MODELING IMPACTS OF MOBILITY ON URBAN AIR QUALITY:
Scenario Analysis for the Brussels-Capital Region[*)]

Paul Safonov[+)]***, Vincent Favrel, and Walter Hecq***
Centre for Economic and Social Studies on the Environment (CEESE),
Université Libre de Free University of Brussels (ULB)
44 Avenue Jeanne, CP 124, Brussels, B-1050, Belgium
Tel: +32 2 650-3588, Fax: +32 2 650-4691
E-mail: PSafonov@ulb.ac.be

Aggravation of transportation intensity and air pollution in urban areas in the last decades is urging the studies on strategic environmental assessment (SEA) of transportation networks and the integration of transport-environment concerns with land-use planning.

This paper tackles the environmental aspects of mobility, induced by major policy options in the Brussels-Capital region. The assessment is based on the Regional Plan of Land Use ("P.R.A.S") and the Regional Plan of Mobility (Plan "IRIS"), and focused on residential areas and office relocation and expansion, development of transportation networks, modal shift, parking, and other urban policies. Substantial presence of European and international organisations and businesses in the city and its heterogeneous population structure are also taken into account.

For the purposes of such analysis a system of models is being developed, including:

1) Forecasts of population and employment dynamics, in accordance to different economic and urban development scenarios. Such forecasts are based on:
    - indicators of economic development by main sectors of activities and respective demand for labor resources;
    - general birth rate and population dynamics;
    - trends and shifts in population and labor resources structure (e.g. from workers to executives, from permanent residents to foreigners and migrants, from town to periphery; growth of the share of middle-aged population, etc.);
    - spatial distribution of the population in the region.
2) Mobility model, providing scenarios of public and private traffic in the region, according to different origin-destination matrices, generated on the basis of the stage 1 calculations and office stock modeling. For transportation network analysis the TRIPS software package is used, which provides powerful tools for assignment and graphical presentation.
3) A model linking mobility and air pollution. The focus is on emission of CO_2, CO, NO_x, SO_2, VOC, particulate matter, and on consumption of non-renewable fuel. COPERT II methodology is used for emissions calculations from traffic, taking into consideration new European/Belgian regulations on vehicles.

Possible scenarios for improvement of the policy making in regional and urban planning in order to reduce the ecological pressure are discussed.

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[+)] The corresponding author, permanently at the Institute of Control Sciences, Russian Academy of Sciences, 65 Profsoyuznaya, Moscow, 117806, Russia. E-mail: Paul.Safonov@ipu.rssi.ru

1. Introduction

Road traffic in the Brussels-Capital Region has continuously increased during the last decade. The reasons of this trend lie mainly in the urban exodus, the employment increase in the Brussels area and its peripheral region, and the continuously increasing population motorization rate. Recent studies (IRIS, 1993) predict the complete saturation of the road network before the year 2005 in the Belgian capital.

The assessment of the impacts of this road traffic increase on the environment in general, and on air quality, in particular, helps not only to evaluate the actual situation but also to assess the possible effects of measures towards a more sustainable transport system.

This study is undertaken in the Centre for Economic and Social Studies on the Environment (CEESE) of Free University of Brussels (ULB), within a project to analyse the ecological aspects of mobility induced by major regional policy options, such as offices' relocation and expansion, transport and other urban policies for the case study of Brussels-Capital region.

Among main environmental impacts of mobility - the emissions of air pollutants (such as CO_2, CO, NO_x, SO_2, VOC, particular matter, as well as others) and the consumption of non-renewable fuel would be assessed.

This paper presents the main idea of the project to create a models system, which will include several components:

1) Demographic forecasts of dynamics of population and employment (per sector) in Brussels-Capital region, as well as spatial distribution of these people over the territory of the region. Here the available data will be used, as well as additional surveying would be required;
2) Dynamic model to provide scenarios of macroeconomic development of main sectors, representing the economy of Brussels-Capital region. By means of such a model we would be able to simulate the behaviour (e.g., till the year of 2020) of main economic indicators, including sector-based structure of gross and net product, and related capital assets and labour resources. Such scenarios will be used to estimate, from one side, the demand in buildings (including offices) and workers in each economic sector, and from the other side, to study the influence of economic activities and related offices relocation and expansion on mobility.
3) In the final stage, a model linking mobility and air pollution would be used. Here “vehicles-emissions” and "non renewable fuel consumption" models, developed at CESSE, would be enhanced in order to account for new European and Belgian regulations on vehicles.

As part of the «Sustainable mobility in the Brussels-Capital Region» project CEESE-ULB is currently developing a methodology for the assessment of the physical effects and external costs caused by air pollution generated by road traffic in an urban area. The approach considers a sequence that follows the five following main steps: human activities, emissions, immissions, physical impact and external costs.

As the first step, a module that allows the assessment of the contribution to air pollutant emissions of traffic, domestic and office heating as the main urban sources is presented in this paper, which gives the methodology for the emission calculations for the transportation model.

