emission of NMVOC increases very slowly from A to D. Then, the emission of NMVOC continues to increase very fast until 2020 (from D to E).

If we let the numbers of vehicles increasing as Business as Usual scenarios, the emission of NMVOC in 2015 will increase from A to B (more than 25% increase than the emission in 2006). Then, the emission of NMVOC continues to increase (from B to C) rapidly until 2020 (more than 55% increase than the emission in 2006).

The above given results showed that although we replaced the private transport by public transport but the emission of NMVOC, NO_x and SO_2 has always shown an increase. Up

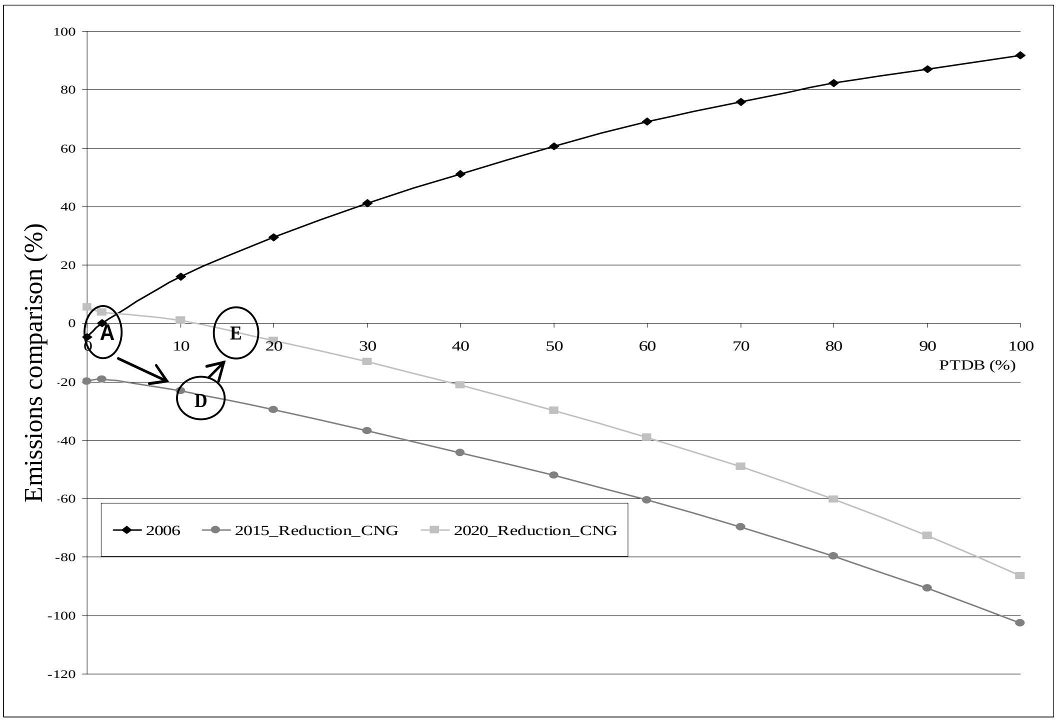

Figure 4.17: Percentage difference between the emissions of NMVOC of 2006 according to percentage of transport done by bus (PTDB) (solid black line) with 2 scenarios: 2015_Reduction_CNG (solid grey line with a circle), 2020_Reduction_CNG (solid grey line with a square).

to now, for the reduction of emission of the pollutants from the public transport, we have found some solution that private vehicles must be replaced with maximum metros, advance technology engines of buses should be used and the cleaner fuel should be changed (replacing the diesel oil by CNG).

In the following scenario, we kept 2 reduction scenarios for 2015 and 2020. However, we replaced all the buses using the diesel oil by the buses using the CNG.

When we replaced the buses using the diesel oil by the buses using the CNG, the emission factor of NMVOC for the buses reduced a factor of 28. However the emission factor of NO_x is still high (reduced only a factor of 3).
The results of NMVOC are shown in the Figure 4.17. The emission of NMVOC reduces significant in 2015 (reducing more than 25%). Then, the emission of NMVOC increases until 2020, however the emission of NMVOC in 2020 is still lower than the emission in 2006 a value of 4%.
The results of NO_x are shown in the Figure B.4.8 of the annex. The emission of NO_x reduces only 5% in 2015. Then, the emission of NO_x increases slowly until 2020 (increasing of 15% the emission in 2015), so the emission of NO_x in 2020 is higher than the emission in 2006 a value of 5 %.

4.6 Conclusions

A complete EI for HCMC is carried out in this chapter. We divided the emission sources into 4 main sources: traffic, industry, residential (included the other sources) and biogenic source.

For the traffic source, we organized a lot of campaigns and surveys for collecting the HCMC's on road traffic information. Then, we used the new EMISENS model in which the new methodology was developed. The EMISENS model which combines the top-down and bottom-up approaches was used to generate the EI. In parallel with the generating the EI for HCMC, we also generated the uncertainties in EI which are created by input parameters. The results showed that if we divide the streets into 3 street categories (highway, rural and urban street), the obtained uncertainties in EI are very high. The percentages of uncertainties range from 31% of total emissions for NO_x to 77.27% of total emission for CH_4. However, when we divide the streets into 5 street categories (keeping the same previous highway and rural street, but 3 urban street categories), the uncertainties in EI reduce significant with the levels of uncertainties in EI are reduced from 30% to 40% depending on the pollutant types.

The spatial distribution of emissions showed that the highest emission is found in the center of the city because of the highest density of streets is found there.

The data for generating EI for others emission sources is limited. So the top-down approach is used to generate the emission for HCMC. The total emission of Vietnam is used to calculate the emission for HCMC. Then we distributed the emissions on space using the population's density and the surface area.

The results of EI showed that the traffic source is the most important emission source (occupied 77.75% of NO_x, 89.77% of CO and 89.39% of NMVOC). And the motorcycle is the most important of traffic emission source (99% of CH_4, 94% of CO, 68% of NMVOC and 61% of SO_2).

As the results showed that the motorcycle is the main source of road traffic emission. The fours abatement strategies of emission are also carried out to evaluate the effort of local government and to evaluate the role of public transport to reduce the emissions. The results showed that the emissions in 2015 of CO and CH_4 will reduce to more than 10% if the HCMC government controls the emissions as planned. The emission in 2020 of CO and CH_4 will also reduce some percentages if the HCMC government controls emission as planned. While if the HCMC government does not follow the planning, the emission of CO and CH_4 in 2015 will increase very fast (more than 30%) and the emission of CO and CH_4 in 2020 will increase more than 60%.

Unfortunately, the emission of NO_x, NMVOC and SO_2 always increase until 2015 and 2020 even the HCMC government follows the planning. Because the public transport using HCMC is mainly the buses. These buses are very backward technology, very old and using the diesel oil so that even we replaced the private transport by the public transport (bus), the emission of NO_x, NMVOC and SO_2 still increase. Up to now, the best solution for reducing the emissions from bus is to make more metro line, but for making metro line is much expensive for HCMC. The second solution is to replace the actual bus using the diesel oil by the buses which use CNG. The results of one more scenario made for testing this solution showed that the emissions in 2015 and 2020 will reduce (the emission of NMVOC reduce more than the emission of NO_x).

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Chapter 5 Numerical simulations of air pollution and abatement strategies to reduce pollution in Ho Chi Minh City

Abstract

Air pollution has deteriorated considerably the health of millions of people in HCMC due to high levels of emissions which caused more than 90% of children under the age of 5 years old suffered from different respiratory illnesses in the city. The objectives of this research are to study the formation of the pollution plume over the city during a 3 day episode in February 2006 and to study different abatement strategies of air pollution for HCMC. The meteorology in HCMC is influenced by local phenomena (slope winds and sea breeze) and global phenomenon (Trade Winds) which create convergence fronts over and cause the formation of the plume of pollutants over the city. The plume of O_3 is developed in the north-western part of the city. The models successfully simulated these phenomena and their results are in good agreement with measurements. Two abatement strategies are studied in this work to help the local government who will make decisions for managing air quality in HCMC. For making a better-informed decision, the probabilistic estimate for the photochemical model is carried out in this research. The traditional Monte Carlo (MC) approach which is applied in this research for the uncertainty analyses is an efficient method of producing a probabilistic output from the photochemical model. The results of two abatement strategies including uncertainty analyses showed that (1) if the local government follows the emission control plan as designed for 2015, the O_3 concentration in 2015 will be similar to the O_3 concentration at present, (2) if the local government follows the emission control plan as designed for 2020, the O_3 concentration in 2020 will decrease around 10%-30% of O_3 at present.

5.1 Introduction

Ho Chi Minh City (HCMC), the largest city in Vietnam, is located at 10°45’N, 106°45’E in the South-eastern region of Vietnam, with an area of 2095 square kilometres (Nguyen, 1996). The city belongs to a transitional region between the South-eastern and Mekong Delta regions. In general the topography of HCMC is not complicated. The high terrain lies in the north-eastern area with an average height of 10-25 meters (inside the city), then go up to 1500m in north-eastern of HCMC. The depression terrain lies in the south-western with an average height of 0.5-2 meters. The city center is about 50km away from the East Sea in a straight line.

HCMC borders Tay Ninh and Binh Duong provinces to the north, Dong Nai and Ba Ria-Vung Rau provinces to the east, Long An province to the west and the south China Sea to the south with a coast of 15km in length. The climate of HCMC is defined as the tropical monsoon climate. The average annual temperature and the annual average relative-humidity are approximately 27°C and 77%, respectively. The local weather is divided into two distinct seasons: the rainy and dry season. The rainy season begins in May and ends in November with an average rainfall of about 1,800 millimeters annually and dry season remains from December to April (Pham et al., 2001).

HCMC is a dynamic metropolitan area, and as many other urban zones, its population and its economic growth increase rapidly. The population of the city was 7.123 million in 2009 and HCMC’s population growth rate was 3.5% per year (Du, 2009). HCMC’s economic growth rate is 12.0% - 12.5 % per year during the period of 2006-2010 (HIDS, 2007). The increase in population leads to the increase in number of vehicles in the city. The main sources of transportation in HCMC are the motorcycles which in 2006 accounted for 2,895,831. The rapid economic growth supported the further establishment of industrial zones and industrial units. Currently there are about 28,500 factories in the city. The huge traffic and industrial units in and around the city release significant amounts of gaseous pollutants into the atmosphere.

Critical concentrations of pollutants are found in the city, exceeding the air quality standards for total suspended particles (TSP), PM10, NO_2 and O_3 (Nguyen, 2002; HEPA, 2006). The concentrations of pollutants in working environments at some enterprises (2006) are regularly higher than Vietnamese standards as shown in Table 5.1

Table 5.1: Pollutants concentration in working environments for some enterprises (in mg/m^3)

Name	TSP	SO_2	NO_2	CO	Noise levels (dB)
Ha Tien cement factory	18.3	-	0.82	-	120
Tan Binh steel factory	7.2	-	0.25	38.5	86
Nha Be steel factory	16	4.2	0.49	12	82
Phi Hung aluminium	6	0.55	0.07	40	89
Satimex wood factories	9.7	-	-	1	95
Allowable concentration (AC)	6	20	-	40	90

(Source: Nguyen et al, 2002)

Values reported (average of 1 hour) and Allowable concentration (maximum 1-h concentration).

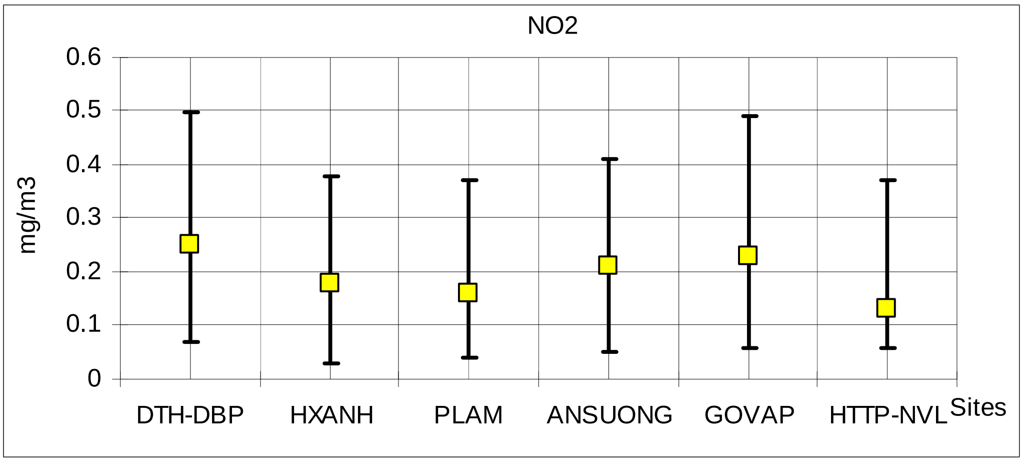


Figure 5.1: Average of 24h concentrations (period of 2006) of NO_2 6 road-side monitoring sites (DTH_DBP, HXANH, PLAM, ANSUONG, GOVAP and HTP_NVL). Vietnamese standard for NO_2 average of 24h is 0.2 mg/m^3. (Source: Ho Chi Minh environmental protection agency (HEPA, 2006)).

Note: TSP (total suspended particles)

"-": value not exits

The concentration of O_3, SO_2, NO_2 and PM10 at road-side monitoring sites regularly exceeded the Vietnamese standard (HEPA, 2006). For example, the concentration of NO_2 at road-side monitoring sites in 2006 (Figure 5.1) exceeded often the Vietnamese standard.

With high concentration of harmful pollutants, the air pollution is a major problem to which several million people are exposed. The research on the relation between air pollution and health (Le et al., 2008) showed that more than 90% of children under 5 years old suffer from different respiratory illnesses in HCMC. It is urgent to determine the amount of emission reduction needed and most polluted areas in the city, in order to design the best abatement strategies for reduction of emission. Pollution-control measures are very difficult to apply because (i) methods are very expensive and (ii) the processes involved in the formation of photochemical episodes are very complex and highly non-linear (Martilli, 2001; Clappier, 2001). The numerical air quality models are able to account for all these processes. They constitute the only reasonable approach to understand the pollution and to test different scenarios of abatement strategies (Clappier, 2001; Rappenglück et al., 2003).

The aim of this research is to test different pollution abatement strategies and to propose the best strategy for the city. In order to achieve the aim of this research, a lot of primary data in form of measurements are collected and analyzed to select the period for numerical simulation. The period with the specific meteorology conditions which relate to high levels of pollutants in city will be chosen for numerical simulation. The dry season of the year is from January to April has been identified as a period in which high pollution is observed in the city (HEPA, 2006). The measurements and the choice of the period of simulation are described in section 5.2. The description and validation of models are presented in section 5.3 and section 5.4, respectively. Section 5.5 presents the abatement strategies for the city. The conclusion is presented in section 5.6. In the following section, the measurement description is presented.

5.2 Measurements description

In 1996, the Institute of Environment and Resources (IER) started intensive data collection with its mobile and automatic air monitoring station fully equipped to analyze pollutants (SO_2, PM10, O_3, NO_x and CO) and meteorological parameters (wind, temperature, humidity, radiation and pressure) for HCMC and for the Mekong Delta area (with the cities of Long An, My Tho, Can Tho, Ca Mau and Moc Hoa). The time resolution of measurement is 10 minutes, however hourly averages are also obtained out of these data. The station reports data at an average elevation of 5 m above the ground. This mobile station measures only 1 week for each two months per city due to the limit of equipment. The results from this station are mainly used to select the episode for simulation. The available measurements around the city (Figure 5.2) are compared with the results of model for the same times of the episode evaluated. Purposes of these comparisons are also to validate the models.

Air quality network (Figure 5.2) in HCMC (by HEPA: Ho Chi Minh environmental protection agency):

At the end of 1992, four semi-automatic ambient air-monitoring stations (PM, SO2, NO_x) and three stations for road-side monitoring (PM, NO_x, Pb, noise) networks were included. These stations monitor only 3 times a day (1 hour in morning, 1 hour in the afternoon and 1 hour in the evening).

In June 2000, the automatic air quality monitoring systems supported by the United Nations Development Program (UNDP) and All Nations International Development Agency (ANIDA) were installed (HEPA, 2005; Nguyen et al., 2002). Among these systems were two urban background stations (monitor PM10, SO_2, NO_x, CO, O_3) and two roadside stations (monitor PM10, NO_x, CO, O_3). They were placed at different locations around the city.

In November 2002, five more new automatic air quality monitoring stations were installed with the support of Norwegian Agency for Development Cooperation (NORAD). These systems included three urban background stations (monitor PM10, SO2, NO_x, O_3) and two roadside stations (monitor PM10, NO_x, CO, O_3). The resolution of measurement of NORAD stations also is 10 minutes. The stations report data at an average elevation of 5 m above the ground. Among the nine automatically stations, there is only one station (DOST) measuring both meteorological parameters and air quality levels. The meteorology parameters acquired from DOSTE (Department of Science, Technology and Environment of Ho Chi Minh city) include wind speed and wind direction, humidity, temperature, solar radiations and air pressure.

Data from two more meteorological monitoring stations (TSN) are furnished by the National Oceanic and Atmospheric Administration (NOAA, 2006) and the Sub-Institute of Hydrometeorology and environment of South Vietnam (SIHYMETE). The TSN station is located in the center of HCMC. This station is positioned in HCMC's international airport. The station of NOAA reports vertical profiles of temperature, wind speed and wind direction once per day (at 0700 LT) by radiosonde. This station also measures the surface temperature and wind at an average elevation of 19m above the ground. The station of SIHYMETE measures the surface temperature (at an average elevation of 2m above the ground) and wind speed (at an average elevation of 10m above the ground). The time resolution of measurement of both stations is one hour.

Choice of the period of simulation

The data which is monitored from 2002 to 2006, from the above measurements are analyzed to select the period of simulation.

The measurements show that the warmest period of the year in HCMC is from January to April. The wind direction in HCMC is mainly divided into three different seasons: easterly wind from February to May, westerly from June to September, northerly from October to January.

The results of air quality monitoring also show that the highest concentrations of O_3 concentrations are found during the warmest period often above the standard. At station ZO and D2 (urban background stations), one-hour average O_3 concentrations of 113 ppb and 112 ppb respectively, were observed during the period of the 6^{th} – 8^{th} February 2006 (while the one-hour Vietnam Air Quality Objective for O_3 is 102 ppb).

The choice of the period of simulation takes into account two principal aspects: (i) it must be representative of an episode of pollution and (ii) it is one of the worst cases of pollution in the whole year in HCMC. In general, the duration of this type of episode is 3 or 4 days (Zarate, 2007) and the greatest possible quantity of measurements during such an episode of pollution must be available. For example, during the period of the 17^{th} –

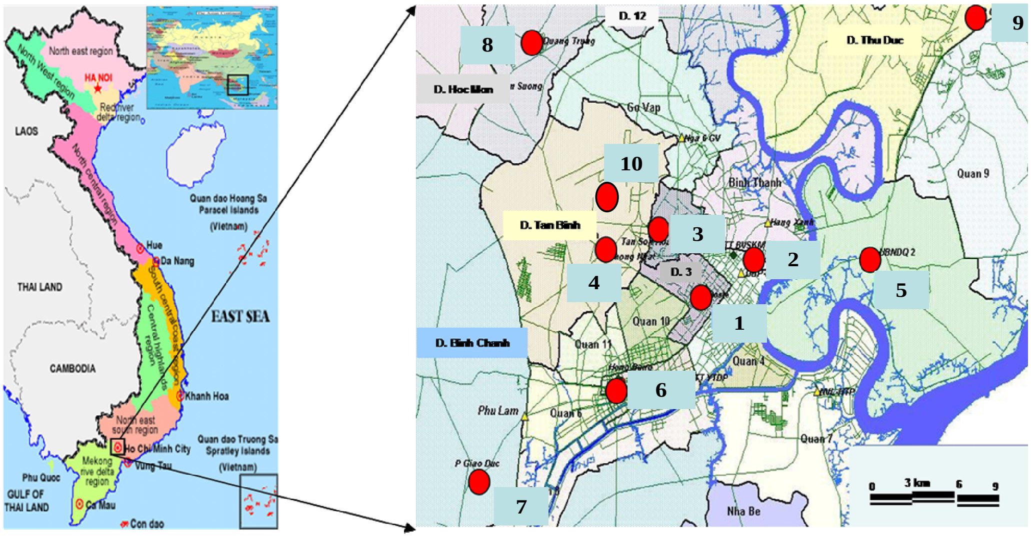


Figure 5.2: The map on the left panel is the location of Vietnam. The map on right panel is presenting the location of monitoring stations in domain simulated. Five road-side stations (1. DO; 4. TN; 6. HB; 7. BC; 9. TD) and four urban background stations (2. ZO; 3. TS; 5. D2; 8. QT) for air quality monitoring are located on the map. The meteorological stations are located in TSN airport (station number 10) and Tan Son Hoa site (station number 3). (Source: Library of Institute of Environment and Resources (IER)-Vietnam).

19th January 2006, the measurement shows that the highest O_3 concentration is 122 ppb at ZO and D2 stations. But we can not choose this period for study because during this period there are very few measurements of meteorology and others pollutants available. The episode of February 6th – 8th, 2006 was selected for the period of simulation because of two reasons: (i) It is during the dry season when temperatures and solar radiations are very strong, (ii) It is one of the most polluted periods in 2006.

In HCMC, the concentrations of NOx, CO in residential area are normally lower than Vietnamese standard. However the solar radiations are very strong in HCMC. Consequently, the high concentration of secondary pollutants (such as: O_3) are regularly observed. Therefore, this research focuses to simulate the pollution of primary and secondary pollutants by using air quality model.

5.3 Models description and set –up

5.3.1 Meteorological model

The FVM (Finite Volume Model) model used in this research is a three dimensional Eulerian meteorological model for simulating the meteorology. The model uses a terrain following grid with finite volume discretization (Clappier et al., 1996). This mesoscale model is non-hydrostatic and anelastic. It solves the momentum equation for the wind component, the energy equation for the potential temperature, the air humidity equation for mean absolute humidity and the Poisson equation for the pressure. The turbulence is parameterized using turbulent coefficients. In the transition layer these coefficients are derived from turbulent kinetic energy (TKE, computed prognostically), and a length scale, following the formulation of Bougeault and Lacarrere (Bougeault et al., 1989). In the surface layer (corresponding to the lowest numerical level), in rural areas, the formulation of Louis (Louis et al., 1979) is used. The ground temperature and moisture, in rural areas, are estimated with the soil module of Tremback and Kessler (Tremback et al., 1985). An urban turbulence module in the model simulates the effect of urban areas on the meteorology (Matilli et al., 2002 b). A second module, the Building Energy Model (BEM, Krpo, 2009), takes into account the diffusion of heat through walls, roofs, and floors, the natural ventilation, the generation of heat from occupants and equipments, and the consumption of energy through air conditioning systems. The FVM model was developed at the Air and Soil Pollution Laboratory (LPAS) of EPFL. This version of FVM used for this work is the versionAC.44, latest available at the time of writing this thesis.

For choosing the domain used in the meteorological simulations, we have to take account of their size and especial resolution due to the capacity of computer. The 4 selected domains (Figure 5.3) are described as following:

+ Domain 1: Resolution of 75 km x 75 km cells 16 x 16 grid points.
+ Domain 2: Resolution of 16 km x 16 km cells 33 x 33 grid points.
+ Domain 3: Resolution of 5 km x 5 km cells 40 x 40 grid points.

+ Domain 4: Resolution of 1 km x 1km cells 34 x 30 grid points, covering the main part of HCMC.

Land use data obtained from the U.S. Geological Survey (USGS) is used as input for the simulations. The parameters for each cell of study domain are calculated by using the various land use types. For the urban land use, two types of urban classes are used: center and surrounding. The center of HCMC has high buildings with high density. The density is lower in the surrounding areas. Therefore two types of urban classes are considered.

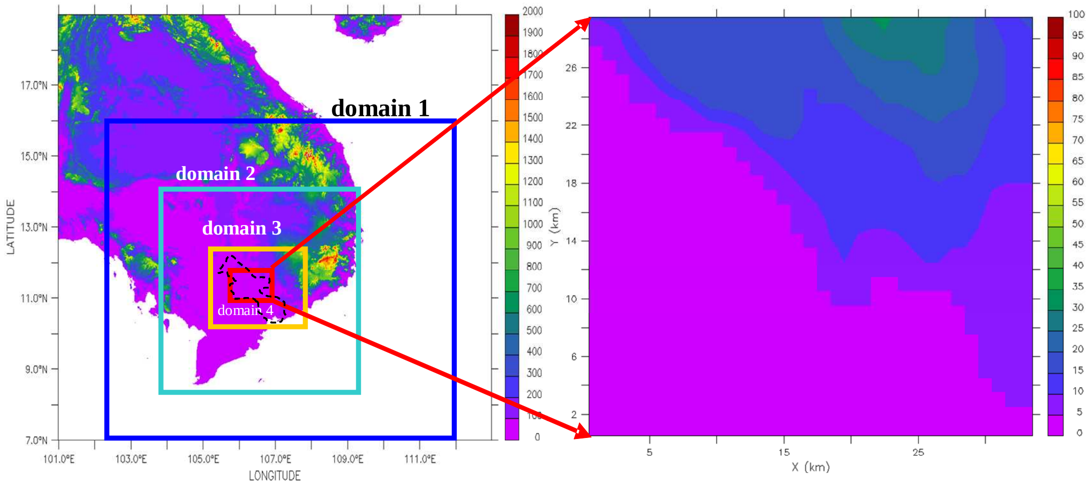


Figure 5.3: Topography of South of Vietnam and description of simulated domains (left panel). The central red square (shown in left panel) used for the air quality simulations (right panel). The circle dotted line (black) is the location of all HCMC. (Source: http://edcdaac.usgs.gov/gtopo30/gtopo30.html (online & free downloading)).

The building heights of center and surrounding are 15m and 5m respectively. For obtaining more realistic initial conditions, a pre-run of one day is computed for the meteorological simulations.

5.3.2 Air quality model

The air quality model used for this study is the Transport and Photochemistry Mesoscale Model (TAPOM) (Martilli et al,. 2003; Junier et al,. 2004) implemented at the Swiss Federal Institute of Technology at Lausanne (EPFL), and at the Joint Research Center in

ISPRA. It is a transport and photochemistry three dimensional Eulerian model. It is based on the resolution of the mass balance equation for the atmospheric substances. This equation includes the advection by the mean wind, the vertical diffusion by the turbulence, the chemical transformation by reactions, the dry deposition and the emissions.

- The chemical transformations are simulated by using the RACM (Stockwell et al., 1997), the Gong and Cho (Gong et al., 1993) chemical solver for the gaseous phase and the ISORROPIA module for inorganic aerosols (Nenes et al., 1998).
- The transport is solved using the algorithms developed by Collella et al., (1984). This algorithm has recently improved by Clappier et al., (1998).
- The photolysis rate constants used for chemical reactions are calculated using the radiation module TUV which is developed by Madronich et al., (1998) at the NCAR4

A domain of 34 km x 30 km (Figure 5.3 (right panel)) with resolution of 1 km in x and y directions is chosen for air quality simulation by using the TAPOM model. The main part of HCMC is located in this domain. In vertical position, the grids extend up to 7300 m with 12 levels. The vertical resolution is 15 m for the first level, and then it is stretched up to the top of the domain at 2000 m (grid stretching factor of 1.2 for lower and 1.6 for upper layers of the grid). For obtaining more realistic initial conditions, a pre-run of one day is computed for the air quality simulations.

5.4 Model validation

5.4.1 FVM model

Boundary and initial conditions

For the largest domain (domain 1), the initial and the boundary conditions are interpolated from results of the National Centers for Environmental Prediction (NCEP). These data NCEP data’s spatial coverage is 2.5 ° latitude – longitude global grid with 144 x 73 points, 90N-90S, 0E-357.5E and temporal coverage is from 01/01/1948 to - present with output of every 6 hours (CDC-NCEP). Domain 1 covers the peninsula south of Vietnam with the two mountain chains (the Truong Son and the Langbiang mountain chains) (Figure 5.3) and the East Sea. A resolution of 75 km in both x and y directions is thus used for simulation of the 1200 km x 1200 km grid. This peninsula belongs to the tropical zone that is strongly affected by Asian Monsoon, in February the main wind direction is easterly. In vertical position the grids extend up to 10 000 m, with 30 levels. The vertical resolution is 10 m for the first level, and then it is stretched up to the top of the domain at 1000 m [(grid stretching ratio equal to 1.2) (Martilli et al., 2002)].

For the smaller domain such as domain 2 (528 km x 528 km), the initial and boundary conditions are obtained using the "nesting-one-way" technique. The results of wind fields are similar to domain 1. The main wind direction is easterly.

For the domain 3 (200 km x 200 km) with resolution of 5 km in both x and y directions, their results show in Figure 5.4. This domain contains the Langbiang mountain chain reaching maximum altitude of around 1500 m in north-east. Further to the East, we can find the East Sea. This diverse geography plays an important role in the atmospheric circulation of HCMC region. The wind fields of this grid are influenced by the Trade Winds coming from the east. And the wind fields of this grid undergo local effects such as slope winds and sea breezes. Results are shown in the Figure 5.4.

Figure 5.4 (a) shows that at 0600 local time (LT), the wind speed is very weak. The wind direction of Trade Winds is more important than the local phenomena. So the wind direction is towards the west and north-west. At 1300LT, due to the sun-heating effect (Figure 5.4 (b)) the weather in the mountain is warm and air masses are pushed up along with the slopes in the north-east of grid. So the wind direction is coming from the south-west in the zone near the mountain. At this time the land is warm, the sea is cooler than the land. So the wind direction in the zone near the sea is towards the land. This wind is stronger due to the accumulation of the Trade Winds. At this time, the local wind phenomena (slope winds and sea breeze) strongly influenced on the wind fields of grid.

At 1700 LT, the weather in the mountain is cooler, so the slope winds phenomenon is weak. The sea breeze phenomenon develops strongly with a direction towards the land. At this time the main wind direction is toward north-west.

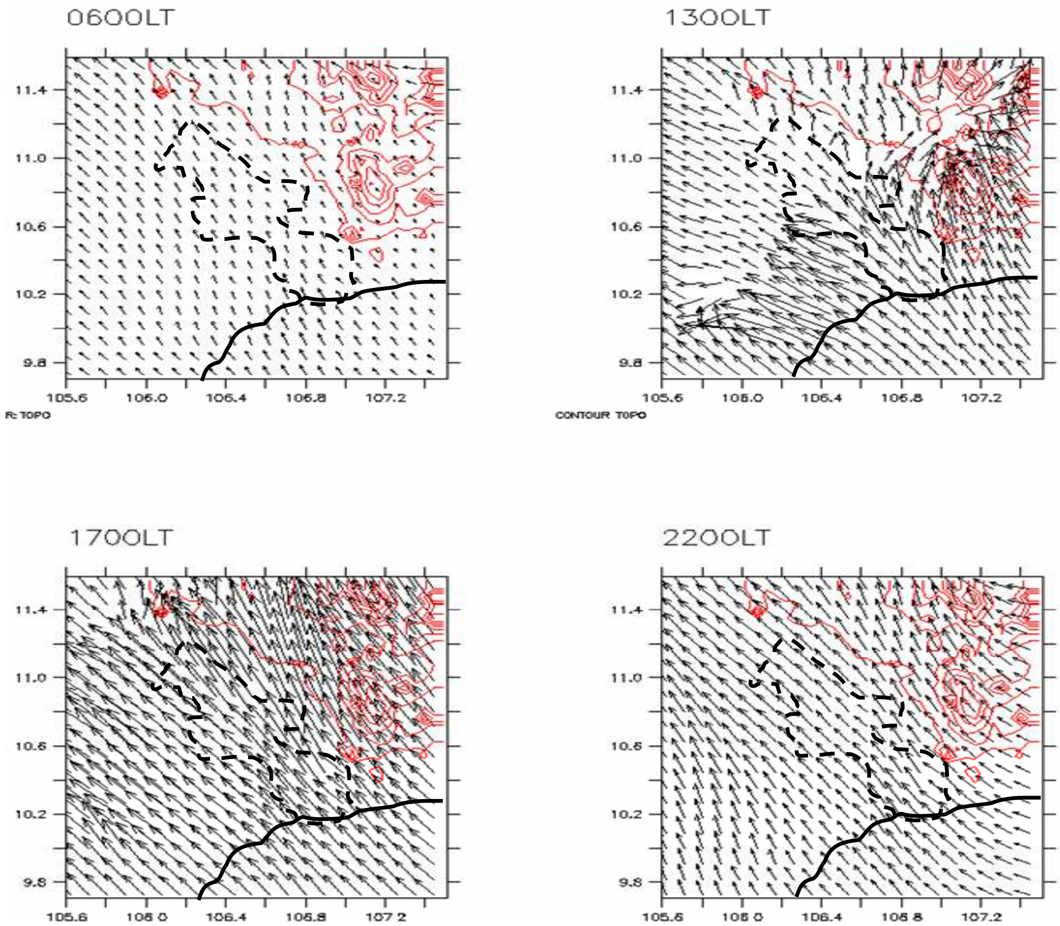


Figure 5.4: Wind field results from simulations at ground level for the domain of 200 km x 200 km, 7th February 2006. Geographical coordinates of the lower left corner: 9.75°N and 105.64°E. Maximum wind speed is 7.5 m s^{-1} at 1700 LT. The circle dotted line is the location of all HCMC. The solid line is the coast.

To sum up, the wind direction is more influenced by global scale than local phenomena in this grid.

Meteorological simulation over HCMC (domain for air quality simulation)

Additional meteorological simulations were performed for the domain for air quality simulations. Domain 4 is presented in Figure 5.3 (34 km x 30 km). This domain includes main part of HCMC. The results from nesting procedure are used over this domain. So

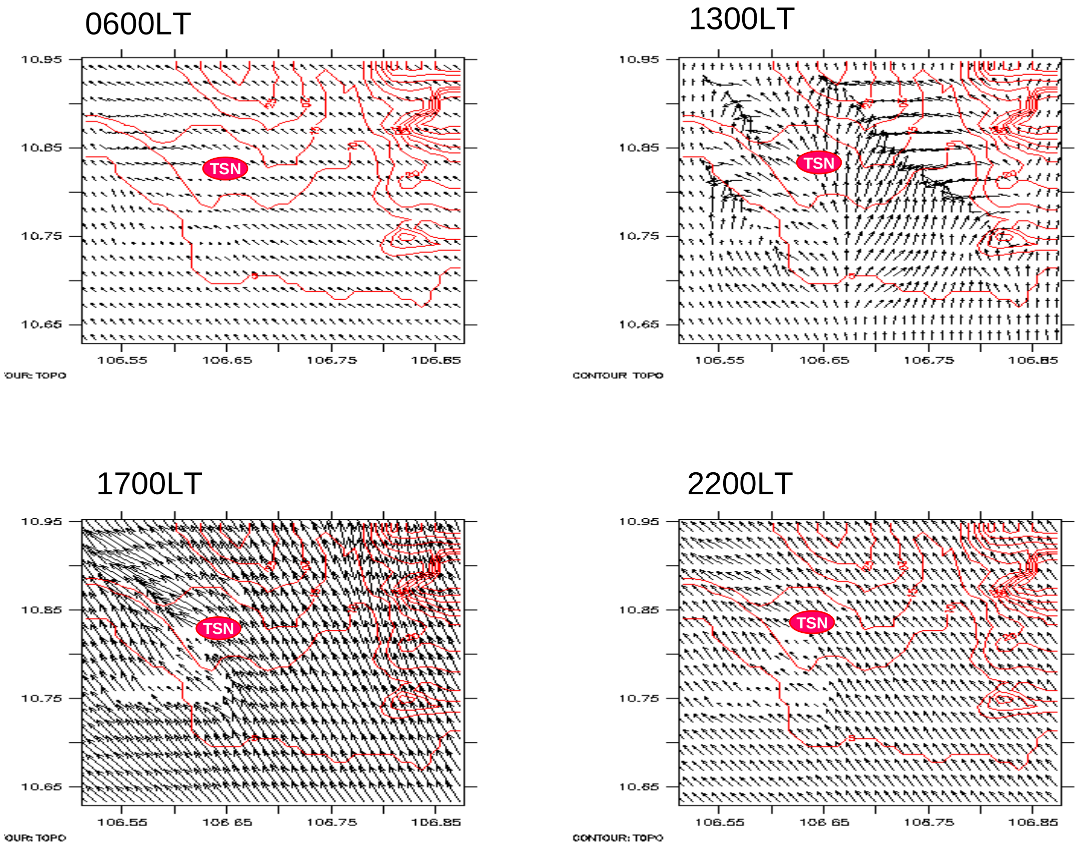


Figure 5.5: Wind field results from simulations at ground level for the domain 34 km x 30 km, 7th February 2006. Geographical coordinates of the lower left corner: 10.64°N and 106.52°E. Maximum wind speed is 5.5 m s^{-1}. TSN is the monitoring station. The results from the previous domain (200 km x 200km) are used as initial and the boundary conditions for this domain. This domain 4 contains only the main center part of HCMC.

that the results from the previous domain (200 km x 200km) are used as initial and the boundary conditions for this domain 4.

- Meteorology at ground level

In the morning, the wind direction in HCMC is towards the north-west.

At 0600LT (Figure 5.5(a)), the wind is influenced by the Trade Winds. At this time we do not observe the sea breeze phenomenon because it is too weak and the Trade Winds dominate the wind direction in the grid at this time.