Road traffic emissions are assessed using both the COPERT II methodology (Ahlvik et al, 1997) and traffic data for the Brussels-Capital Region. Emissions from other activities are taken into account on the basis of statistical data and suitable emission factors in relation with economic and meteorological data. Three pollutants - nitrogen oxides, particulate matter and sulphur dioxide - are considered.

While considering the impacts of air pollution (e.g. in terms of building deterioration, health effects, climate change, etc.), the general approach associates to traffic a sequence based on the five following steps: human activities, emissions, immissions, physical impacts and external costs. This is the classical approach namely used in major studies such as ExternE (European Commission, 1995) for the assessment of externalities in the energy sector and which has recently been updated for its application to the transport sector.

This paper deals specifically with the three first steps of this sequence by presenting a model that makes it possible the determination of the share of responsibility that can be attributed to road traffic in order to explain the pollutant concentrations measured in the Brussels-Capital region. The model is divided in two specific modules. The first one links the economic activities with the emissions levels. The second one determines the resulting immissions by modelling the relationship between the previously calculated emissions and different pertinent meteorological variables.

The model works at an aggregated level by considering an average pollution level for the area studied. It estimates the emissions and the resulting immissions for that area on a daily basis for the period 1994-1996. The pollutants considered are: nitrogen oxides, nitrogen dioxides, particulate matter and sulphur dioxide.

The new model will be synthesised for analysis of influence of offices relocation and job changes, as well as recent urban and transport policies, on the mobility of people in urban centre. On the basis of the information available, and additional data to be collected for Brussels-Capital region, environmental impact of such mobility would be analysed.

Results of modelling and recommendations for policy making in regional and urban planning would comprise the practical output of the study.

2. State of the Art

This section presents the approaches and models, which provide the methodological basis fo the construction of the models system for the Integrated socio-economic-environmental analysis of urban mobility.

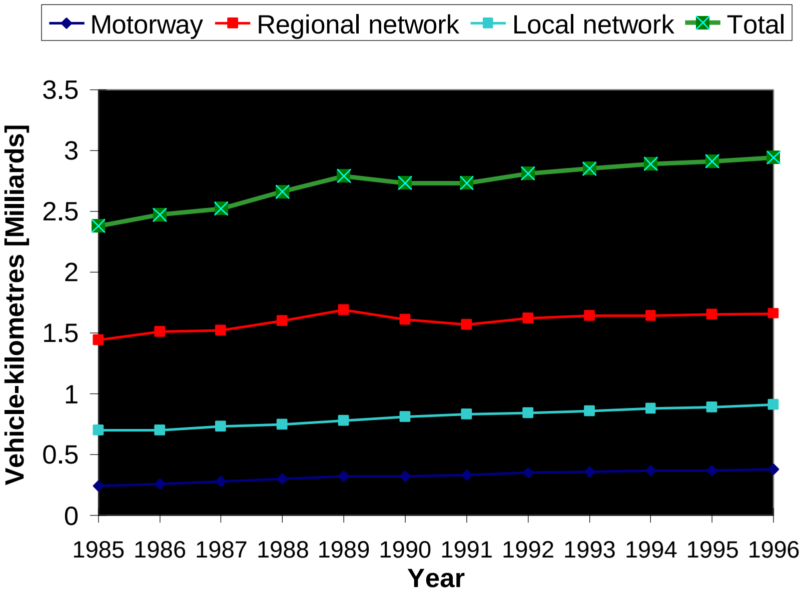
Economic development forecasting

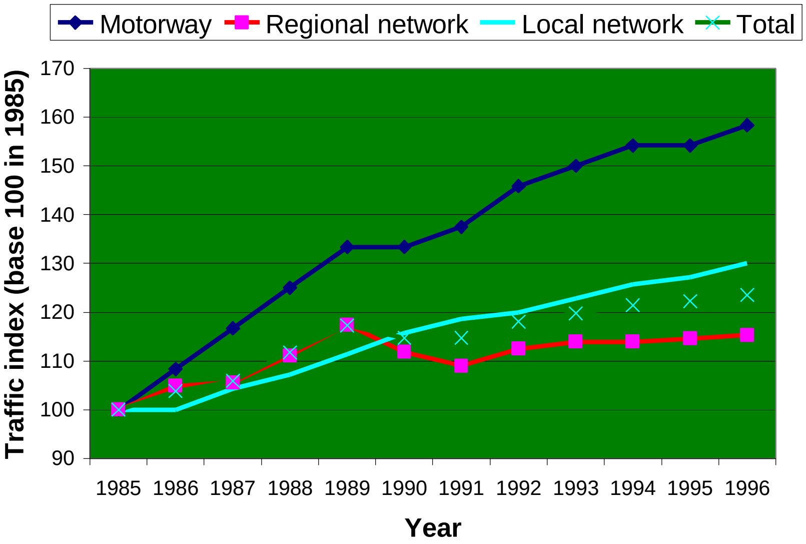
The forecasts are based on the use of a system of ecological-economic models (Safonov, 1996), which includes: block of fixed assets dynamics; several kinds of linear and non-linear production functions; algorithms for balanced forecasting of technological structures; nature block describing dynamics of the main environmental indicators (such as: air and water pollution, state of forests and soil, mineral and bio-resources uses etc.) with self and artificial restoration, economic and anthropogenic influences taken into account.

To provide a complex of integrated tools for interactive construction and analysis of such models and thus to support decision making, the Nature-Economy Simulation SYstem (*NESSY*) was developed (Safonov, 1991). Former applications of the system include several case studies aimed at modelling scenarios of environmental-economic development in Russia and Germany (Safonov, 1996a), and for the purposes of this study, a version, adopted for urban economy development would be based on available data for the Brussels-Capital region.

Modelling of passenger transport

The figures below give the aggregated dynamics (in absolute and relative terms respectively) of the past development of the mobility in the region per category of vehicles.





The number of person/vehicle-trip originating in each zone (trip generation) is treated like a function of demographic and socio-economic variables: population, car ownership, income, etc. Estimation techniques are handled differently following trip purposes: business trips, journeys to work and social/leisure trips. This classification is not exhaustive and may be refined as needed. Methodology uses econometric tools to assess the number of trips per trip purpose. Input data are, amongst others, based on household surveys. In this frame, estimation is made on the basis of travel behaviour of groups, households or persons. The person-category approach, i.e. at the level of the individual, has several advantages as it has a better compatibility with other steps (modal choice, assignment) which are based more on individual behaviour of the travellers rather than on households.

<u>Distribution models</u>

This second step estimates where the "produced" trip will go to and where the "attracted" trip comes from. For this purpose, trips leaving or entering a zone are spread into an Origin/Destination (O/D) matrix of transport flows (and traffic loads) for the model zone. Matrices O/D represent the number of trips between each centroid node. Each element of the matrix O/D represents the number of vehicles/passengers (or number of tonnes moved), per modelling time period, with origin *i* and destination *j*, for all *ij* coded on the model zone (where *i*, *j* represent nodes). Here the experience of the author will be used in development O/D matrix (Safonov, 1997), which would be necessary for the mobility model for the Brussels-Capital region.

<u>Offices relocation modelling</u>, tackles, among others, the following specific aspect:

- *Parking policy* can restrict traffic access, for example by giving preference to residents over commuters, limitation of parking provision for offices and other employment sites, *and* priority parking for environmentally friendly vehicles as part of an overall traffic policy. Following the referendum on car traffic in 1992 (RBC, 1993, *Plan Iris*). For instance, Amsterdam has chosen parking policy as the main instrument to reduce car journeys. The overall aim of reducing car traffic by 35% will be achieved by reducing commuter parking, giving priority to residents, constructing underground car parks and eliminating on-street parking from many areas or charging at a much higher rate.

- *Early consideration of environmental implications in the urban planning process.* Environmental Impact Assessment can be a powerful tool for anticipating the likely consequences of projects of offices relocation. Among policy options the following could be of particular importance:

  - <u>integrating land use and transport planning</u>**.** It is widely accepted that urban form, that is the pattern and density of development within and between settlements, influences travel patterns. The spatial planning system is a key mechanism influencing urban form. Other enabling factors such as price mechanisms, and availability of public transport would obviously need to be in place.

  - <u>increasing urban densities around points of high accessibility</u>. The common feature shared by different solutions is the idea of increasing urban densities around points of high accessibility, and especially points of high accessibility to public transport: "right business in the right place". The Hague can be a successful example where 2 office locations at *Centraal* and *Hollands Spoor* station were identified to improve mobility of 3000 employees. Project of sitting work places at accessibility points in Copenhagen is another case study in this approach;

- encouraging mixed land use schemes. Over-rigid land use zoning has been criticised as one of the causes of new single use development areas within cities. Mixed use is an urban form, which offers the opportunity for reduction in movement overall, particularly if linked to traffic restraint systems. At the city scale it implies seeking a balance of houses, jobs and facilities in each broad sector of the city through whatever broad zoning or land allocation system is used in that particular country.
- flexibility of design. The flexible design of buildings means that buildings are not restricted to a single function. The same basic structures can serve school, office and factory uses. Changes in technology and the imperatives of ecology will offer the opportunity to make buildings ever more flexible and responsive.

Linking of mobility models and air pollutant emissions as well as non renewable fuel consumption models.

Econometric models estimate transport for a country or a region as a whole, on a yearly, quarterly or monthly basis. The only linking contribution that could be expected from econometric models is the possibility of considering forecast scenarios. Their ability to predict future changes of fuel consumption, vehicle mileage or vehicle fleet composition could be useful for the assessment of future air pollution reduction measures. The major disadvantage of existing models is the aggregate character of the data, which make it impossible to get measurements such as mean speed and to distinguish between the different categories of vehicles-travelling needed for emission model use. However, the latter parameters can be assessed from surveys and calculations (exogenous character). New econometric models can be built to distinguish vehicles travelling (or other measures of travel demand) under different modes and to split, for example, urban from non urban vehicles travelling, provided statistics are available. Further investigation would be requested to assess this possibility. The existing econometric models, which have been constructed for other goals than emission assessment, partly satisfy the requirements of emission models, provided no simplifying assumption is made. However, econometric models are able to predict fuel consumption, but without differentiating different fuel types. Once again, if data on total annual fuel consumption for each type of fuel could be found, models could be built on a time series basis, e.g. using as explanatory variables the relative price for each type of fuel. Econometric models can be linked with emission models, such as COPERT II (Ahlvik *et al*, 1997), which calculates the total annual fuel consumption as a calibration parameter for estimating uncertain parameters (e.g. average annual mileage driven on each road class and for each vehicle category).