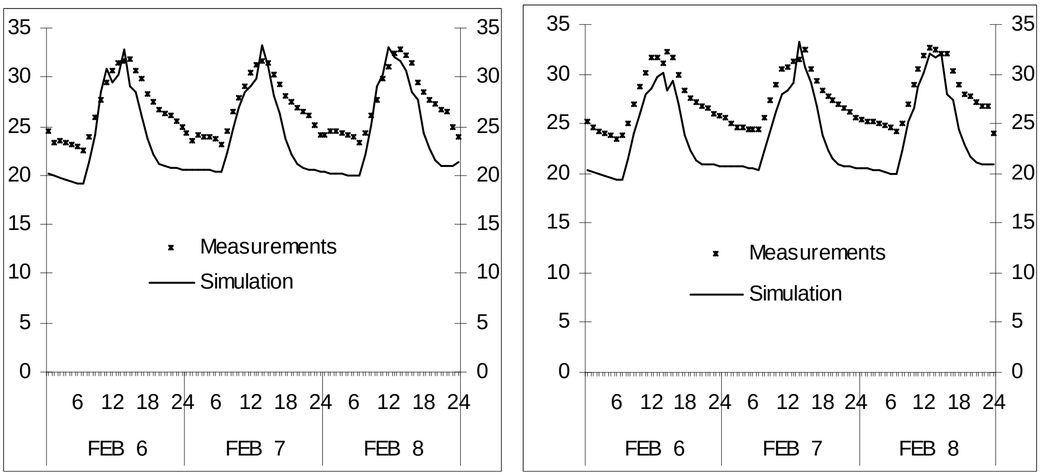


Figure 5.6: Comparison between the results of simulated (solid line) and measured (starts) temperature (°C) at ground level in TSN (left) and TSH (right) stations, 6^{th} – 8^{th} February 2006.

By 0900LT the wind is stronger and we observe the development of some small converge zones, produced due to the slope winds phenomenon developed in the city (the slope winds phenomenon occurs after about 2 hours of sun rises which warm up the ground).
Until 1300LT as shown in Figure 5.5(b), the sun light has warmed up the ground rapidly. The slope winds are stronger at that time and air masses come up from the south plateau toward the highland area in the north. Some other air masses come from the east. Three main converge fronts can be perceived in the grid.
The wind speed increases strongly and reaches its maximum at 1700LT as shown in Figure 5.5(c). At this time the warming of the ground reaches its maximum and the sea breeze phenomenon develops strongly. From 2200LT until the next morning, wind fields are similar to 0600LT as it shown in Figure 5.5(d).

The measurements taken during the episode are used to validate the results of meteorological simulations. The results of TSN and TSH stations (Figure 5.2) show daily and nightly temperature values (Figure 5.6). In general, FVM reproduces correctly the variation of the temperature. The results show that during all the day, measured and modeled temperatures are very similar. The model predicts well the time of the day when the sun rises (0700LT) and temperatures start increasing. The maximum value of

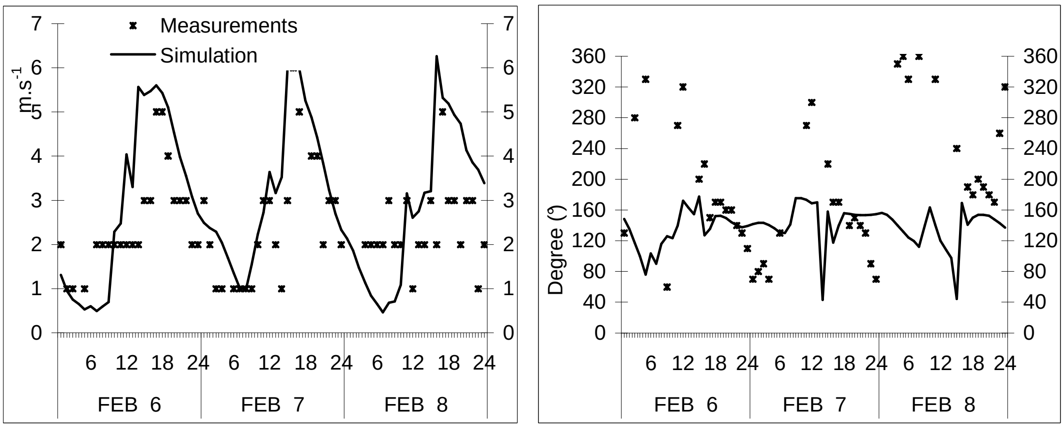


Figure 5.7: Comparison between the results of simulated (solid line) and measured (starts). The wind speed in $m.s^{-1}$ (left panel) and wind direction in degree (°) (right panel) at ground level in TSN station, 6th – 8th February 2006.

temperatures (between 1200LT and 1500LT) is 35.19°C. However it underestimates nightly temperatures, this can be explained by the NCEP nightly temperatures are also underestimated. These boundary conditions contribute to cool down the borders of the grid, and then the simulations are underestimated.

The measurements of TSN station (Figure 5.7(left)) show very clearly the daily and nightly maximum and minimum wind speed values. Unfortunately, there are very few measurements for meteorology over HCMC area. The TSN station is located a little bit in west part of domain. We observed that minimum wind speed values are between 0500LT and 0700LT, when land and sea are coolest. The minimum wind speed was observed at the same time together with a change in the wind direction (Figure 5.7(right). The maximum wind speed values observed during the day occur at the same time with the maximum of development of local phenomena (slope winds and sea breeze). The change in wind direction due to the slope winds cannot be seen clearly because TSN station is situated towards the west of city where the local phenomena are less notorious. In addition, the slope winds develop strongly in north-east part of the domain.

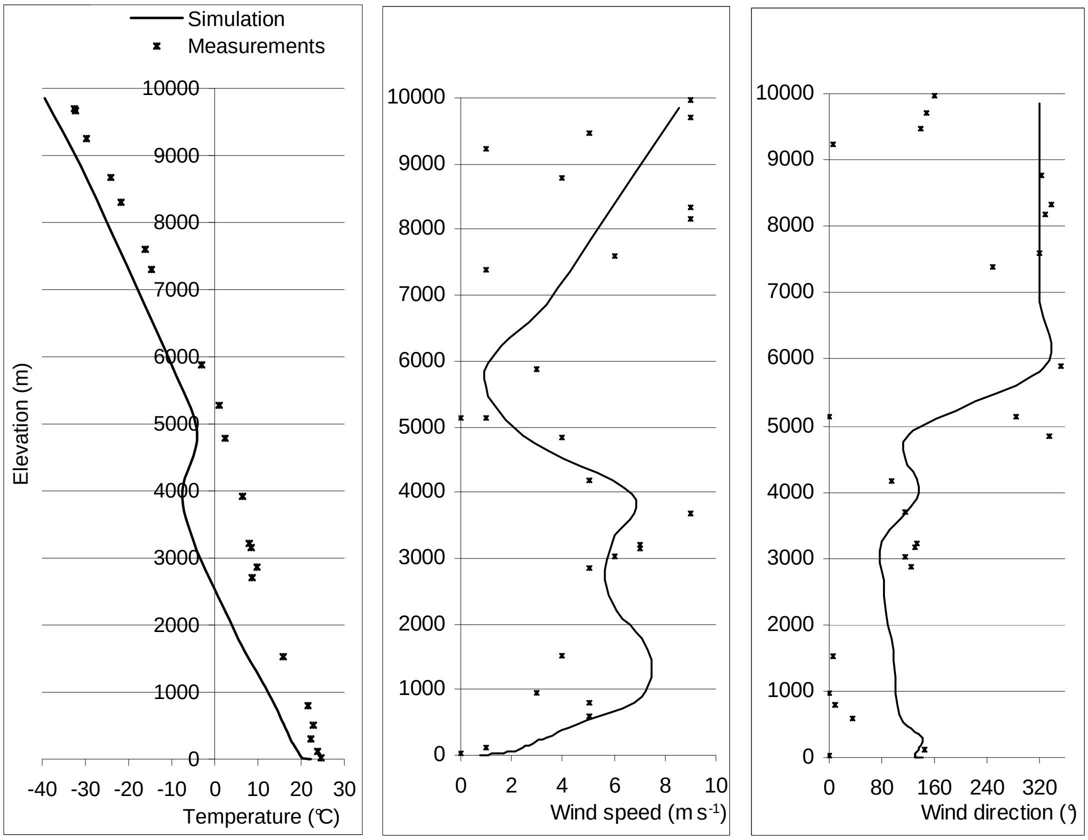


Figure 5.8: Comparison between the results of simulated (solid line) and measured (starts) vertical profiles of temperature (left panel), wind speed (middle panel) and wind directions (right panel) at ground level in TSN station, 0700 LT on 7th February 2006. The Y axis represents the elevation in meters above the point of measurement.

- Vertical meteorological profile

Figure 5.8 shows the vertical profile of temperatures, wind speed and wind directions at 0700LT at TSN station for both observations and simulations. The left panel of Figure 5.8 shows that there is a thermal inversion layer between 300 m and 500 m at 0700LT. This layer has an important role in stocking the pollution. The simulated temperatures are lower than the observed ones, which is in agreement with the low nightly temperature simulated (Figure 5.6). The middle and right panel of Figure 5.8 show that in general the wind speed and wind direction of simulation in vertical are similar to observations.

In summarize, 6th – 8th February is an episode which is representative for the meteorology of HCMC during the dry season of the year. The meteorology is influenced by the local and global phenomena. Slope winds and sea breezes are developed over HCMC. Low temperatures at night generate a thermal inversion layer in the morning. The wind flow is mainly towards the north-west. Three main convergence zones are found in the north part of the city where a great disturbance in the wind can be seen in a very clear way. These phenomena play an important role for the dispersion of pollutants.

5.4.2 TAPOM model

The results of emission inventory (EI) which were developed in the chapter 4 of this thesis are used as input for the TAPOM model. The EI are calculated for a working day during February 2006 with a temporal resolution of one hour and a spatial resolution of 1 km x 1km. For simulating photochemical processes, it is necessary to have information on different components of reactive non volatile organic compounds (NMVOC). In HCMC, the measurements on different components of NMVOC are not available for generating the EI. So, the values of NMVOC are split from a study of the city of Bogotá, Colombia (Zarate, 2007). In Bogotá, the main emission of NMVOC is the road traffic source and the light vehicles running with gasoline (LVG) are the main emission source of NMVOC. In HCMC, the main emission of NMVOC is also the road traffic source, among them the motorcycles running with gasoline are the main emission source of NMVOC. The emission of VOCs species between LVG and motorcycles are similar (Tsai, 2003; Brown, 2000). Therefore the emission of VOCs species of Bogotá and HCMC are similar and the values of NMVOC split of Bogotá are similar to HCMC. The same percentages of repartition are calculated every hour to the total NMVOC emissions. The categories of NMVOC in the split are: ETH = Ethane; HC3, HC5, HC8 = Alkanes; ETE = Ethene; OLI = Internal alkenes; OLT = Terminal alkenes; ALD = Acetaldehyde; TOL = Toluene; KET = Ketones; ORA2 = Acetic acid; HCHO, CSL = Cresol; XYL = Xylene.

Initial and boundary conditions for the photochemical simulations are based on measurements obtained by the Institute of Environment and Resources –VNU (IER-

VNU) and the HCMC environmental protection agency (HEPA). Measurements taken from stations located in the surrounding of HCMC. They show 30 ppb of O_3 and very low values of NO and NO_2 (0.19 ppb).

A pre-run of one day with the same emissions and wind fields is performed. This calculation provides more realistic initial conditions for the air quality simulations. The air quality simulations are run for the episode of 3 day 6th - 8th February 2006.

a) Evaluation of the uncertainty in air quality simulation

Results of numerical simulations are more reliable if the estimation of uncertainties in model prediction is generated. The uncertainties of the air quality model due to input parameters could be generated by using the standard deviation (square root of variance) around the mean of the modelled outputs (Hwang et al., 1998). Up to now, the Monte-Carlo (MC) technique is a brute-force method for uncertainty analysis (Hanna et al., 2000). A simple programme was developed (named EMIGEN) using the MC technique for generating different emission files. The MC technique used in EMIGEN includes different steps: (1) we generate a series of random numbers which follow a normal distribution (section 3.2.5 of chapter 3); (2) the EI results of EMISENS model (traffic source) are used as the input parameters for EMIGEN. The uncertainties of the input parameters for other sources (industrial, residential and biogenic sources), are calculated by using the available data which is estimated the emissions in HCMC (Mics-Asia, 2000; Ohara et al.,2007; Zhang et al.; 2009 and many others); (3) Running EMIGEN to get one hundred EI files. These hundred EI files are used as input for the air quality model. The uncertainty and the median of pollutants are calculated from 100 MC air quality simulations. The results of pollutants and their uncertainties from the output of the air quality modeling are divided into two pollutant types, primary and secondary pollutants. Their results from 100 MC in using TAPOM model, are shown in the following Figures (Figure 5.9 (a) and (b)).

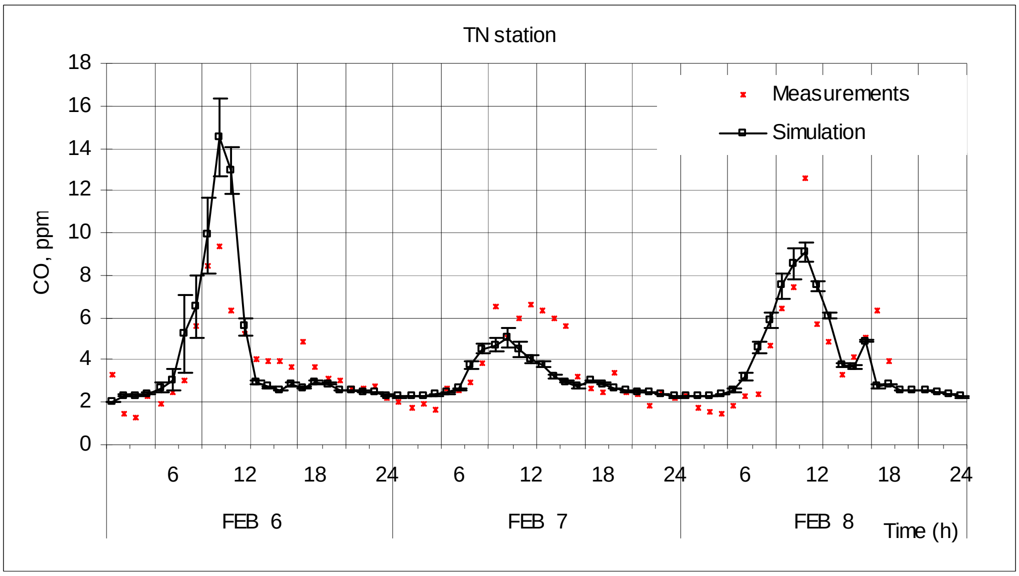
b) Simulation of primary pollutants

TN station is located in the center of HCMC, and D2 station is located around the city, but both stations are representative for ambient air quality. They are not situated beside the road. Figure 5.9 (a) shows that the concentration of CO (from measurements and simulations) has an important peak in the morning, between 0700LT and 1000LT. However, Figure 5.9 (b) shows that the peak of NO_x (from measurements and simulations) is presented later, between 0900LT and 1200LT. The peak is related to the highest emissions from traffic mainly due to the rush hour during this time period in HCMC. The peak of NO_x appears late than the peak of CO (around 2-3 hours) because the high emission of CO is related to the private vehicle (motorcycles and cars), while the high emission of NO_x is related to the trucks (heavy and light trucks). In HCMC, trucks have limited circulation from the city center during rush hours (6:00-8:30 and 16:00-20:00). The peak is amplified to a very high concentration due to a low mixing height in the early morning. At this time the temperature of the air masses are still cold, the vertical diffusion of pollutants is very weakly so the pollutants are stored at ground level. The air-monitoring network in HCMC includes 9 stations but due to the lack of calibration and maintenance of the equipments, measurements are available only for some day at some stations. The values of the peaks of both CO and NO_x are in good agreement with observations. The peaks of measurements and observations appear at the same time. Then, the emissions of pollutants decrease until later afternoon.

The second daily peak of CO and NO_x is observed around 1700LT and 1800LT because this is a second rush hour of the day. The peak is lower than the peak observed in the morning because at this time the ground is warmed up and there is strong vertical dispersion of pollutants. This peak is related to the traffic and it is sometimes underestimated by the model which may be attributed to an overestimation of the wind speed at this time.

The results from simulations which are shown in Figure 5.9 are the mean values of one hundred MC simulations. Probabilistic estimate are shown by plotting concentration enveloped (mean $\pm 1\sigma$) with time. Figure 5.9(a) shows that the uncertainty for the CO simulated differ by a maximum of 1.8 ppm ($\approx$34.4% of mean value) at rush hour 0700 LT – 0800LT on 6^{th} February 2006. The minimum uncertainty is 0.01 ppm ($\approx$0.5% of mean value) which is observed in the middle of all nights from 6^{th} to 8^{th} February 2006.

(a)



(b)

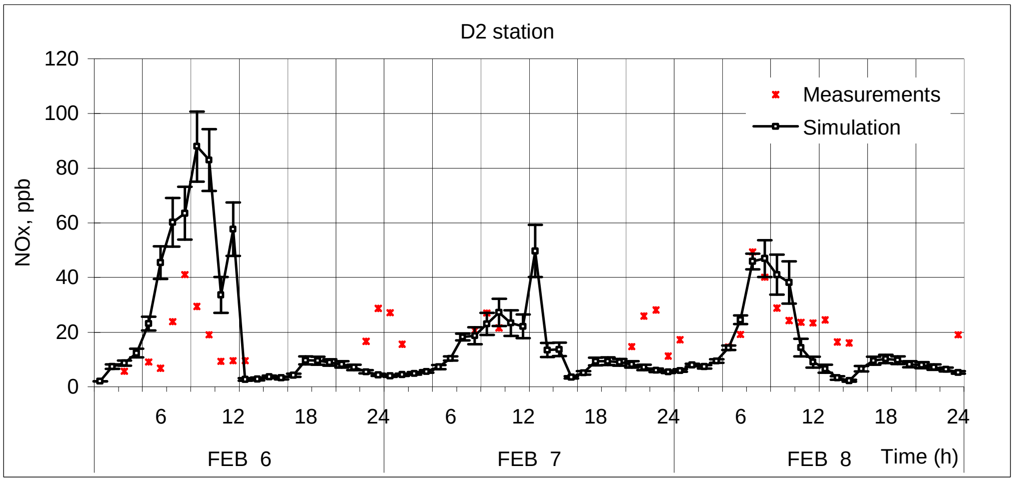


Figure 5.9: Comparison between the results of measurements (stars) and simulation (solid line) during the selected episode (on 6th - 8th February 2006) for CO (ppm) and NO_x (ppb) at TN and D2 stations, respectively. The uncertainties of CO and NO_x from 100 MC simulations are presented by 1σ (standard deviation). NO_x refers to NO + NO_2.

Figure 5.9(b) shows that the NO_x uncertainty differs by a maximum of 11.28 ppb ($\approx$13% of mean value) at the same time of appearance NO_x peak. The minimum uncertainty is 0.47 ppb ($\approx$5.9% of mean value) which is observed during the middle of night.

c) Simulation of secondary pollutants: Ozone

- ***Spatial distribution of Ozone (O_3)***

The main emissions of primary pollutants are found in the center of the city (located in Figure 5.2 where the TS, TN, DO, ZO and D2 stations are described). Figure 5.10 shows the plume of O_3 developed during the 7^{th} February 2006. The spatial distribution of O_3 is formed depending on the meteorological conditions and the primary pollutants

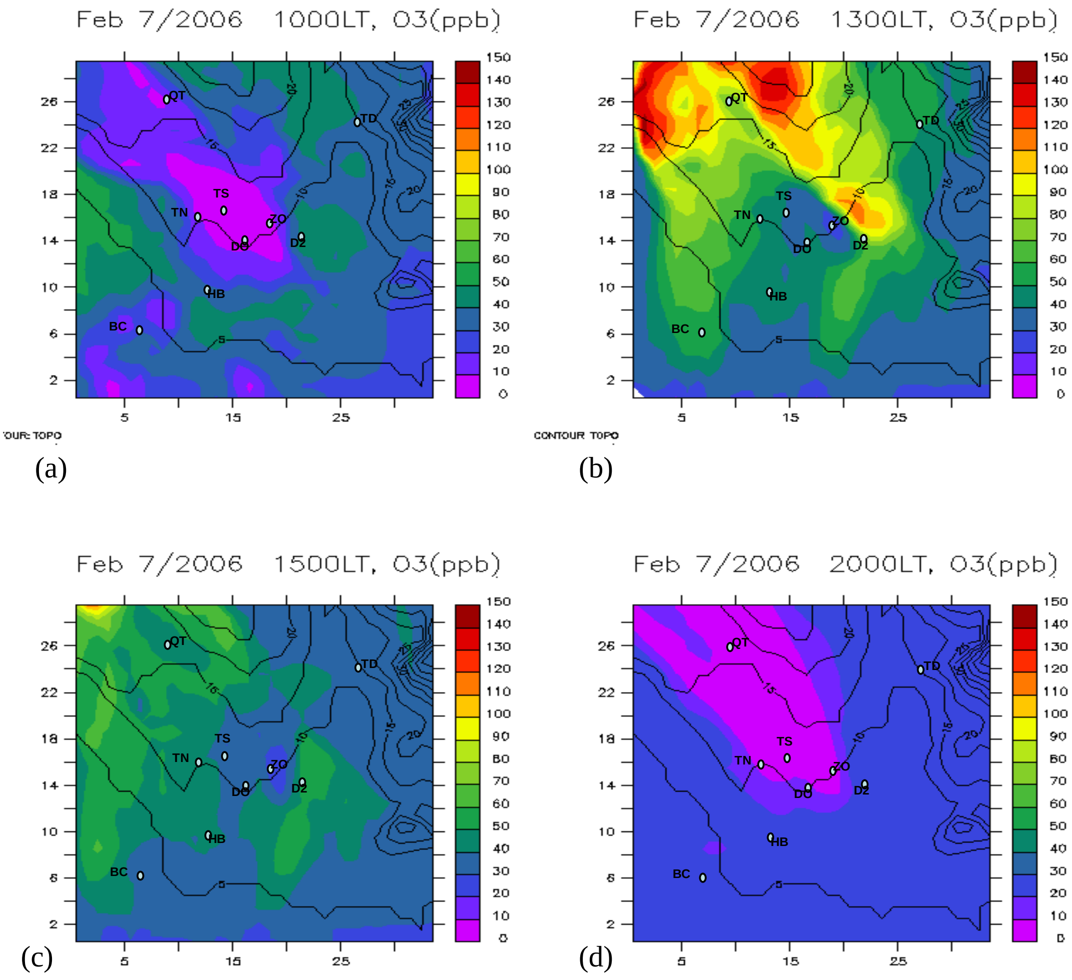


Figure 5.10: Map of Ozone concentrations (ppb) at ground level in the domain of 34 km x 30 km, at 10LT00 (upper left panel), 1300LT (upper right panel), 1500LT (lower left panel) and 2000LT (lower right panel), 7^{th} February 2006 and measurement stations. The different colours are the O_3 levels.

concentrations. In the early morning, there are very high concentrations of NO_x stored in the center of the city, which generates O_3 destruction at this location, while Figure 5.10(a) shows that at 1000LT O_3 is being formed in the neighbouring city. At this time pollutants are pushed to the north-west of city by the wind coming from the south-east. Figure 5.10(b) shows that until 1300LT, the time with the highest solar radiation, the maximum quantity of O_3 is formed, while the wind is divided in three main convergences, which divides the plume of O_3 into two different small plumes. Two O_3 maxima are formed at this time on 7th February, 140ppb and 150 ppb, for the northern and north-western parts of the city respectively. Then, until 1400LT the wind direction is the same wind direction than at 1300LT. However the wind speed is very strong (two times stronger than at 1300LT), which pushes rapidly the O_3 plume to go up to the north and north-west of the city. Figure 5.10(c) shows that at 1500LT the plumes leave the basin of HCMC through the north and north-west. The O_3 concentrations remain low in the city (75ppb of O_3 at 1500LT). Then, at 2000LT the wind direction is the same wind direction than at 1000LT. At 2000LT there is not solar radiation coming to the earth which prevents O_3 production and promotes the destruction of O_3, especially in the north-western part of the city.

Figure 5.11 shows the spatial distribution of O_3 concentrations during the 8th of February 2006. In the morning the wind coming from south-east pushes the high concentrations of NO_x from the center of the city towards the north-eastern part which promotes the process of destruction of O_3 in the north-east. Figure 5.11(a) shows the maximum concentration of O_3 at 1000LT 70 ppb, generated in the southern part of the city. Around 1300LT the wind pattern changes, one part of the pollutants is transported to the south-east and another part to the western part of the city. Figure 5.11(b) shows that at 1300LT, two O_3 maxima are computed, 200ppb and 170 ppb, for the south-eastern and western par of the city respectively. After 1300LT, thanks to the change in the wind pattern, the wind direction is coming from south-east which pushes the pollutants towards the north-west of the city. Figure 5.11(c) shows that until 1500LT the two plumes of O_3 leave the basin of HCMC towards north-west. The ozone concentrations remain in the city (120ppb of O_3 at 1500LT). Then the wind speed becomes stronger and gets its maximum value at

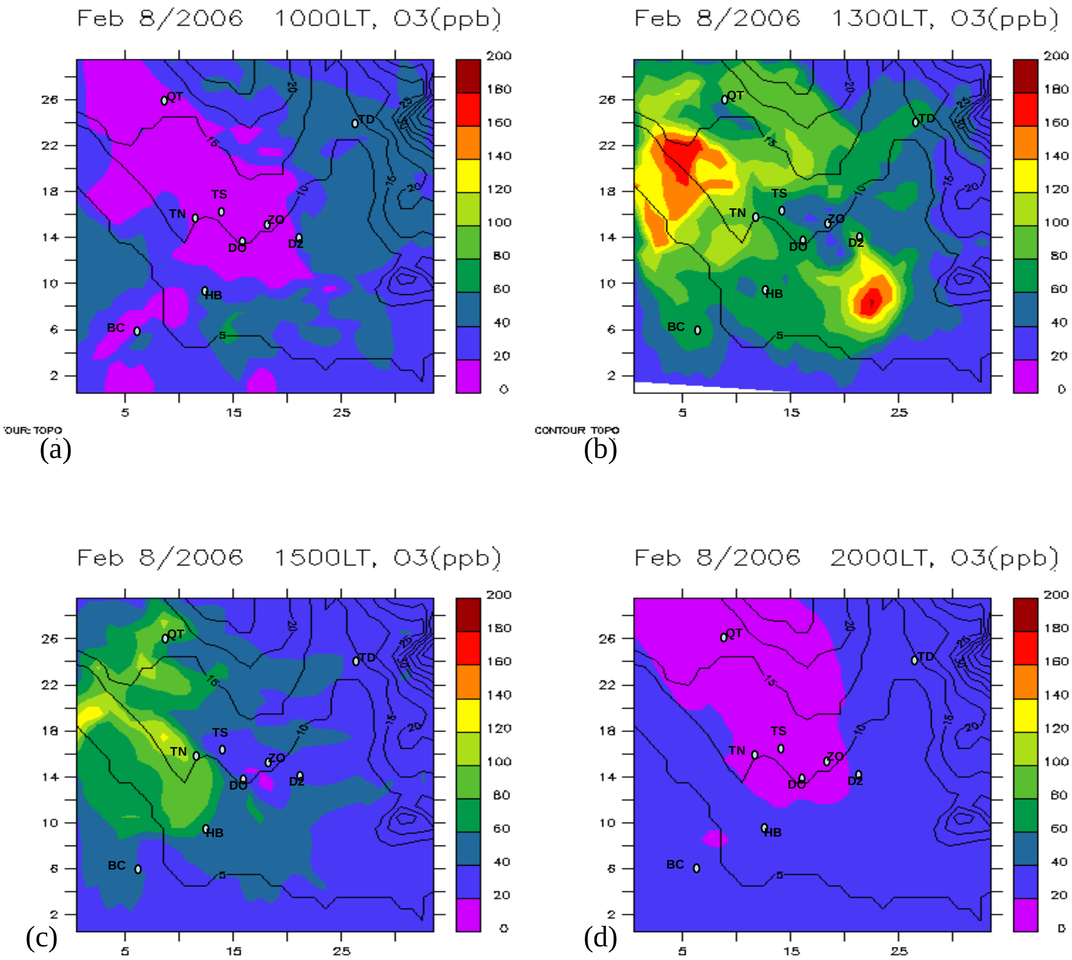


Figure 5.11: Map of Ozone concentrations (ppb) at ground level in the domain of 34 km x 30 km, at 10LT00 (upper left panel), 1300LT (upper right panel), 1500LT (lower left panel) and 2000LT (lower right panel), 8th Feb 2006 and measurement stations. The different colours are the O_3 levels.

1600LT. At this time, all the pollutants are pushed toward north-west and the maximum ozone in the city is 55ppb.

- ***Comparison with measurements***

The results from simulations shown in Figure 5.12 and Figure 5.13 are the mean values of 100 MC simulations. Probabilistic estimates are shown by plotting concentrations (mean $\pm 1\sigma$) with time. HB station is located in the center of HCMC, and D2 station is

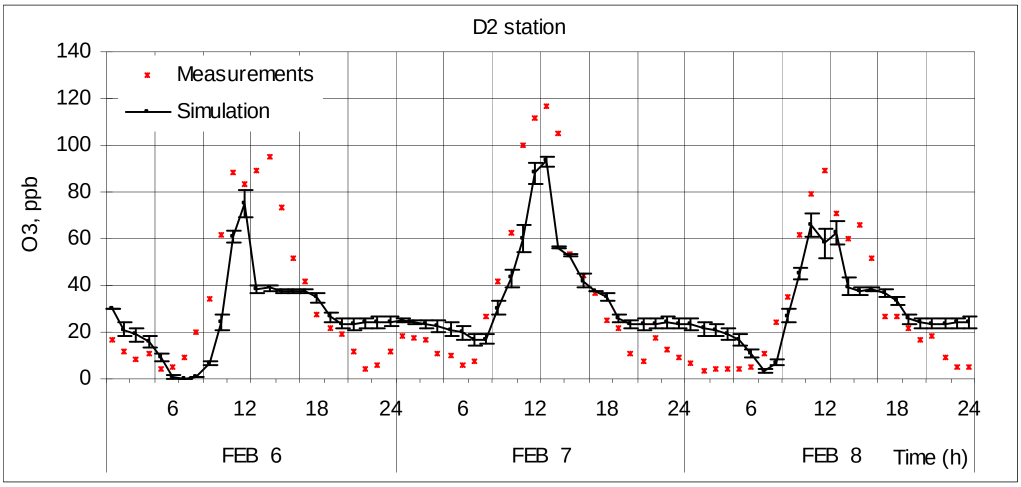


Figure 5.12: Comparison between the results of measurements (stars) and simulation (solid line) during the selected episode (on 6th - 8th Feb 2006) for Ozone (ppb) at D2 station. The uncertainties of O_3 from 100 MC simulations are presented by 1σ (standard deviation).

located suburban the city (Figure 5.2). In general the concentration of O_3 in D2 station (Figure 5.12) is higher than in HB station (Figure 5.13) because D2 station is situated closer to the O_3 plumes than HB station. The highest concentrations of O_3 are observed in the north and north-west of the city. As both of these two stations are not situated in the O_3 plumes, they are not representative of the evolution of the O_3 plume.

The simulation shows high O_3 levels at the same stations as the measurements do on 7 February as shown on Figure 5.12, indicating a good reproduction of the plume position. We can see that the HB station is located closer to the south of the city than the D2 station (Figure 5.10), this confirm the fact that pollutants are being transported in the northern and north-western direction at 13LT00 on 7 February. Unfortunately the measurements of Ozone for the stations around the city are not available, so we can not compare the results between simulation and measurements for that zone.

The uncertainty analysis for the air quality model is also studied by running 100 MC simulations. Figure 5.12 and Figure 5.13 show that the uncertainties of O_3 differ by a maximum of 5ppb ($\approx$8.6% of mean value) at 1100LT-1300LT on 6th - 8th February 2006 at both stations. The minimum uncertainty of O3 is 1ppb ($\approx$15% of mean value) at 0700LT – 0900LT on 6th – 8th February 2006 at both stations.

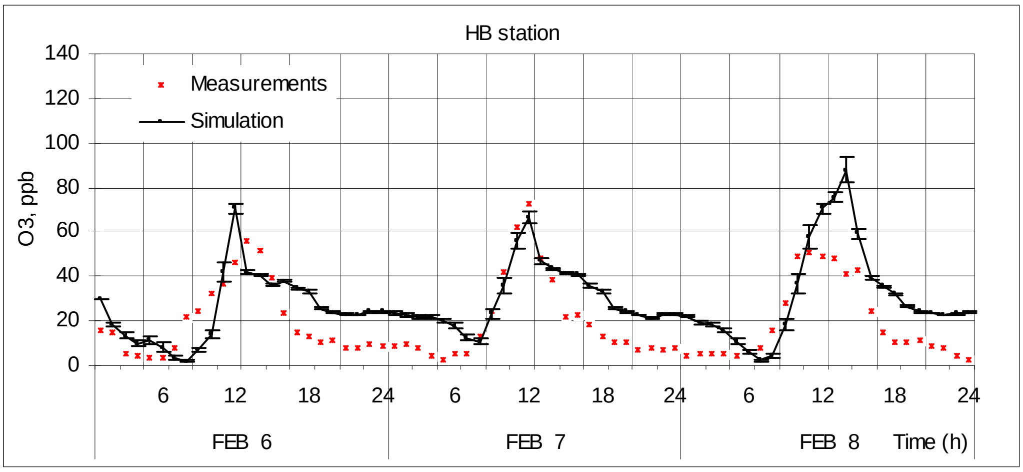


Figure 5.13: Comparison between the results of measurements (stars) and simulation (solid line) during the selected episode (on 6th - 8th Feb 2006) for O_3 (ppb) at HB station. The uncertainties of O_3 from 100 MC simulations are presented by 1 σ (standard deviation)

In summarize, 6th – 8th February 2006 is a period which is representative for one of the highest O_3 episodes during the dry season of the year in HCMC. It is found that the O_3 concentrations overpassed the limited standard during this period. The highest 1h average O_3 concentration of 120 ppb, 150ppb and 240ppb were observed on 6th, 7th and 8th February, respectively (while the 1h Vietnam Air Quality Objective for O_3 is of 100 ppb). The primary pollutants (NO_x, CO, VOC…) show highest values in center of city where the highest density of traffic is found. So the huge part of population in the center of HCMC is living with unfavourable conditions due to high concentration of primary pollutants. However, in the case of secondary pollutant (O_3) we can see that it has most favourable conditions for the population living in the center of HCMC and unfavourable for the population living in the north and north-west of HCMC. Once the models were shown able to reproduce and understand the principal characteristics of pollution in HCMC, it is very useful to study different strategies to reduce pollution for the city in the future. Two main strategies will be study in section 5.5.

5.5 Abatement strategies and discussion

One of the most important functions of the air quality models of the meso-scale 3D is their capacity to simulate strategies to reduce pollution. For over 15 years, a lot of studies to evaluate air pollution abatement strategies have been carried out by using air quality models (Metcalfe et al., 2002; Palacios et al., 2002; Zarate et al., 2007). The previous study on air quality in HCMC (section 5.4.2) shows that it is urgent to establish emission control scenarios. The scenarios should be the most effective for reducing pollution levels.

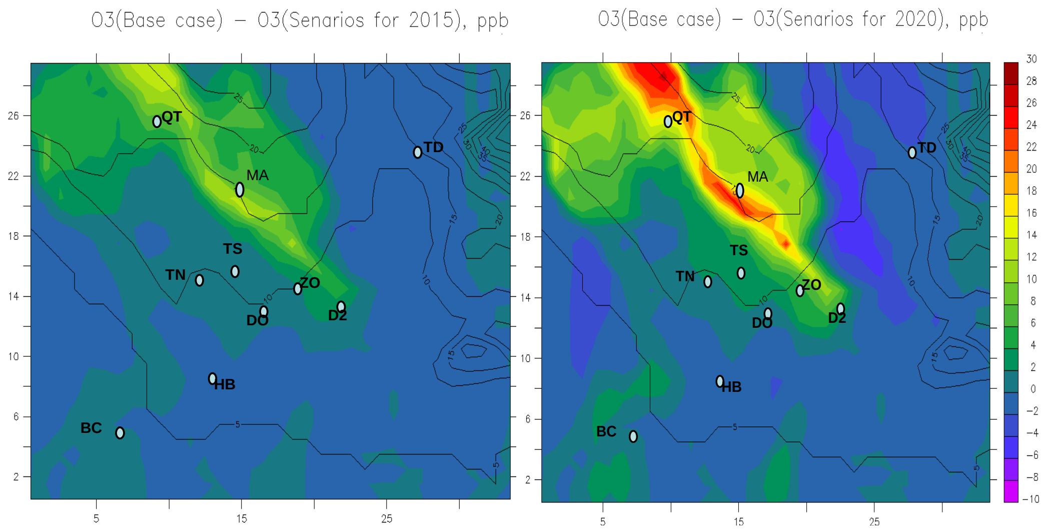
Over some recently years, the results of air quality monitoring have shown that the pollutants exceeded regularly the standard limits in HCMC due to the emissions from the traffic source (Hepa, 2005; Hepa, 2006). The local government has started to design some air quality control plans for traffic in HCMC. The first plan is designed for the year 2015 and the second plan is designed for the year 2020. The two air quality control plans are shown in detail in section 4.5.2 of chapter 4 (named: (1) Emission reduction scenario for 2015 and (2) Emission reduction scenario for 2020).

The main ideas are that in 2015 the HCMC government will perform many activities to control air pollution concerning the road traffic source (Trinh, 2007). They are: (1) controlling the emission of all vehicles (Thang, 2004), (2) the first metro line will be finished at the end of 2014 (Bao du lich, 2008) and (3) HCMC government will add 3000 new buses during 2006-2015 (Tuong, 2005).

For the year 2020, four metro lines will be constructed (metro system will replace 50% of total motorcycle) (Bao du lich, 2008) and the number of buses will be increased to 4500 during 2006-2020.

From the previous plans, we built the emission inventories for the year 2015 and 2020 by using the EMISENS model (section 4.5.2 of chapter 4).

The results of EI of the two strategies are used as the input for EMIGEN programme (section 5.4.2(a)). EMIGEN is run included random processes to get 100 output EI files for each strategy. For calculating the uncertainty in EI, we consider the uncertainties of input parameters of two strategies are similar to the uncertainties of input parameters of 2006.