Network flow models. For road networks, there is an asymmetry between individual and public transport. Individual transport is measured in the number of vehicles. On the contrary, public transport is usually measured in number of passengers. For linking purposes, only measurement in the number of vehicles can be used. In the case of models dealing with the number of passengers, the model must be able to convert this value into the number of vehicles. From our analysis, in general, mobility models cannot directly provide emission models with usable data. Adjustments and approximations are necessary. According to emission types, three cases are distinguished.

– *Hot emissions and fuel consumption.* Considering data requirements the main incomplete data for hot emission calculation are the following :

  - number of vehicles per category,
  - kilometres driven per vehicle category on different road section types,
  - average speed per road type taken into account or allocation of typical traffic situations to the road network with respect to different road section types.

However mobility models provide :

- number of vehicles per mode on each O/D trip and the paths/route chosen for each trip,
- average speed of a representative vehicle in function of road link characteristics (bends, slopes) and in function of the flow on the link.
- From mobility models, it is thus possible to infer for each O/D trip : the number of vehicles travelling per mode and the average speed from the origin to the destination (knowing the average speed on each link type travelled). Trip distance, number of kilometres travelled per time period, number of starts can also be deduced from the input and output of the mobility models. Matching problems between hot emission or fuel consumption calculation and mobility models remain in the calculation of kilometres driven per vehicle category and of kilometres driven per road type.

  Attention must be paid to the fact that mobility models are a modelling of the reality and the output data still remains an estimation associated with uncertainty. It is perhaps negligible for the objectives for which mobility models have been initially built (analysis of congestion, economic inefficiencies, alternative development patterns, etc.) but for linking with emission models, we have to assess the degree of certitude needed for input data (average speed, trip distances, etc.) to get acceptable results. Finally, the transportation network area studied with mobility models is still partly covering the actual transport network.

– *Cold start emissions.* Considering cold start emissions and fuel consumption, apart from meteorological parameters and fuel properties, the data required that could possibly be supplied by mobility models concern :

  - average trip length per vehicle trip;
  - total annual kilometres of the vehicle for each category;
  - distance travelled by the vehicle;
  - number of starts per day and per vehicle;
  - parking duration before the trip.

The travelled distance and the number of starts per day and per vehicle can be supplied by mobility models with the same remarks as for hot emissions while considering the vehicle category split.

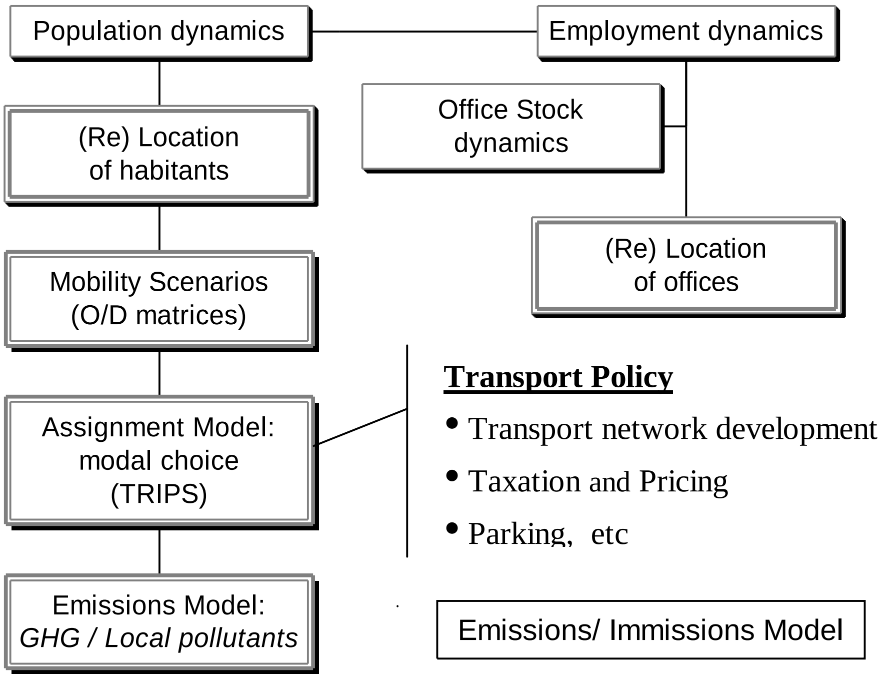
– *Evaporative emission: similar* uncertainty with cold start emissions remains with regard to the parking duration between trips. The same remark as for cold start emission has to be made concerning parking location.