(a) (b)

Figure 5.14: Effect of two strategies on O_3 concentration (ppb) fields for the 7th Feb 2006 at 1300LT ground level in the domain 34 km x 30 km. Figure (a) represents the reduction of O_3 concentration in 2015 from the ozone concentration in 2006. Figure (b) represents the reduction of O_3 concentration in 2020 from the ozone concentration in 2006. The measurement stations are shown in Figure 5.2.

The EI files are the input files for 100 MC air quality simulations. The results of 100 MC air quality simulations will be used to evaluate the uncertainties of abatement strategies. The results of two strategies are shown in the following sections of 5.5.1 and 5.5.2.

5.5.1 Spatial distribution of O_3

The impacts of two strategies on the levels of tropospheric O_3 in HCMC are shown in Figure 5.14 (spatial distribution of O_3), Figure 5.15 and Figure 5.16 (results on 3 monitoring stations).

As discussion in section 4.5.2 of chapter 4:

- If HCMC follows the reduction plan for the year 2015, the reductions for the HCMC grid area as a whole are 3.3% for CO, SO_2, and CH_4 emissions. There is an increase in NO_x emissions of 8%. The impacts of the proposed emissions changes on O_3 are shown in Figure 5.14 (a). Mean values of O_3 are reduced from 28.5 ppb to 28.0 ppb and the maximum from 150 ppb to 136 ppb on 7th February.

- If HCMC follows the reduction plan for the year 2020, the emission reductions for HCMC grid area as a whole are 8.6% for CO and 12.5 % for CH_4, there are increases in NO_x, SO_2 and NMVOC emissions of 20.1%, 7.6% and 6.2% respectively. The impacts of the proposed emissions on O_3 peak are shown in Figure 5.14 (b). Mean values of O_3 are reduced from 28.5 ppb to 27.6 ppb and the maximum from 150 ppb to 120 ppb for 7th February. The results show NMVOC – sensitive ozone production in HCMC because ozone decreasing with increasing ambient levels of NO_x.

The highest reduction of O_3 concentration is found at the same place of the principal O_3 plume for both abatement strategies. A deeper analysis of this reduction will be discussed by plotting the O_3 concentration variable with respect to time and its uncertainties. In this study we select some stations where we find the maximum of O_3 reduction, the medium of O_3 reduction and the minimum of O_3 reduction. The MA, D2 and HB stations are chosen for the maximum, medium and minimum reduction zones, respectively (Figure 5.14). Their results are shown in the following section.

5.5.2 Analysis of Ozone at different measuring stations

Strategy in 2015

Figure 5.15 shows the reduction of O_3 concentrations ($\overline{\Delta O_3}$ in equation 5.1) in 2015 from the O_3 concentration in 2006 and its uncertainties ($\sigma_{\overline{\Delta O_3}}$ in equation 5.2) in different stations (in this section we will consider the standard deviation as the uncertainty).

The Delta O_3 ($\overline{\Delta O_3}$) and uncertainties of O_3 ($\sigma_{\overline{\Delta O_3}}$) presented on Figure 5.15 are calculated using equations (5.1) and (5.2). These values are calculated from 100 MC simulations for the base case and 100 MC simulations for each strategy.

$$Delta\ O_3 = \overline{\Delta O_3} = \frac{\sum_{i=1}^{100}(O^i_{3\_Base\ case} - O^i_{3\_2015})}{100} \qquad (5.1)$$

where: i is the number of simulation

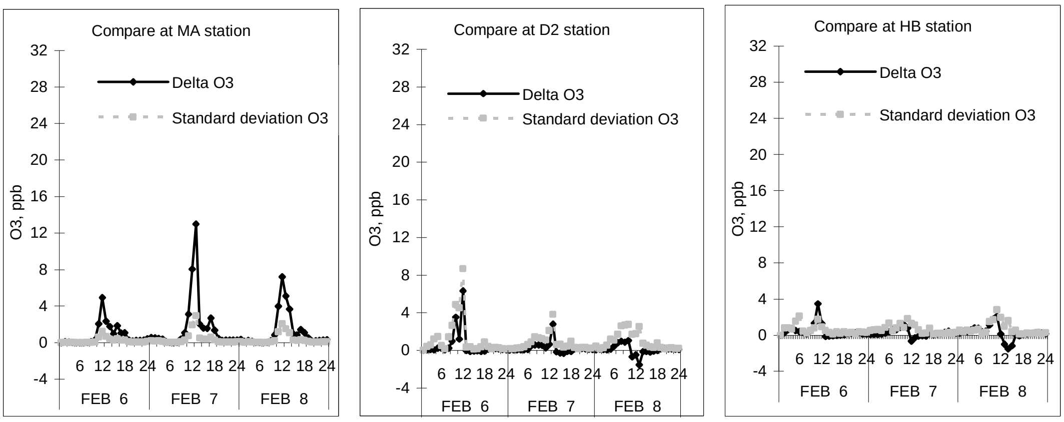


Figure 5.15: Reduction of O_3 (in ppb) in 2015 (strategy in 2015) from the ozone concentration in 2006 and its uncertainties, for the first layer near the ground during the selected episode (on 6th - 8th Feb) at MA, D2 and HB stations.

$O^{i}_{3\_Base\ case}$ is the O_3 concentration of base case (2006) for the ith simulation

$O^{i}_{3\_2015}$ is the O_3 concentration of strategy in 2015 for the ith simulation,

$$\text{Standard deviation of } O_3 = \sigma_{\overline{\Delta O_3^*}} = \sqrt{\frac{\sum_{i=1}^{100}(\Delta O_3^i - \overline{\Delta O_3})^2}{99}} \tag{5.2}$$

where: ΔO_3^i is the difference in O_3 concentration between the base case and the strategy in 2015 for the ith simulation.

The highest uncertainties of O_3 reduction appear at the same time of the highest O_3 reduction at 1200LT - 1400LT of each day (Figure 5.15). The highest reduction of O_3 concentration at MA, D2 and HB stations during 6 - 8 February are 14ppb, 6.7ppb and 3.9ppb respectively. However, the highest uncertainties of O_3 reduction at MA, D2 and HB stations are 3ppb, 9ppb and 3.5ppb respectively. So, the uncertainties of O_3 reduction are in general similar to the O_3 reduction. We can not conclude that the change in O_3

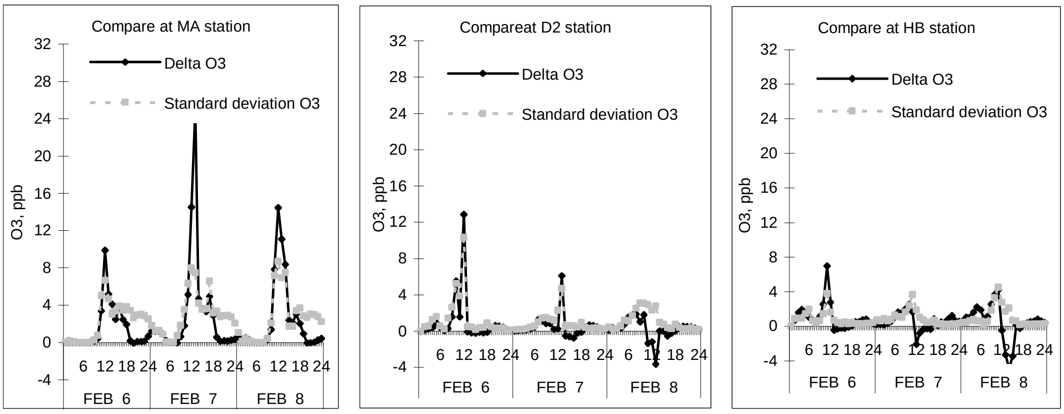


Figure 5.16: Reduction of O_3 (in ppb) in 2020 (strategy 2020) from the ozone concentration in 2006 and its uncertainties, for the first layer near the ground during the selected episode (on 6th - 8th Feb) at MA, D2 and HB stations.

concentration is due to the impact of the emission control plan because the change can probably be due to the impact of uncertainties of input parameters.

For the evolution of primary pollutants of the strategy in 2015, the concentrations of NO_x in simulations will increase 7% than those were in 2006. However, the concentrations of CO and CH_4 decrease around 10% and 8% respectively than those were in 2006.

In summarize, there is very little impact of the emission control plan in 2015 because the values of pollution reduction are small.

Strategy in 2020

Figure 5.16 shows that the highest uncertainties of O_3 reduction ($\sigma_{\overline{\Delta O_3}}$) also appear at the same time of the highest O_3 reduction ($\overline{\Delta O_3}$) at 1200LT - 1400LT of each day. In general, the O_3 concentration in 2020 is lower than the O_3 concentration in 2006. There are some small zones (1300LT – 1500LT at D2 and HB stations, Figure 5.16) where we can see that the O_3 concentration in 2020 is higher than the O_3 concentration in 2006. However these zones are outside the plumes of O_3 and the increased values of O_3 are very small which are not important. In addition, the O_3 concentrations in these zones are very low.

The highest reduction of O_3 concentration at MA, D2 and HB stations during 6^{th} – 8^{th} February are 23.5ppb, 13.4ppb and 7.8ppb respectively. While, the highest uncertainties of O_3 reduction at MA, D2 and HB stations are 8.2ppb, 11ppb and 5.1ppb respectively. So, the O_3 reduction is higher than the uncertainty of O_3 reduction in all stations. It means that the change in O_3 concentration is due to the change in emissions from the emission control plan.

For the evolution of primary pollutants of the strategy in 2020, the concentrations of NO_x in simulations will increase 16% than those were in 2006. However, the concentrations of CO decrease around 7% than those were in 2006.

In summarize, this emission control plan in 2020 has strong impact on the primary (NO_x) and secondary pollutants (O_3) in HCMC. However, their concentrations are still higher than the limit of WHO and Vietnamese standards.

5.6 Conclusions and outlook

The numerical approach of simulating an episode of photochemistry is used to study air pollution in HCMC and two abatement strategies including uncertainties with success. This research has used a nested meso-scale meteorological model (FVM) and an air quality model (TAPOM). The meteorology of HCMC is influenced by the local phenomena (slope winds and sea breeze) and the global phenomenon (Trade Winds).

The air quality modeling helped us to better understand the distribution of pollutants over HCMC. The O_3 plumes are found in north-west of the city during the selected episode. The results of air quality modeling showed that the simulated O_3 concentrations are higher than the limiting standard about 1 $\div$ 2 times. The uncertainty in the air quality model result is carried out by using the 100 MC simulations. The uncertainty in the results of simulation was found about 15% of mean value.

For the better understanding about emission control plans of the city in future two abatement strategies are studied in this research work. The abatement strategy in 2015 shows that O_3 concentration in 2015 will be similar to the present O_3 concentration level. However, the abatement strategy in 2020 shows that O_3 concentration in 2020 will decrease around 10% - 30% than the present concentration level of O_3. We can conclude that the 5 metro lines in 2020 are very important for improving the air quality for HCMC, because the metro systems will replace 50% of motorcycles from the city.

Finally it should be better if we have more measurement stations and measure the real VOCs (Volatile organic compounds) concentration for validation of air quality model. Further research should study more abatement strategies for the city such as: replacement of the buses used diesel oil by the buses used natural gases, reduced the traffic flow in center of city where the highest emissions are appeared, etc. And doing more study on meteorological and air quality in different seasons throughout the year in HCMC is also necessary to understand the meteorological and air pollution regime during a year in HCMC.

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Chapter 6 Conclusions and future work

6.1 Conclusions

Air quality in large cities of the world is more and more deteriorating. Road traffic emissions are the main culprit which causes air pollution in such cities. Existing methods for generating emission inventory (EI) for road traffic sources are expensive and take a lot of time. Consequently, it is extremely difficult to design efficient abatement strategies to reduce air pollution in such cities. This work was devoted to develop and validate a new model for generating EI for road traffic source. Then, this new model is applied to study effective abatement strategies for reducing of air pollution in Ho Chi Minh City (HCMC), Vietnam.

In the first part of this thesis, the new road traffic emission model (called EMISENS ≡ EMIssion SENSitivity) was developed. An innovative EMISENS model to generate road traffic emissions was developed and validated. EMISENS model is able to calculate a road traffic emission in several steps with different levels of complexity. In the first step, EMISENS generated an aggregated EI for the whole domain with a minimum of input parameters by using top-down approach. In the second step, the model computed the uncertainties of these input parameters using Monte-Carlo (MC) technique, these uncertainties are used to identify which of the parameters have the greatest impact on the emissions and should be improved. Finally, the input parameters are distributed in space and time for calculating space and time distributed emissions by using bottom-up approach. So, the main innovative components in EMISENS are: (i) the model computes a total amount of emissions and distribute it in time and in space using a methodology fully compatible at the same time with a top-down and a bottom-up approach, (ii) the model computes the emissions and the uncertainties within a reasonable computing time and (iii) the model formulation is based on a well known and well referenced methodology to facilitate the access to standard database for input parameters.

In this work, Strasbourg city is proposed as reference case to validate EMISENS model because in Strasbourg the necessary inputs for development EI is well organized and an accurate EI is available for comparison. The validated results after validating show that the EMISENS model is able to calculate road traffic emissions for cities in developed countries as well as in developing countries at every levels of complexity. Once we finished validating the EMISENS model we used EMISENS to run for the different simplifications of input parameters which correspond with the situation of developing countries to evaluate the level of errors created by limiting of input parameters for generating EI. Four scenarios with different simplifications were studied. Their results proved that we can simplify many different input parameters when we generate EI such as (i) it could be used only one average emission factors in stead of using hot emission factor and cold emission factor, (ii) vehicles could be grouped into 5 vehicle categories (motorcycle, car, bus, light truck and heavy truck), etc.

The second part of study in this thesis comprises the application of EMISENS model to generate EI over HCMC due to the developing conditions of the city and especially high pollution of the air. For generating EI for traffic sources, a lot of campaigns and surveys were organized during 2007 and 2008 for collecting the HCMC's on road traffic information. The previous information was used to generate EI for road traffic emissions in HCMC and also generate the uncertainties in emission which cause from input parameters. The study of uncertainties in emission confirmed that:

- The most sensitive parameters are the hourly street mileage for urban street category and the emission factors for urban street category.
- Motorcycle has the highest impact on the uncertainty in emission results.
- It is better to divide streets of HCMC into 5 street categories (3 urban street categories, 1 rural street category and 1 highway street category) than into 3 street categories (1 urban street category, 1 rural street category and 1 highway street category) because of the accuracy of EI in case of 5 street categories is higher than the accuracy of EI in case of 3 streets categories.
- The highest emissions are found in the center of the city where the highest street density is found.

For generating EI for industrial, residential and biogenic sources, the data is limited therefore the top-down approach was used to generate these emission sources for HCMC. After generating EI for all emission sources in HCMC, some conclusions are extracted as follows:

- The traffic source is the most important emission source in HCMC. Emissions from traffic source occupy more than 80% of total emissions in HCMC.
- Motorcycle is the most important among traffic emission source. Emissions from motorcycle contribute more than 90% of total traffic emissions in HCMC.

Due to these reasons, four abatement strategies of emission were studied. The main objective of these strategies is to replace motorcycle by public transport. Some conclusions of fours strategies are summarized as follows:

- If we follow the HCMC's emission control as planned for 2015, the emissions of CO and CH_4 in 2015 will reduce about 14% than the emission in 2006. However the emissions of NO_x will increase about 7% than the emission in 2006.
- If we follow the HCMC's emission control as planned for 2020, the emissions of CO and CH_4 in 2020 will reduce about 8% than the emission in 2006. However the emissions of NO_x will increase about 20% than the emission in 2006.
- If the HCMC government does not controlling emissions (Business as Usual strategies), the emissions in 2015 will increase more than 25% than the emission in 2006.
- If the HCMC government does not implement the strategies to control emissions (Business as Usual strategies), the emissions in 2020 will increase more than 55% than the emission in 2006.

For all the strategies, the emissions of NO_x increase significantly because the public transport in HCMC is mainly buses using diesel oil (responsible of NO_x emissions). So that the last strategy which replaced the actual buses using diesel oil by the buses used Compressed Natural Gas (CNG), was tested for the year 2015. Consequently, all the emissions in 2015 will reduce.

Finally, the previous EI, the meteorological and air quality models were used to study air quality in HCMC and study effective abatement strategies for improving air quality in HCMC. For improving the accuracy of air quality simulation, we used 100 MC simulations during air quality simulation. The uncertainty and the median of pollutants are calculated from 100 MC. Results were validated with measurements during a selected pollution episode on 6-8 February 2006. The conclusions are:

- The meteorological field of HCMC is influenced by local phenomena and global phenomenon.
- Meteorology of HCMC is influenced by slope winds in north-eastern part of the domain where the high altitude is found.
- Meteorology of HCMC is influenced by sea breeze in south-eastern part of the domain because this area is close to the East Sea.
- The results of meteorological simulations are in good agreement with the measurements.
- Under given circumstances such as the period chosen for air quality simulation, the morning pollution is pushed towards the north-west of the city. Consequently, O_3 plumes are found in north-west of the city.
- The highest concentrations of O_3 are found in center of O_3 plume. These concentrations of O_3 are about 2 times higher than standard limit.
- The results of primary pollutants and secondary pollutants between air quality simulations and measurements are in good agreement.
- The uncertainty in the results of simulations of O_3 is found about 15% of mean value.

After validation the capacity of air quality model for simulating air quality in HCMC, we used this model to study two effective abatement strategies for HCMC. The results of EI for the two abatement strategies in second part of this PhD work are used as input of air quality model. Each abatement strategy was run 100 MC simulations. The results of these 100 MC simulations are used to calculate the mean value and the uncertainties in abatement strategies. The conclusions are:

- Effective abatement strategy for 2015: the concentrations of O_3 in 2015 are similar to the O_3 concentrations in 2006.

- Effective abatement strategy for 2020: the concentrations of O_3 in 2020 will decrease until 30% of O_3 in 2006.

In summary, the developed model EMISENS for generating road traffic emissions provides the new approach to manage urban air quality. This model has been applied several cities (for both developed and developing countries) in the world, such as Agadir city in Morocco (by Hicham and Habiba), Bogotá in Colombia (by Sandra and Jan), Bangalore in India, Korea, Strasbourg in France and HCMC in Vietnam. Their results are highly valuable for air quality management. HCMC is one of the cities applying EMISENS model to study effective abatement strategies for reducing pollution. This is the first study on air quality in HCMC based on modeling approach. The author really hopes that this scientific contribution will improve the air quality in large cities in the world, especially for Ho Chi Minh City.

6.2 Future work

During this PhD thesis, we tried to work for the best. However there are some recommendations for future research works. These recommendations are:

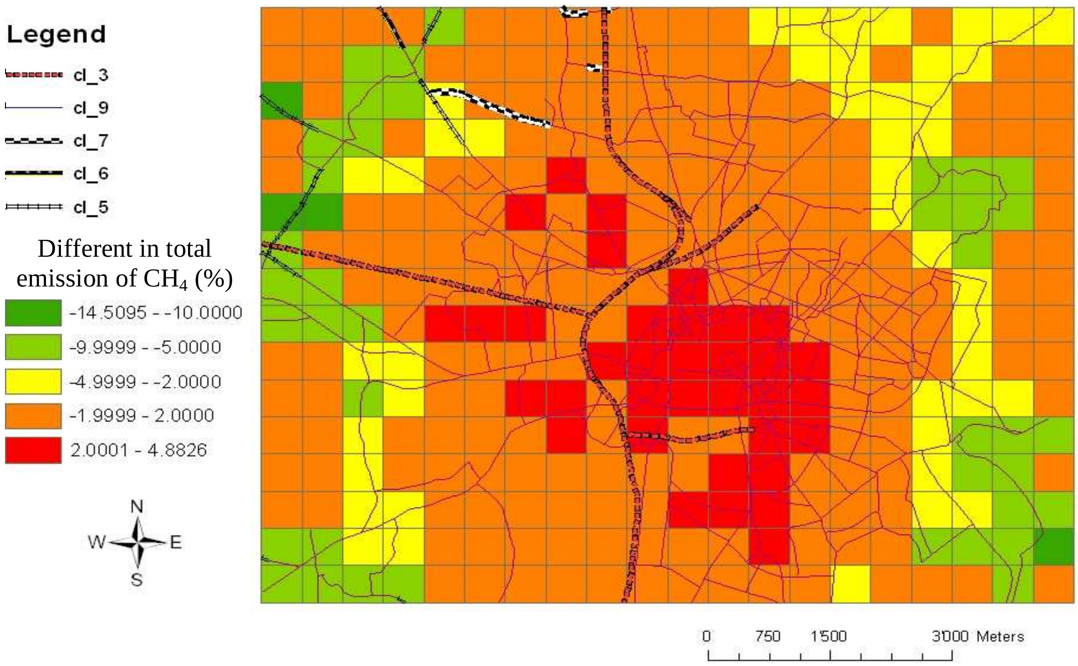
- Nowadays, almost all the large cities in the world have traffic jam problems because the infrastructure of large cities can not keep pace with the amazing urbanization and its economic growth. If a traffic jam occurs, the environmental problems are worse. So it is necessary to introduce a module in EMISENS model for estimating the emission when a traffic jam occurs.
- We should design an interface of the EMISENS model in order to use it more easily. Then, we should convert the EMISENS model to other language (eg. C++) in order to run under Window environment because EMISENS runs currently under Linux environment.
- Application of this model on other developed cities should be done in order to improve the quality of model validation.
- Studying the air quality in HCMC has many difficulties due to the limit of information and data. Some of them are: (1) the concentrations of VOCs should be measured because up to now there are no measurements of total VOCs

concentrations for HCMC. (2) The EI for industrial, residential and biogenic sources must be improved and the future efforts should be done with the purpose of collecting of data from these sources.

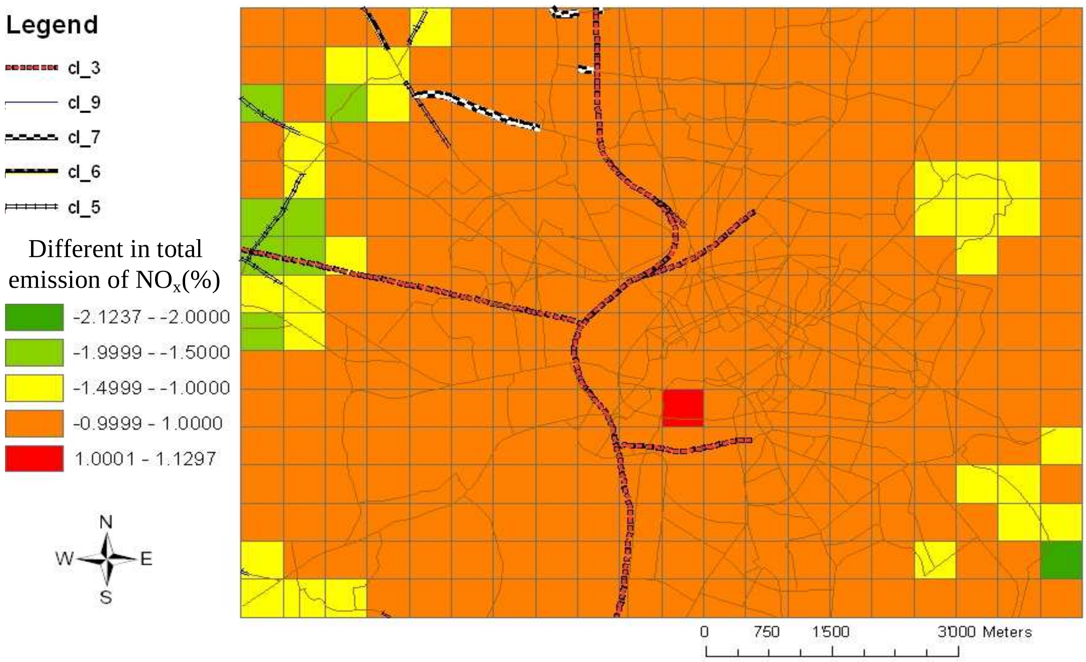
- Supplementary simulations should be performed in different seasons throughout the year in HCMC to understand the meteorology and air pollution regime during a year in HCMC. Additionally, effective abatement strategies should be studied under different meteorological conditions in order to get definitive conclusions.
- Another interesting track for the future research is the study of other additional abatement strategies for the city, such as (1) we replace the buses used diesel oil by the buses used CNG, (2) we reduce the traffic flow in center of city where the highest emissions are appeared (e.g. the private cars are banned to circulate in center of city during the rush hours).

Annex A. Diagrams and Figures of chapter 3

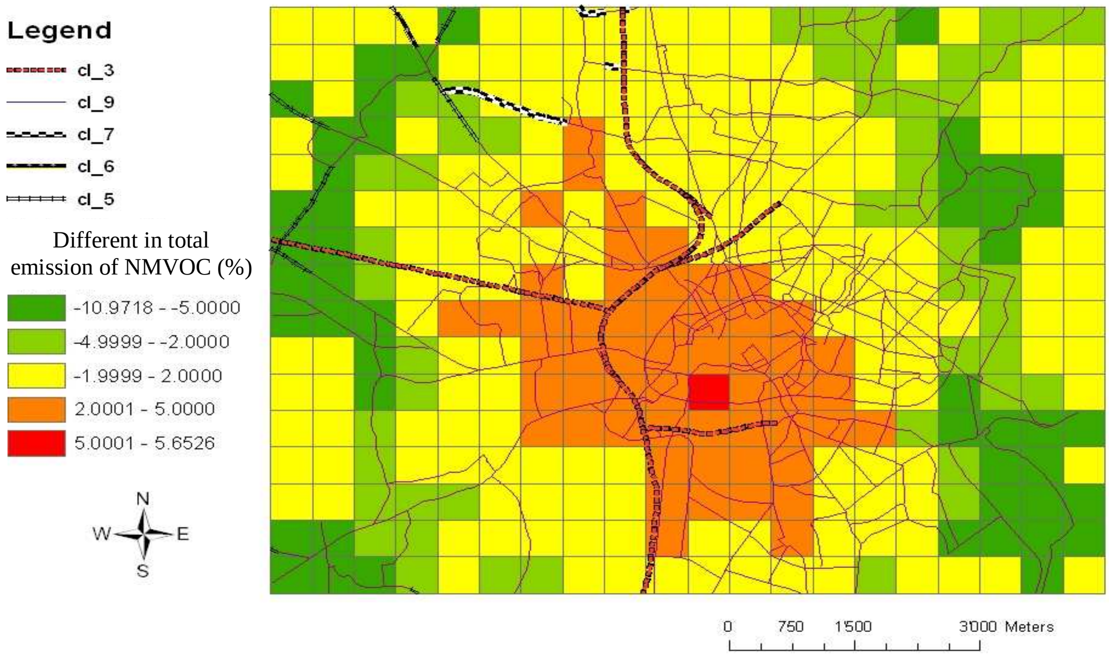
3.1 Scenario 1



A .3.1.a: The difference in emission of CH_4 (in %) between reference case – scenario 1 on the study domain. Different street categories are already defined in Figure 3.1.

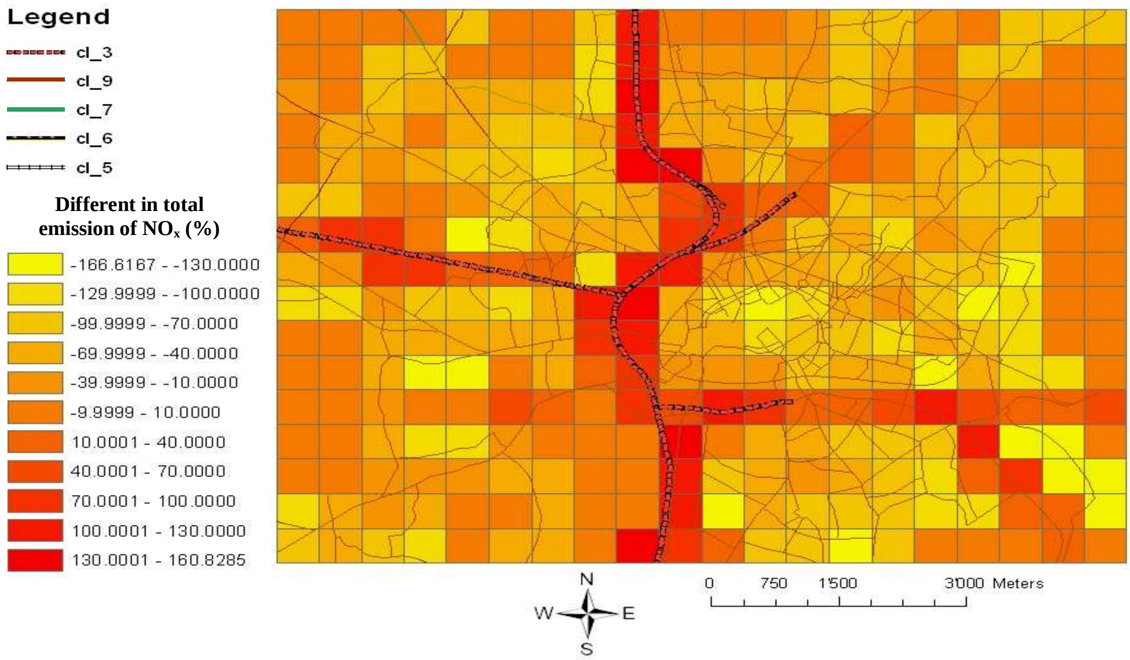


A. 3.1.b: The difference in emission of NOx (in %) between reference case – scenario 1 on the study domain. Different street categories are already defined in Figure 3.1.

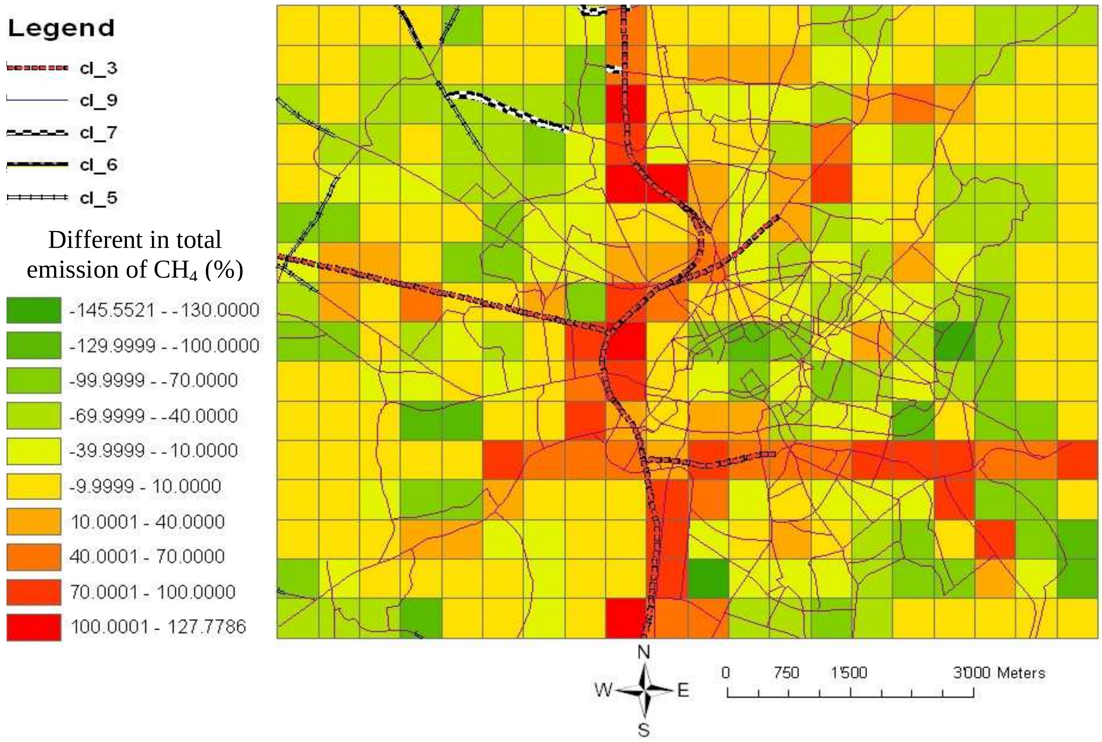


A. 3.1.c: The difference in emission of NMVOC (in %) between reference case – scenario 1 on the study domain. Different street categories are already defined in Figure 3.1.

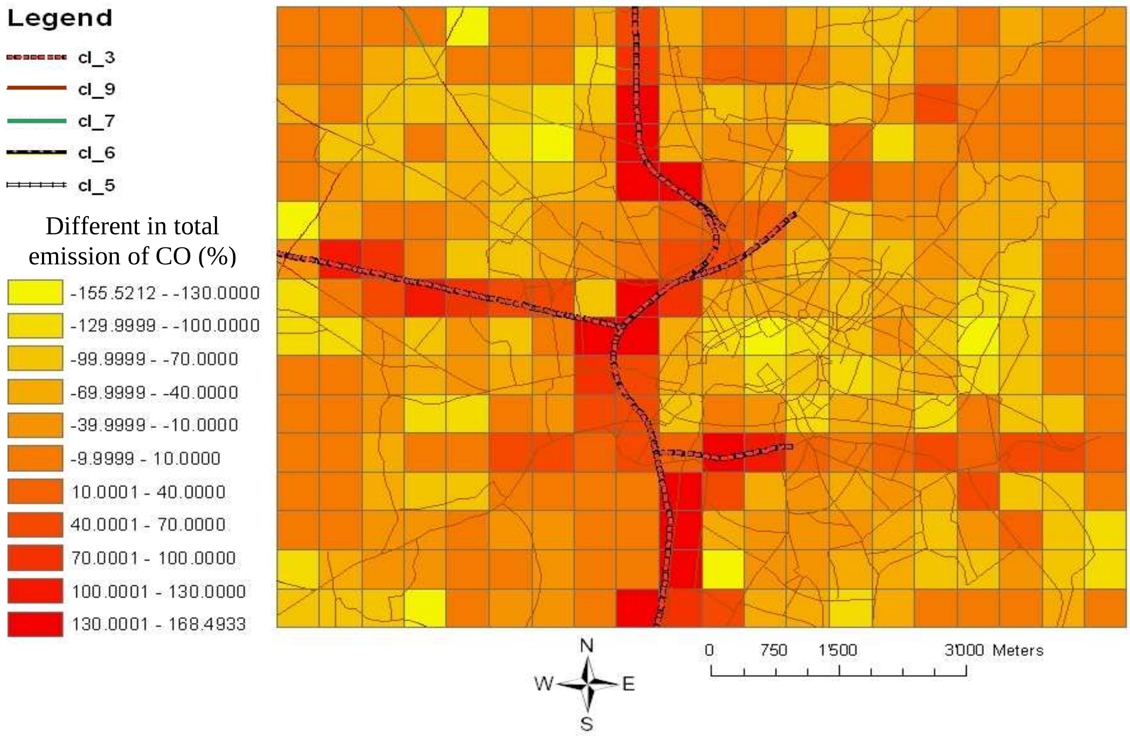
3.2 Scenario 2



A. 3.2.a: The difference in emission of NOx (in %) between reference case – scenario 2 on the study domain (Strasbourg). Different street categories are already defined in Figure 3.1.

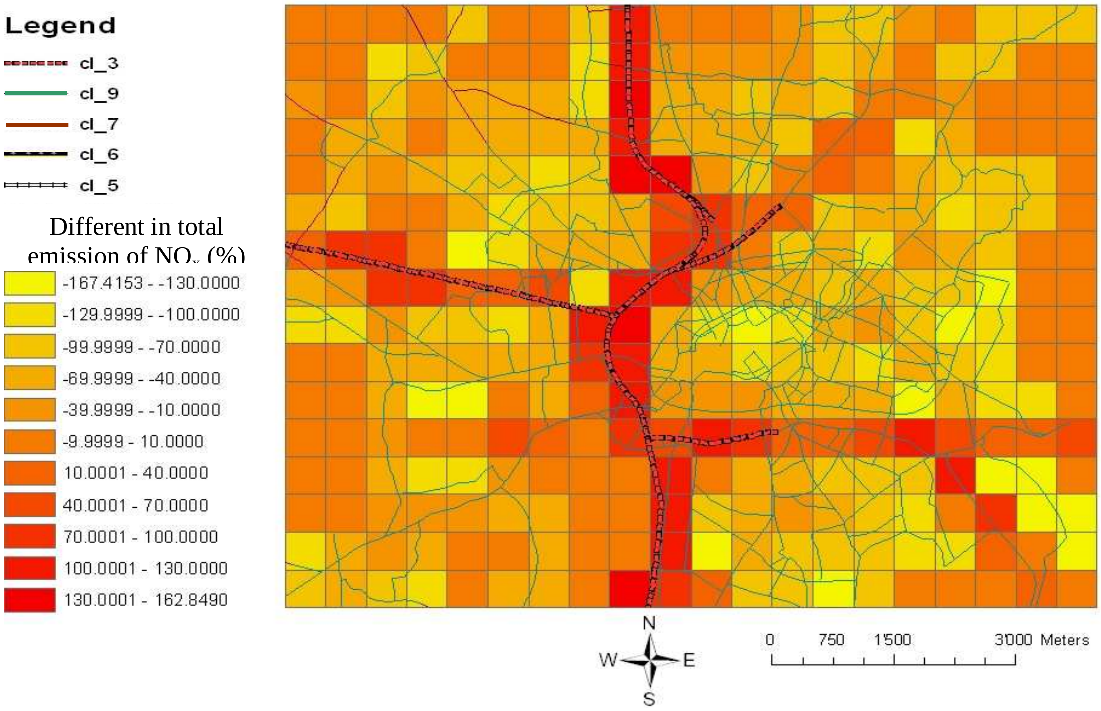


A. 3.2.b: The difference in emission of CH4 (in %) between reference case – scenario 2 on the domain (Strasbourg). Different street categories are already defined in Figure 3.1.