In a linking perspective, the road network must be distinguished from the rail networks, for which statistical data are easily available and observable so that linking with mobility models is a minor problem as compared to the road networks.

1. Integrated Mobility Model Development for the Brussels-Capital Region

The structure of the System of Models is presented on the scheme below and includes:

- *Population and Employment dynamics spatial forecasts* (per sector of activity) in RBC
- *Main Economic sectors development model*
  Economic scenarios will be used to estimate the demand in buildings (including offices) and workers in each economic sector.
- *Office stock dynamics* (supply): spatial econometric models
- *Mobility model*: O/D matrices generation and static assignment for public and private transport.
- *Air pollution*: “vehicles-emissions” & "non renewable fuel consumption" models (⇨new European/Belgian regulations on vehicles)



4.1. Availability of Data

The data from different sources is available at the moment for the author and research group at CESSE-ULB. But nevertheless, an in-depth study of the recent literature with a following update of the information base is required to achieve the best results for the project goals.

The main sources of the data are envisaged to be:

a) Different statistical documents from the National Statistical Institute and from the administration of the Brussels-Capital region, to provide (among other) mainly:

- macro-economic and input-output information;
- demographic data with details on spatial and structural distribution of the population and labour resources. In particular, there can be obtained some special data of interest with regard to mobility issues (such as: dynamics of ratio between residents and commuters, "white-collar" workers and manual workers, etc.);
- information on the office space stock and its structure;
- estimation of demand for offices in different sectors of business;
- important political considerations related to offices relocation and mobility (e.g., the European presence in Brussels, regionalisation impact on office space market, town planning policy to reduce office zones and increase of "housing-office" zones, etc.).
- distribution of office stock by location and by age category, including potential of its renovation;

b) Brussels Office Survey (Jones Lang Wootton reports), Review of Office Property (by Brussels Capital Region), and other sources, providing information on:

- business activities related to demand for offices (e.g., new multinational head quarters in Brussels, etc.) and the structure of offices use by type of activities (International administrations, Belgian administrations, foreign companies, Belgian companies, others);
- recent availability and forecasts of the future supply of the office spaces over different districts of the Brussels-Capital region;
- property taxes and rental prices, as factors influencing the market of offices and their respective redistribution between different businesses;

c) Various data on demographics, mobility, and office space market, available from the "Plan IRIS" reports (as an example and with comparison to other studies and documents available).

d) Meta-data base, recently being developed at CESSE-ULB, which collects information on air pollution, and different aspects of transport and mobility in the Brussels-Capital region.

Some more specific data requirements are also described in the following sections of the research program.

4.2. Demographic spatial forecasts.

The data from the above mentioned sources would be analysed and the following indicators would be modelled for the Brussels-Capital region:

- general birth rate and population dynamics,
- main trends and shifts in population and labour resources structure, e.g.:

  - from permanent residents to foreigners and migrants,
  - from town to periphery,
  - from workers to executives,
  - growth of the share of middle-age (working) population
- spatial distribution of the population over main zones of the Brussels-Capital region, according with different assumptions on the urban policy.

The methods for building forecasts would include different statistical analysis techniques, as well as meta-analytic investigation of different existing studies.

The results of the forecasts would be, from one side, entries to the macroeconomic models of the project's Phase 3, making use of labour resources for each economy sector, and from the other side, the spatial distribution and densities of the residential areas would be an input to mobility models of the Phase 4.

4.3. Development of a model for forecasting the economic activity in Brussels-Capital region and respective demand for offices relocation/expansion, and mobility.

A version of the above mentioned regional ecological-economic interactions model (Safonov, 1996), adapted to the Brussels-Capital region would reflect, from one hand, the structure of economic activities, and from the other, the basic groups of labour resources according with their mobility preferences.

As important factors, influencing the mobility, the structural changes in the economic activities, especially related to technical progress, would be considered. For example, there could be mentioned an effect of decreasing mobility and demand for office use due to fast development of telecommunications and information technologies (such as Internet).

So, finally, the model would make use of information on offices relocation and expansion to simulate the changes in mobility as a function of overall distances covered by employees using different types of transport (private and public).

4.4 A model linking the mobility and air-pollution in the Brussels-Capital region.

The last step in our 3-phase simulation model is to analyse the impact of mobility on the indicators of environmental quality. We would focus in this project on air-pollution (recognising the importance also of problems of noise, vibration and smell, which would stay outside the framework of this study). Main air pollutants under consideration would be: carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), particulate matter.

Gasoline and diesel-oil consumption would be also assessed.

The "Bruxelles-air" model of urban atmospheric pollution (Hecq *et al*, 1995) will be used as a reference and is described below (see also *Favrel and Hecq* (1998) for more details).

Basic approach

Some authors demonstrated that there are statistical correlation between concentrations of pollutants in the urban atmosphere, pollutant emission and some meteorological parameters like wind speed or temperature (Benarie, 1980). On the basis of this conclusion, Cross & Lacey (1981) developed a simple model to forecast sulphur dioxide and black smoke concentration levels in urban environments. This model produced good results in London even though it was less sophisticated than most of the forecast-oriented models usually mentioned in the literature. The idea behind this approach is that only some predominating variables, carefully selected on the basis of a statistical approach, determine pollutant concentrations in an urban atmosphere. This type of approach has also been used by other authors (Hallez *et al.*, 1989; Meurrens *et al.*, 1983; Hallez *et al*. 1982) to develop another type of model where the influence of different meteorological factors is taken into account in the form of multiplying functions.

On the basis of these findings, the CESSE developed an econometric type model based on a non-linear multiple regression analysis. This model has been constructed after having studied the influence of various parameters related to pollutant concentrations in an urban atmosphere (Hecq *et al.*, 1992; Hecq and Taminiaux, 1993; Hecq *et al.*, 1994; Hecq *et al.*, 1995).
The model is designed as a statistical relation between a dependent variable - the pollutant concentrations measured at different monitoring sites in the Brussels urban area - and the two following types of explanatory variables:

1. *Economic variables*: emissions related to the main economic activities in the urban area (traffic, indoor heating, industry, etc.);
2. *Meteorological data:* wind velocity, mixing height, precipitation, temperature, daily period of sunshin, etc.

The most pertinent meteorological data have been selected on the basis of statistical analysis. Whereas these data are directly available from the routine measurements performed in the region, the economic data have to be evaluated on a daily basis for the period considered. The specific module described in the next section performs this.

Module : Economic activity – Emissions

As major economic activity related variables, the model uses the daily emissions caused both by the indoor heating (see description in *Favrel and Hecq* (1998)) and the road traffic, dicussed below. Emissions from local industry is not specifically evaluated since it is virtually non-existent in the Brussels urban area while it could be non-negligible for some pollutants (e.g. particulate matter generated in the direct neighbourhood of the region). Its impact is integrated as external import together with the background level considered in the model formulation.

We describe here the specific methodologies used to assess these emissions for the following pollutants: nitrogen oxides (NO_x), particulate matter (PM) and sulphur dioxide (SO_2) for traffic only.

The calculation of the annual emissions from road traffic is based on two types of data. First, the volume of traffic has to be estimated, e.g. in the form of vehicle-kilometres driven by the different vehicle categories within the area considered. We used the regional statistics that provide the number of kilometres driven on the road network each year. Second, suitable emission factors are required for the different vehicle categories circulating in the Brussels area. Average speed dependent emission factors proposed in the COPERT II methodology (Ahlvik *et al.*, 1997) have been used.

COPERT distinguishes for each vehicle category (passengers cars, light duty vehicles, heavy duty vehicles…) different sub-categories defined on the base of the successive emission legislation and the technological concept (cylinder capacity, catalyst, fuel…). For the period considered, the Belgian vehicle fleet has been distributed according to these sub-categories on the base of the available statistics. Effective traffic composition in the Brussels-Capital region on the different road classes (motorway, national road and urban street) has been deduced from federal statistics.

For each road class, a representative average speed has been attributed to the main vehicle categories (passenger cars, light duty vehicle, heavy duty vehicle, bus and coach).

Using the yearly mileage and the representative average speed of each vehicle category on each road class, the methodology developed provides the annual emissions generated by road traffic in the Brussels-Capital region. Hot emissions and cold start emissions are distinguished. Cold start emissions represent the additional emissions resulting from vehicles while they are warming up or with a catalyst below its light-off temperature. The ratio of cold to hot emissions and the fraction of kilometres driven with cold engines are calculated using the yearly average temperature and an estimate of the average trip length following the COPERT methodology.

The overall calculation can be summarised as follows:

$$AET_i = AET_{i,hot} + AET_{i,cold} \qquad (4)$$

$$AET_i = \sum_j \sum_k EF_{i,j,k,hot} \cdot AVM_{j,k,hot} + \sum_j \sum_k EF_{i,j,k,cold} \cdot AVM_{j,k,cold} \qquad (5)$$

Where,

i	pollutant index;
j	vehicle category index;
k	road class index;
AET_i	annual emission of pollutant *i* due to road traffic;
$AET_{i,hot}$	annual emission of pollutant *i* due to road traffic with hot engines;
$AET_{i,cold}$	annual emission of pollutant *i* due to road traffic whit cold engines;
$EF_{i,j,k,hot}$	emission factors of pollutant *i* for vehicle category j driven on road class k with hot engines;
$EF_{i,j,k,cold}$	emission factors of pollutant *i* for vehicle category j driven on road class k with cold engines;
$AVM_{j,k,hot}$	annual vehicle mileage for vehicle category j driven on road class k with hot engines;
$AVM_{j,k,cold}$	annual vehicle mileage for vehicle category j driven on road class k with cold engines.

Daily emissions required by the model are obtained using suitable traffic indices. Two indices are combined: a daily index - defined as a function of the day in the week - and a monthly index – defined as a function of the month in the year. These indices were constructed from traffic counts at representative sites in the Brussels urban area in order to account accurately for the variations in the traffic intensity all along the year. Daily emissions are then obtained by multiplying the average daily emission (i.e. global annual emission divided by the number of days in the year) by both indices.