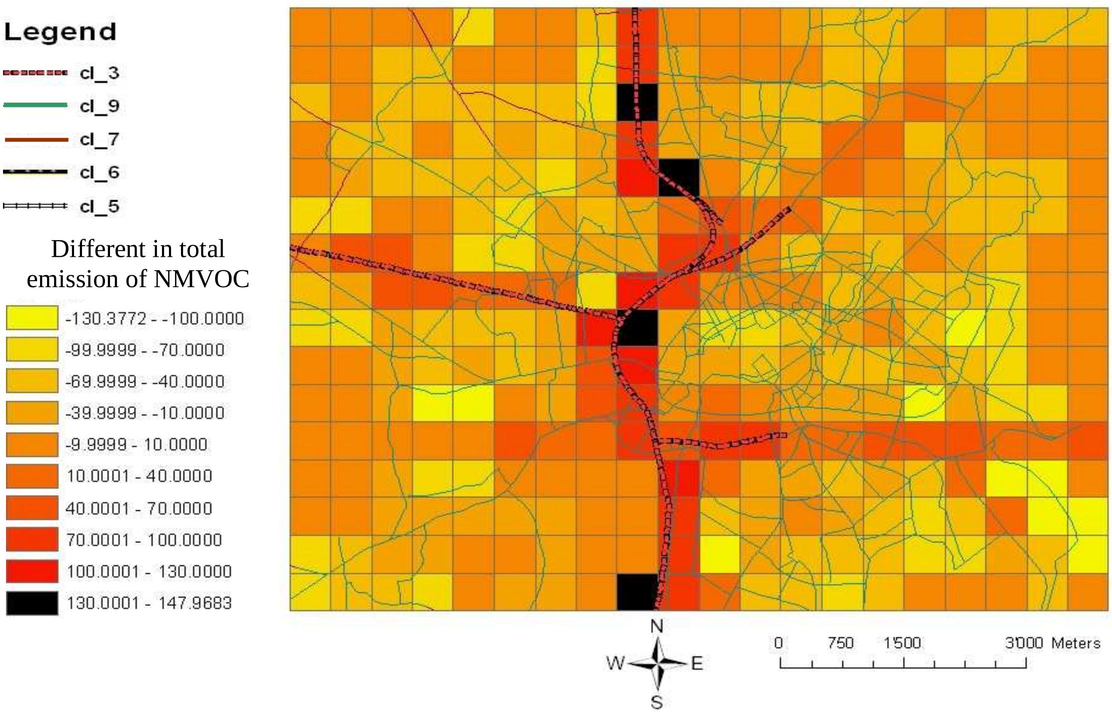


A. 3.2.c: The difference in emission of CO (in %) between reference case – scenario 2 on the domain. Different street categories are already defined in Figure 3.1.

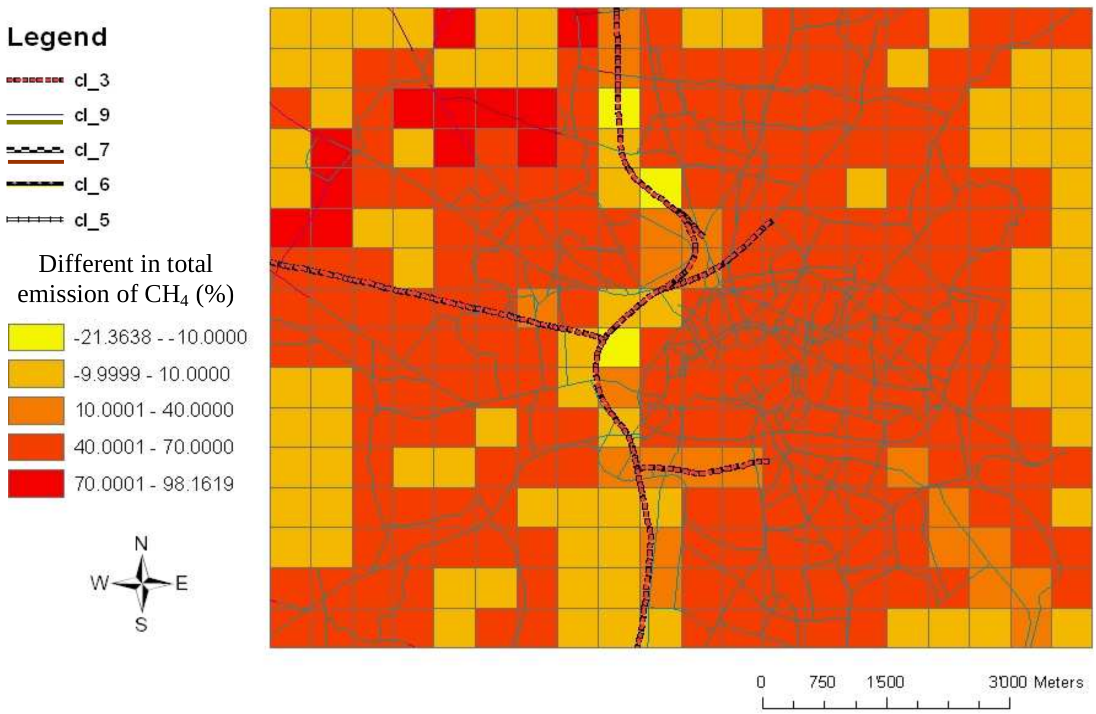
3.3 Scenario 3



A. 3.3.a: The difference in emission of NOx (in %) between reference case – scenario 3 on the domain. Different street categories are already defined in Figure 3.1.

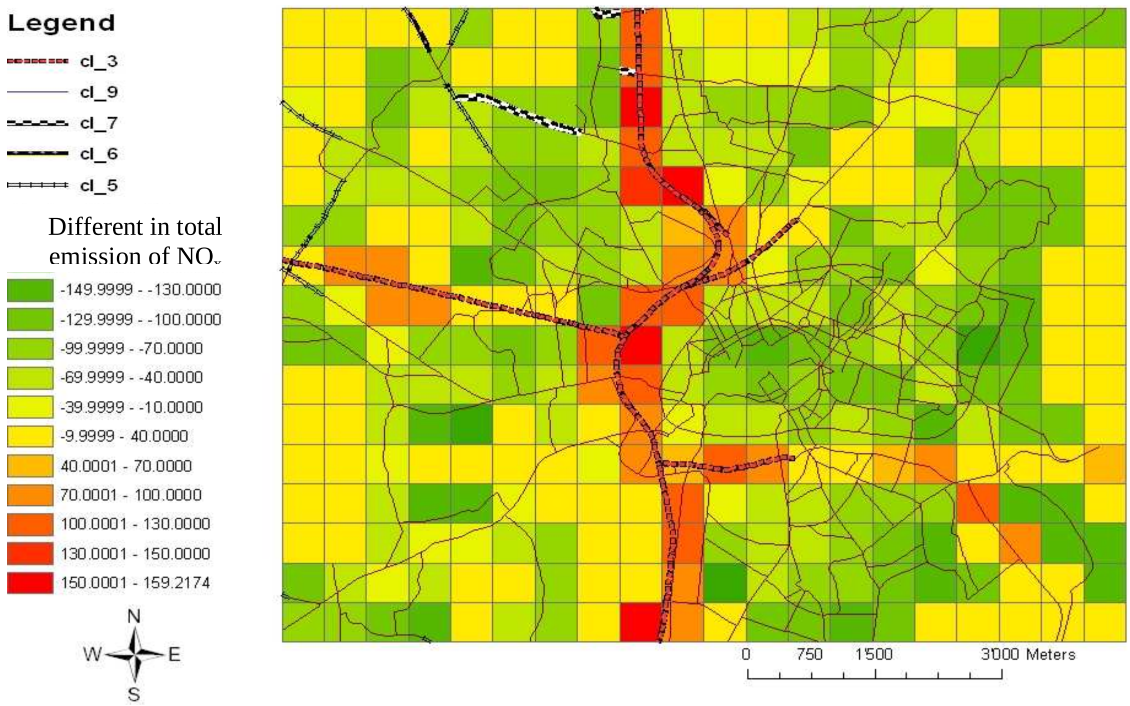


A. 3.3.b: The difference in emission of NMVOC (in %) between reference case – scenario 3 on the domain. Different street categories are already defined in Figure 3.1.

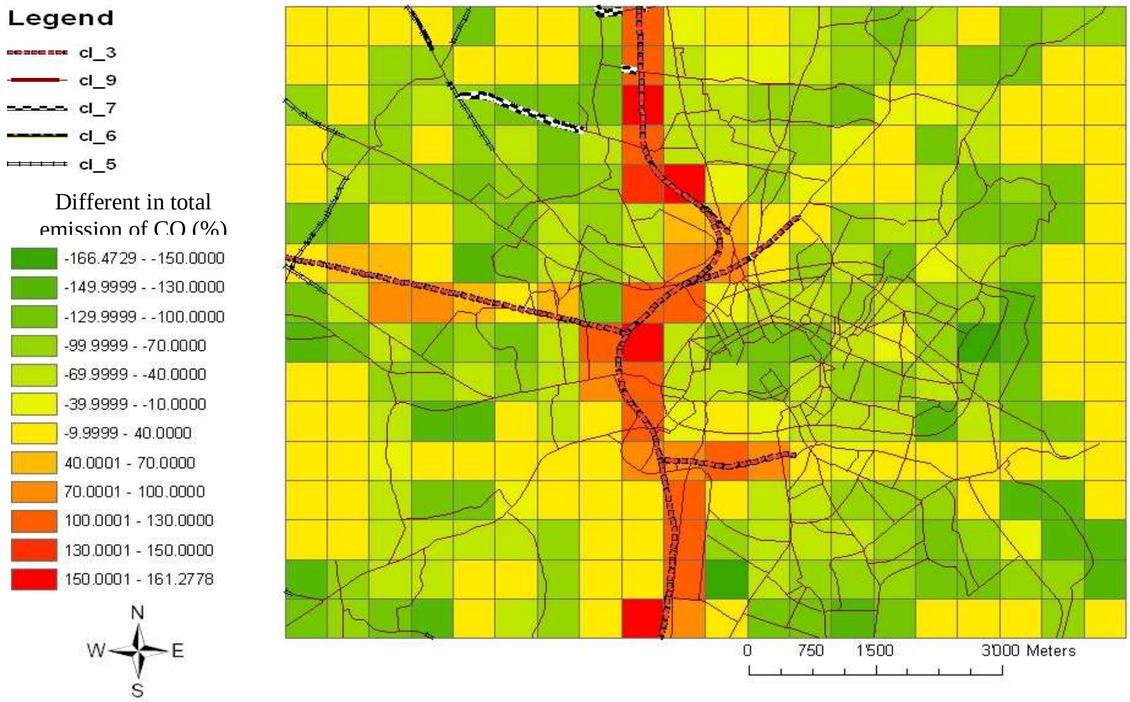


A. 3.3.c: The difference in emission of CH4 (in %) between reference case – scenario 3 on the domain. Different street categories are already defined in Figure 3.1.

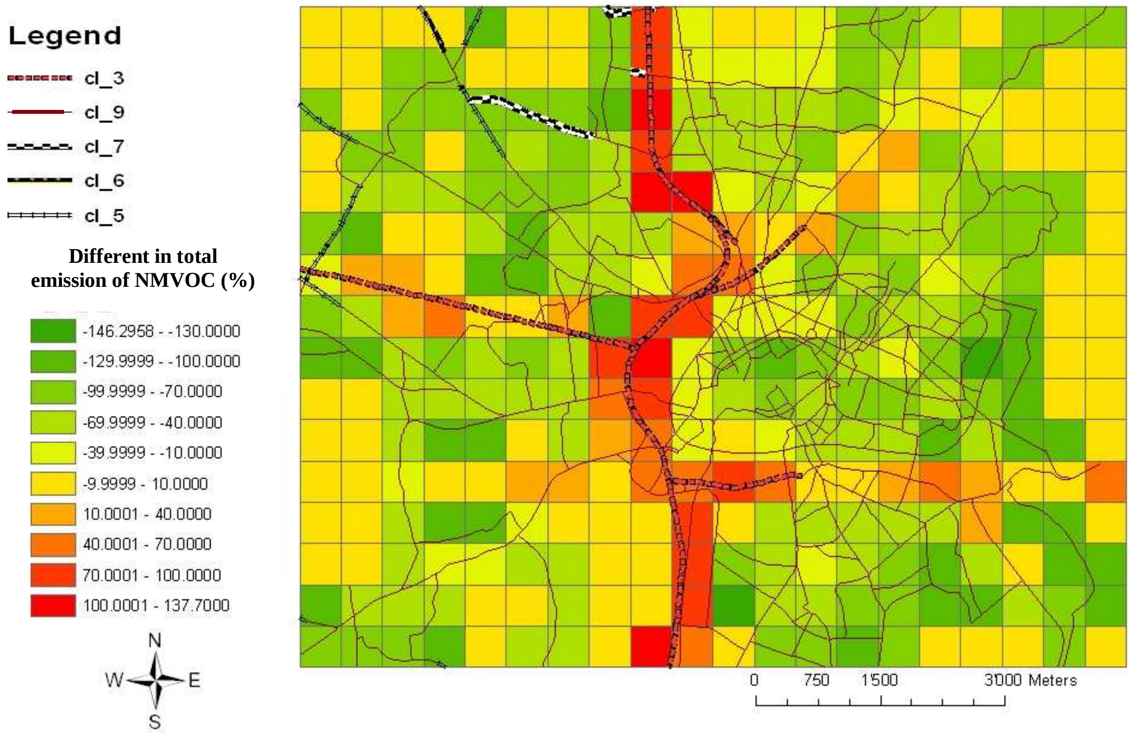
3.4 Scenario 4



A. 3.4.a: The difference in emission of NOx (in %) between reference case – scenario 4 on the domain. Different street categories are already defined in Figure 3.1.



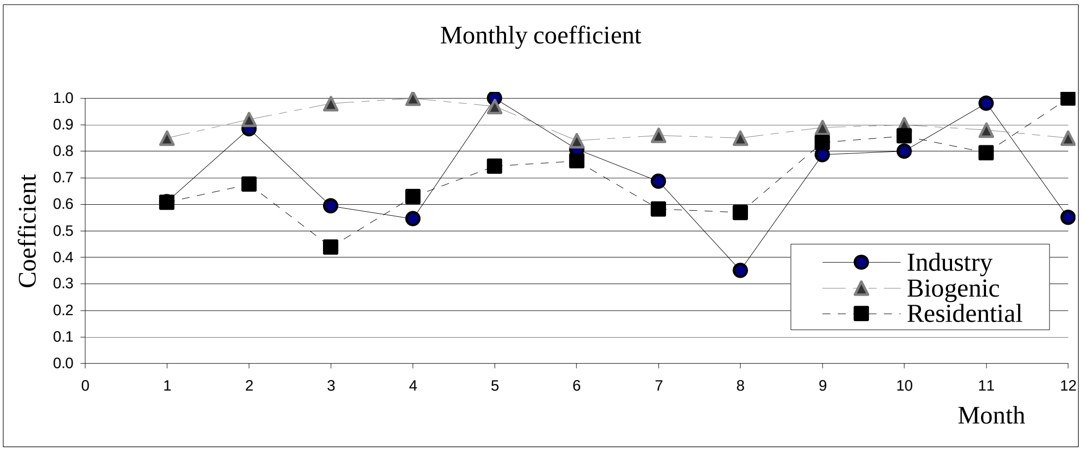
A. 3.4.b: The difference in emission of CO (in %) between reference case – scenario 4 on the domain. Different street categories are already defined in Figure 3.1.



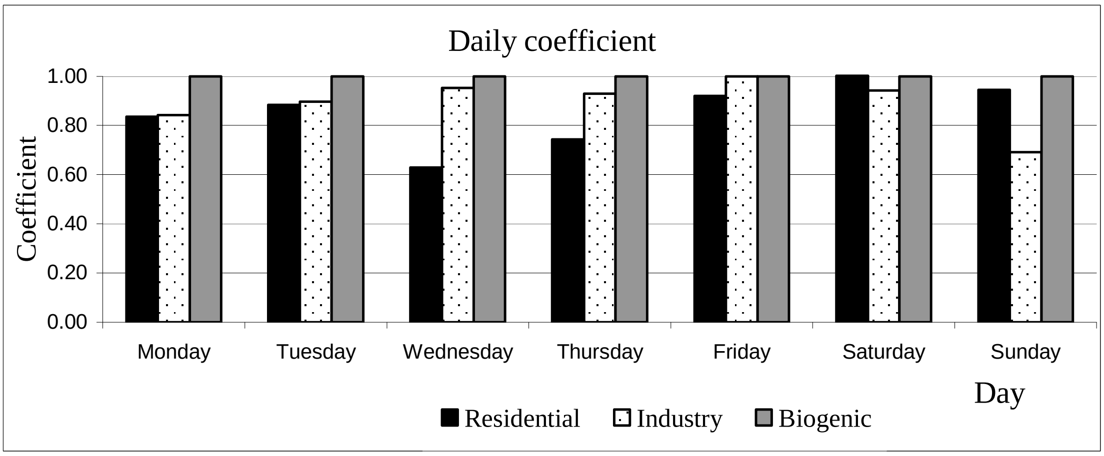
A. 3.4.c: The difference in emission of NMVOC (in %) between reference case – scenario 4 on the domain. Different street categories are already defined in Figure 3.1.