Module: Emissions – Immissions

Each pollutant – particulate matter (*PM*), sulphur dioxide (SO_2), nitrogen monoxide (*NO*) and nitrogen dioxide (NO_2) - is modelled separately leading to four sets of equations. Each set of equations contains as many equations as daily observations in the time period considered.

The general form of the equations constituting the model establishes a statistical relationship between the three variable categories described above - pollutant concentrations, meteorological data and economic variables - and lies on two types of relation between the time series:

- linear relation between the pollutant concentrations observed and the emissions from indoor heating and road traffic;

- exponential relation between the pollutant concentrations observed and meteorological variables such as wind-speed, precipitation, mixing height and daily period of sunshine.

Note that the daily average temperature is linearly related to the pollutant concentration by way of the degree day concept mentioned above.

The original feature of this formulation is that it simultaneously takes account of the different influences, economic as well as meteorological, on the level of pollutant concentration in the ambient air. Furthermore, in the general equation, the “emission term” and the “meteorological term” are multiplied by each other rather than simply added. This last feature makes the model highly non-linear both in its variables and its parameters. The details of this block of the model can be found in *Favrel and Hecq* (1998).

Results and discussion

The approach developed enables a relationship to be established, first, between economic activities and emissions and, second, between emission and immissions in the ambient air. The methodology has been applied to the current situation in the Brussels-Capital region. The following sections summarise the most notable results with respect to emissions assessment, emissions-immissions relationship modelling and share of responsibility of the main economic activities in the overall pollution concentrations.

Pollutant emissions

First, the model assesses the amount of pollutants emitted by road traffic and indoor heating for the period 1990-1996. Its application gives the results presented in Figure 1 for particulate matter, Figure 2 for sulphur dioxide and Figure 3 for nitrogen oxides. In these figures the part of the emissions due to indoor heating can be distinguished from those due to traffic, and so on for each of the three pollutants considered.

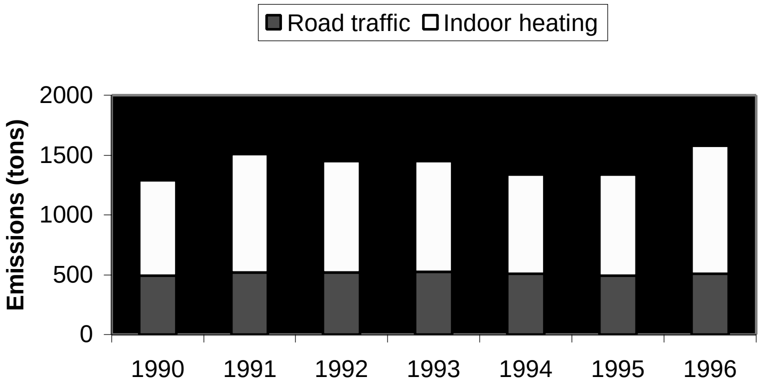


Figure 1: Particulate matter emissions from indoor heating and road traffic in the Brussels-Capital region.

In Figure 1, we can notice that over the period analysed the particulate matter emissions from road traffic have a nearly constant level of about 500 tons per year, while those from indoor heating fluctuate around a mean value of about 900 tons per year. These fluctuations can easily be explained by the variations in the annual average temperature. Cold years result in higher fuel consumption and consequently higher pollutant emissions. On an average for the period 1990-1996, the contributions of the two sectors of activity to the yearly particulate matter emissions in the Brussels-Capital region are estimated at 36% for the road traffic and 64% for the indoor heating.

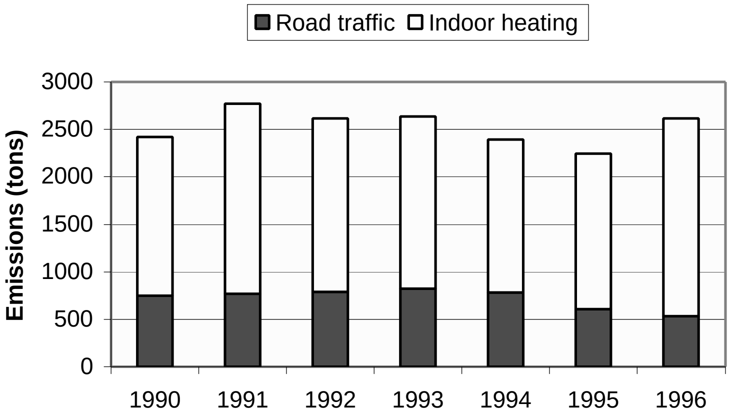


Figure 2: SO_2 emissions from indoor heating and road traffic in the Brussels-Capital region.

While considering the SO_2 yearly emissions in the Brussels-Capital region, the Figure 2 shows that for road traffic the emissions have slightly increased between 1990 and 1993 to reach a value of 819 tons per year. Between 1993 and 1996, the SO_2 emissions from traffic have decreased of about 35%. That can be explained by the introduction of new standards for the reduction of the diesel fuel sulphur content, first in 1994 and second by the end of 1996. SO_2 emissions from indoor heating fluctuate around the average value of 1809 tons per year with the same remark as for PM emissions regarding the year to year variations. The contributions of road traffic and indoor heating to the SO_2 emissions are estimated at 29% and 71% respectively.

Finally, we can see at the Figure 3 that road traffic is mainly responsible for the annual nitrogen oxides emissions in the Brussels urban area with up to 71% of the total emissions on an average for the period 1990-1996. We can noticed also the continuous decrease in the absolute emissions of NOx from traffic during this period, from about 6300 tons in 1990 to about 5100 tons in 1996. Considering the continuous increase of the overall mileage driven in the area during this period, this decrease can only be explained by the driving fleet characteristics evolution as a consequence of the introduction of more stringent emission standards during the last years.

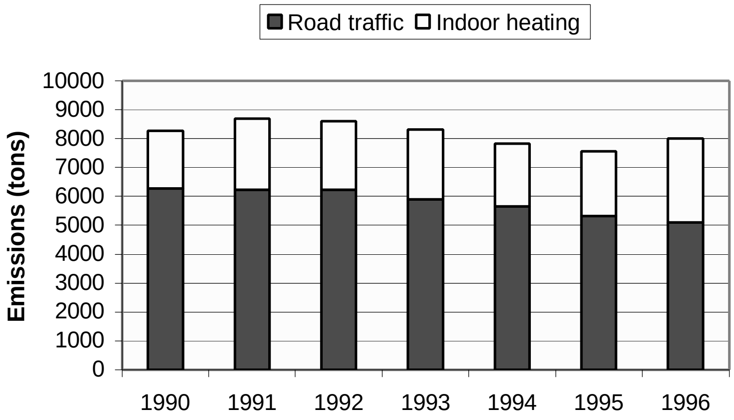


Figure 3: NOx emissions from indoor heating and road traffic in the Brussels-Capital region.

Pollutant immissions

While considering the pollutant concentration in the Brussels urban area, in *Favrel and Hecq* (1998) it was attempted to estimate the daily evolution of the concentrations of particulate matter, sulphur dioxide, nitrogen oxide and nitrogen dioxide. Due to gaps in the pollution data available, the analysis to the period 1994-1996. Comparison between the concentrations measured and those estimated by the model for the four pollutants considered during the year 1996 demonstrates good agreement between the two time series which demonstrates the model ability to reproduce the daily evolution of pollutant concentration in the Brussels area.

Conclusions and Further Steps

The approach developed allowed both to assess the emissions from the main human activities responsible for the urban air pollution and to determine the share of responsibility of these activities in the pollutant concentrations measured in the Brussels urban area. The results demonstrated a good agreement between the concentrations observed and those estimated by the model. On the base of the model, the contribution of road traffic to the pollutant immissions in the Brussels-Capital region has been determined. Road traffic appears to play a very important role in the nitrogen oxides pollution with a contribution of 73% for NO and 53% for NO_2 on an average for the period 1994-1996. In relation with particulate matter pollution, simulation based on the total suspended particles measurement in the area has demonstrated a relative small contribution of road traffic, while a simulation based on local measurements of black smoke established the contribution of road traffic to 66%. While considering sulphur dioxide, the contribution of road traffic appears to be important mainly during the summer months while winter immissions are dominated by the indoor heating seasonal influence. The contribution of road traffic to SO_2 immissions has continuously decreased these last years.

Further analysis on the linking of emission models with mobility models, would be mainly concentrated on network flow model, using the above described methodology for emissions calculation. Desegregated model, based on the data on mobility in the region, would provide then the spatial distribution of each pollutant in the area under study and allow for a more detailed analysis aimed at environmental policy recommendations coherent with the urban development plan of the region.

5. Simulation tools. Calibration/validation of models system, scenarios prerequisites

As a basic computer tool for spatial analysis of mobility the package TRIPS will be used (*TRIPS, 1999*), which is a set of inter-related modules as listed below. These contain the ‘building blocks’ of a model, enabling the user to access the features and facilities to build models, which meet individual requirements.

- Highway Assessment
- Public Transport Assignment
- Demand Modeling
- Matrix Estimation
- TRIPS Graphics
- TRIPS Manager - Graphical Project Management Tool
- Data Processing TRIPS and Showman Plus

According with the data collected at the first phase of the project, the calibration of the model developed at phases 2-5 will be needed to adjust parameters of cost functions, emission coefficients and other important controls of the models system.

Scenario simulations would be based on different groups of assumptions and targets for the policy making in the Brussels-Capital region, in particular, for:

- urban/regional planning in the long term perspective (till the year of 2020 or longer),
- transport policy in the urban area and its surroundings,
- offices stock and market development,
- regulations on vehicles use,
- road taxation and other environmental instruments.

Possible scenarios for improvement of the policy making in regional and urban planning in order to reduce the ecological pressure are being developed.

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