Annex B. Diagrams and Figures of chapter 4

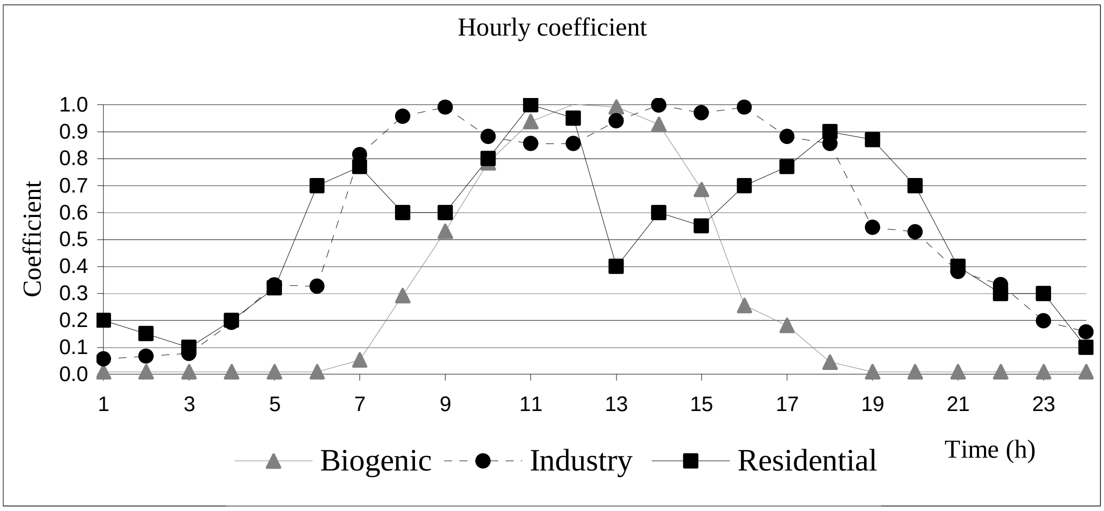
B. 4.1 Monthly coefficients of Industry, Residential and Biogenic sources

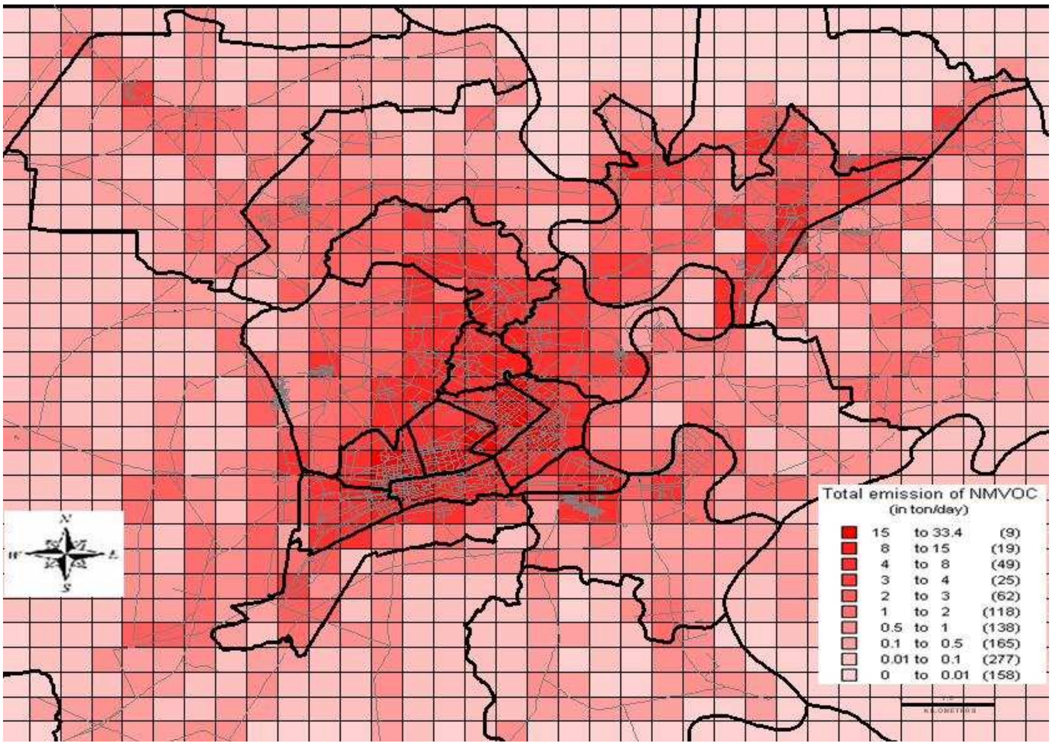


B. 4.2: Daily coefficients of Industry, Residential and Biogenic sources

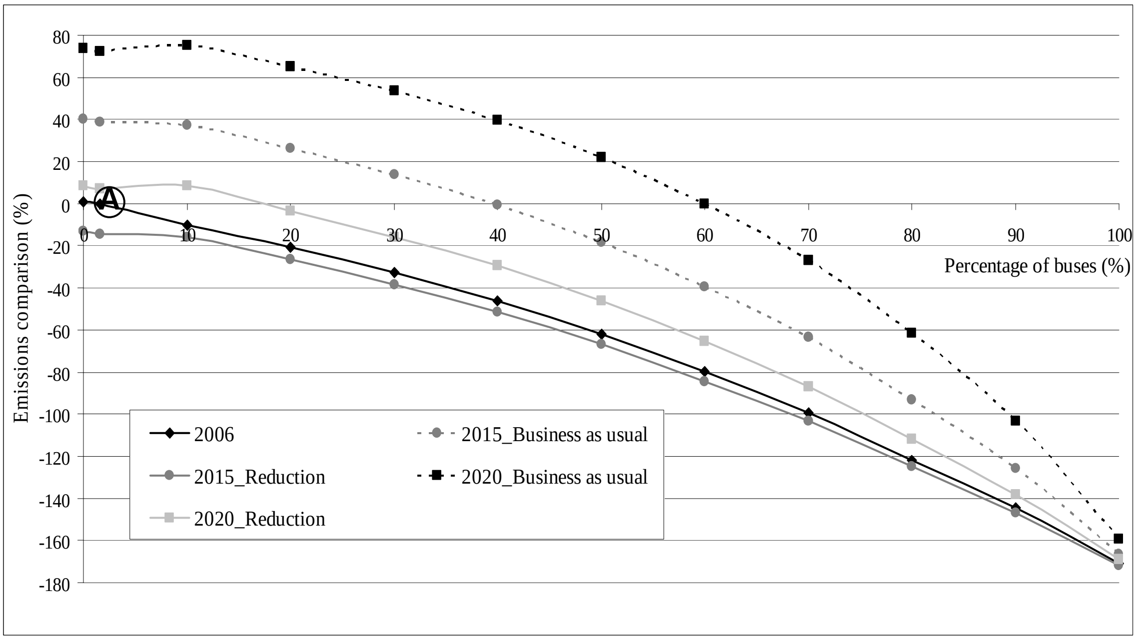


B. 4.3: Hourly coefficients of Industry, Residential and Biogenic sources

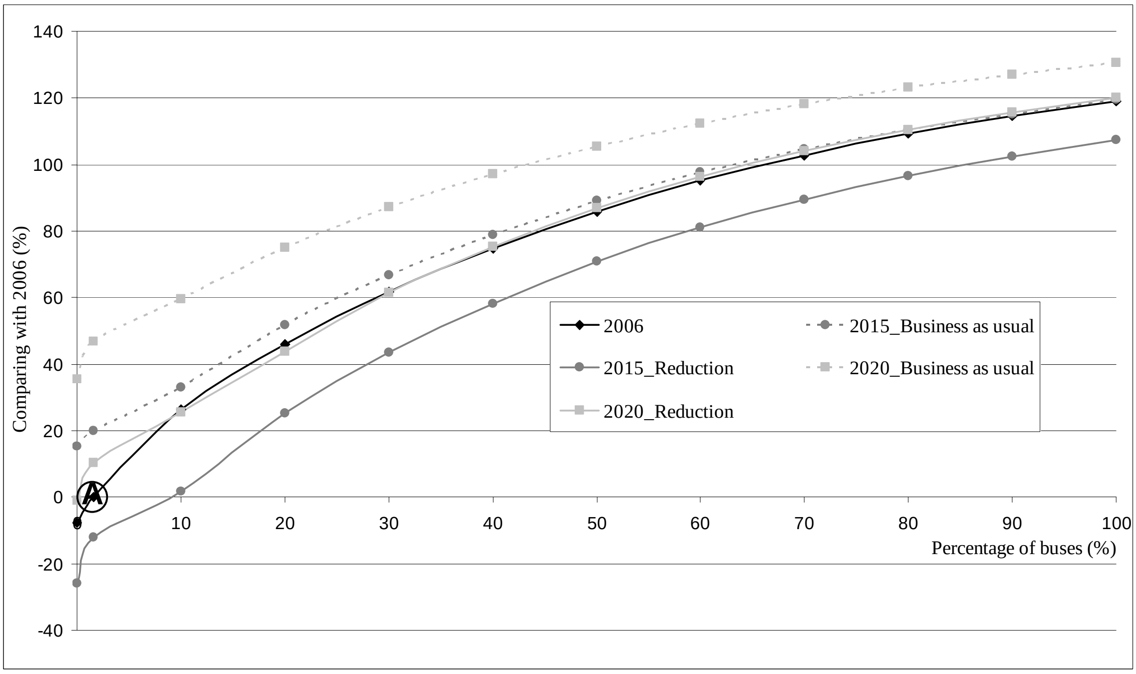




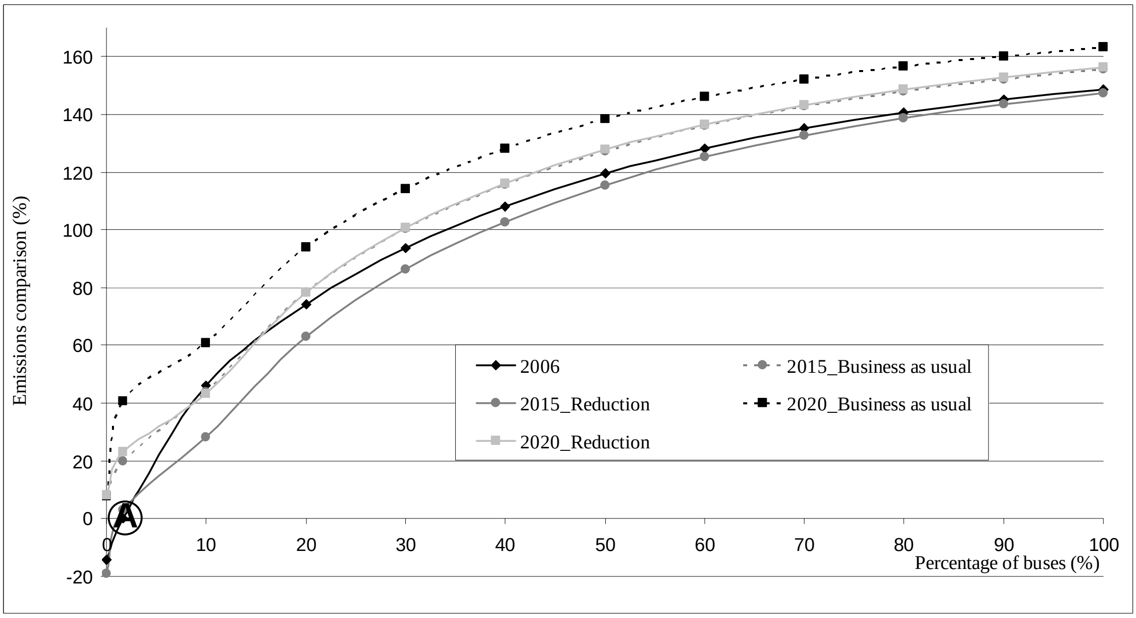
B. 4.4: The emission map of NMVOC in space for all sources. The contour of the districts (black colour) and the street network (grey colour). The numbers in parenthesis are the number of cell.



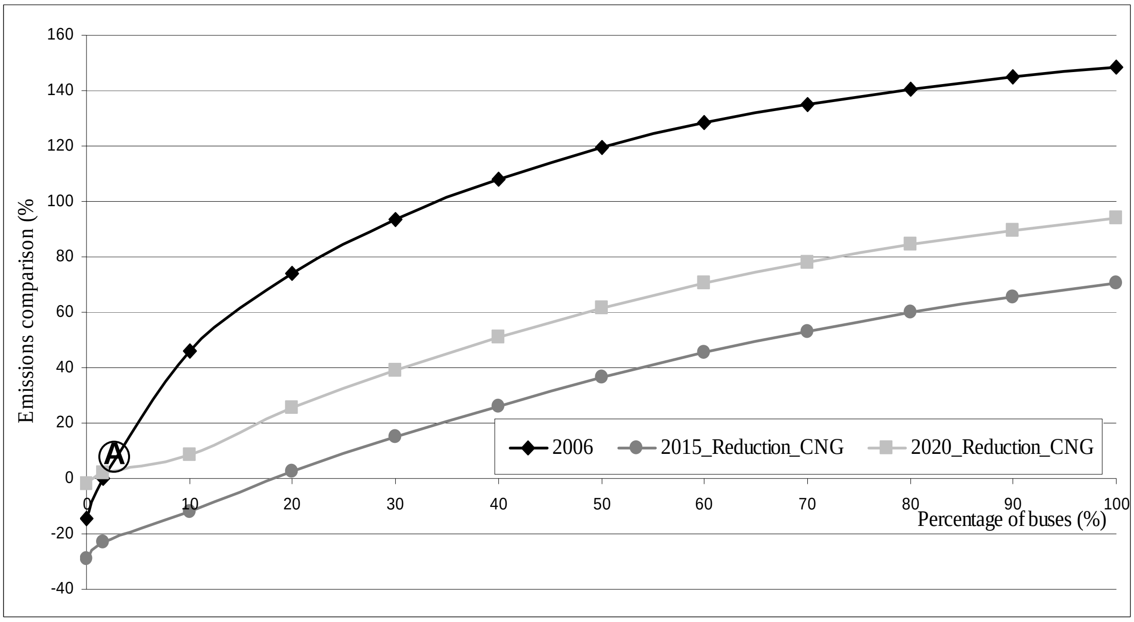
B. 4.5: Percentage difference between the emissions of CH_4 of 2006 according to percentage of transport done by buses (PTDB) (solid black line) with 4 scenarios: 2015_Reduction (solid grey line with a circle), 2020_Reduction (solid grey line with a square), 2015_Business as Usual (dash grey line with a circle), 2020_Business as Usual (dash grey line with a square). A is the real emission of 2006.



B. 4.6: Percentage difference between the emissions of SO_2 of 2006 according to percentage of transport done by buses (PTDB) (solid black line) with 4 scenarios: 2015_Reduction (solid grey line with a circle), 2020_Reduction (solid grey line with a square), 2015_Business as Usual (dash grey line with a circle), 2020_Business as Usual (dash grey line with a square). A is the real emission of 2006.



B. 4.7: Percentage difference between the emissions of NO_x of 2006 according to percentage of transport done by buses (PTDB) (solid black line) with 4 scenarios: 2015_Reduction (solid grey line with a circle), 2020_Reduction (solid grey line with a square), 2015_Business as Usual (dash grey line with a circle), 2020_Business as Usual (dash grey line with a square). A is the real emission of 2006.



B. 4.8: Percentage difference between the emissions of NO_x of 2006 according to percentage of transport done by buses (PTDB) (solid black line) with 2 scenarios: 2015_Reduction_CNG (solid grey line with a circle), 2020_Reduction_CNG (solid grey line with a square).

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Professional Curriculum Vitae

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Personal informations

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Education and degrees

2006 – 2010: PhD student at the Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland

2003 – 2005: Master of Environmental Science at the Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland

1997 – 2001: Bachelor of chemistry at the University Sciences Natural Tp.HCM, Vietnam National University, Ho Chi Minh City.

Work experience:

Date	Name of Organization	Work Experience	Job Title
9/2001-6/2003	Institute of Environment And Resources - Vietnam National University, Ho Chi Minh City (IER-VNU/HCM)	System of Laboratories (This Labo. was equipped with the most up-to-date analytical instrument (GC, GC-MS, AAS…) and apparatuses in determining microelements including pesticides traces in the environment) - Participate many projects in air quality field - Analyze special Organics compounds and heavy metals by GC-MS (GC- Mass spectrometry) and AAS	Researcher
6/2004-4/2005	Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland)	Modeling of Meteorology and Air pollution	Researcher
5/2005 – 9/2006	IER-VNU/HCM	Work in Air pollution Lab.	Researcher and Lecture
10/2006-present	EPFL	Emission inventory, Modeling of Meteorology and Air pollution	Assistant doctoral

Research :

2008 – Up to now: Participare in project on: Develop the methodology and analysis of organotins for Ho Chi Minh City ports.

2005 – 2009: Participate in ABC project (Atmospheric-Asian Brown Cloud) – VietNam – Switzerland

2005 – 2006: Participate in Monitoring air pollution in HoChiMinh city project.

6/2004 – 3/2005: Master thesis for 10 month at LPAS - Ecole Polytechnique Federal de Lausanne – Switzerland: “Meso-scale modeling of the air quality in Ho Chi Minh: evaluation of the effectiveness of various strategies to reduce pollution”

2003	Participate in TanHoa-LoGom canal project: Monitoring on water quality
2003	Participate in Monitoring air pollution project: Monitoring air pollution in Southern Viet Nam
2001 – 2002:	Participate in SaiGon - DongNai River Project: Monitoring and evaluation water quality.

Publications:

Q.Bang, HO., Clappier, A., Golay F., Sajjad, S.H., 2010. Study of abatement strategies to reduce pollution in Ho Chi Minh City, Vietnam. Submitted to Climatic Change Journal.

Q.Bang, HO, Clappier, A., 2010. Emission inventories over Ho Chi Minh City, Vietnam. Submitted to Atmospheric Environment Journal.

Q.Bang , HO., Clappier, A., Zarate, E., Hubert, V.D.B and Sajjad, S.H., 2009.
A preliminary study of Ozone in Ho Chi Minh City. Submitted to Climatic Change Journal.

Luong, V.V., Q.Bang, HO., Nguyen.V.T., 2008. Simulating the pollutant transmission caused by transportation in Ho Chi Minh City. Hydro-meteorology Journal, 570, p. 5-12.

Q.Bang, HO., Clappier, A., Zarate, E., Hubert, V.D.B., Fuhrer, O., 2006. Air quality meso-scale modeling in Ho Chi Minh City: evaluation of some strategies' efficiency to reduce pollution. Vol 9, N° 5, 2006. Journal Science and Technology Development.

Lam, M.T., Mai, T.A, Tu, T.T.C, Q.Bang, HO: Research on pollution of heavy metals in sediment of canal system in HoChiMinh City, 2003. 15^{sth} Chemistry for development.

Presentations:

Q.Bang, HO., Clappier, A., Golay F., 2010. Development and validation of a model to estimate road traffic emissions for Air quality study. Romand's GIS lab. 2nd edition. 15 March 2010. Geneve, Switzerland.

Q.Bang, HO., 2007. Development of a methodology for generating road traffic emissions. 2007. Final project at IER –VNU/HCMC, Vietnam.

Fuhrer, O., Q.Bang, HO., Zarate, E., Clappier, A., 2006. Air quality modeling in Ho Chi Minh City, Vietnam, 2006. 6th International Conference on Urban Climate, Göteborg, Sweden, 12-16 june 2006, presentation orale.

Fuhrer, O., Ho, M. D., Q.Bang, HO., Belalcazar, L.C., Zarate E., Clappier A., 2006. Air quality modeling in Ho Chi Minh City, Vietnam, 2006. Environmental Seminar Series, ETH Zürich, Switzerland

Posters:

Q.Bang, HO., Clappier, A., Golay, F., 2010. Development and validation of a model estimate road traffic emissions. ENAC Research day 9 June 2010 “Living with risks: How to build new forms of expertise” at EPFL-Lausanne, Switzerland.

Krpo, A., Q.Bang, HO., Clappier, A., Blond, N., 2009. Stratégies d'aménagement urbain pour une atmosphère plus saine: projet Atmopolis, Forum REALISE, 26-27 mars 2009, Strasbourg, France.

Teaching:

1. Air pollution
2. Modeling of air pollution
3. Exhaust gas treatment
4. Solid waste treatment

Computer knowledge:

Operating systems:	UNIX (Solaris), Linux and Microsoft offices.
GIS software:	MapInfo, ArcGIS.
Programming:	Pascal, FORTRAN, MATLAB, Mathematica and C.

Languages:

Vietnamese	Mother tongue
English	Fluent
French	Fluent

Prizes:

N°	Year	Name of prize	Note
1	1997	Golden prize on Chemistry of High school in Mo Duc District, Quang Ngai Province	
2	2001	Golden Cup: Chemistry for young people team Contest at Ho Chi Minh City	
3	2006-2007	Excellence lecturer & researcher prize of Vietnam National University, Ho Chi Minh City (VNU-HCM)	