“Prospective Research for Brussels”

Integrated modelling of the urban development, mobility and air pollution analysis in the Brussels-Capital region: Policy measures based on environmentally friendly vehicle technologies

Final Report

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1 Summary

The introduction of clean vehicles could provide an interesting contribution towards a significant reduction of harmful exhaust gases, which is a key element of a sustainable transport policy. This can help Belgium to meet its Kyoto targets (abatement of greenhouse gases), to reduce its energy dependence on fossil fuels and to place itself on the path towards a sustainable development of transport.

Within this scope, the use of alternative powered means of transport like electric and hybrid vehicles should be taken into consideration. In urban traffic, due to their beneficial effect on environment, electrically propelled vehicles are an important factor for improvement of traffic and more particularly for a healthier living environment.

Facing new vehicle technologies however, one has to recognize that *unknown is unloved*; both the policy makers and the consumers have a difficult choice when confronted with vehicles that are not yet distributed on a large scale, because of a lack of relevant information on these products, their performance, their cost, their energy consumption and their environmental effect.

The general objective of the underlying project is to define and compare several transport policies through the use of a simulation tool, aiming to assess the environmental and energetical effect of traffic and focusing on the introduction of alternative vehicles, energy sources and traffic policies. The creation and availability of a simulation tool allowing to implement a synthetised mix of measures, and to analyse their effect on environment, mobility and energy usage, contributes to the creation of a powerful policy instrument.

The introduction of different traffic and mobility policies is not easy to assess since there is an interaction between traffic modes, vehicles types, traffic emissions, traffic routes, etc. and all policies managing their deployment. As an example, introducing traffic (parking) tolls for thermal vehicles in the city centre will reduce the amount of petrol and diesel cars and favour electric vehicles to drive in this area. Hence the amount of pollution in the city centre will decrease. However the thermal vehicles will search other routes outside this area and will lead to an increase of emission on these roads. The overall result should be evaluated. To be able to evaluate these complex problems a powerful software model combining traffic models with emissions models, as developed in the framework of this research, is required.

Different approaches to analysing the environmental aspects of vehicle technologies and to evaluating the effects resulting from their use in terms of emission reduction and energy consumption can be proposed. Each of these approaches has its own level of complexity and precision. The simplest approach consists of referring directly to the vehicle emission levels which laid down in the European directives. These emission levels however and based upon standardised

cycles which are not really representative of actual vehicle use. Such an approach can thus not be expected to yield valuable output. A more refined approach consists in resorting to emissions models. These models enable a link to be set up between traffic, its different parameters (speed, acceleration and technical features) and the resulting pollutant emissions. Different categories of models can be distinguished:

- Emission models based upon statistical emission factors defined in function of an average speed calculated on a large number of tests with actual vehicles. This is the methodology followed by Copert 3 [1] / Meet 4 [2].

- More refined models which make use of emission factors expressed as a function not only of speed but also of a dynamic parameter such as acceleration.

- Models enabling vehicle dynamics to be simulated on the basis of detailed modelling techniques (speed cycle, gear changing, new technologies, etc.) and the characteristics of the different vehicle components (VSP).

The simulation software developed by the VUB-ETEC [3,4,5] and deployed in the framework of this programme encompasses both static models (Copert/MEET), as well as dynamic models (VSP- Vehicle Simulation Programme), coupling them with a traffic assignment model (TRIPS) in order to yield results on both local and regional levels.. These traffic and vehicle simulation models will be used to evaluate the feasibility of the introduction of new technologies for various categories of passenger and goods vehicles, by assessing different scenarios from the technical and environmental points of view, focusing on the situation in the Brussels-Capital Region. This research project integrates transport aspects with energy and environmental aspects , assessing the potential impact of. the introduction of new vehicle technologies:

- Developing of measures to reduce greenhouse gases through the use of more efficient technologies on one hand and the optimization of traffic organization on the other hand.

- Developing sources of alternative and/or renewable energy and analyzing the environmental aspects.

- Improving the energy efficiency and reducing of emissions in the transport sector in the framework of rational use of energy and sustainable development.

- Proposing policy measures associated to urban mobility and pollution.

The proposed multi- actor project allows a combination of expertise and efforts of two partners (CEESE-ULB and ETEC-VUB) in construction of an Integrated model for urban development, mobility and air pollution analysis for the Brussels-Capital region, and its application to analysis of possible scenarios of sustainable mobility in the region. . See also Implementation Diagram (Illustration 1.1).

Integrated urban development, mobility, and air pollution modelling for the Brussels-Capital region:

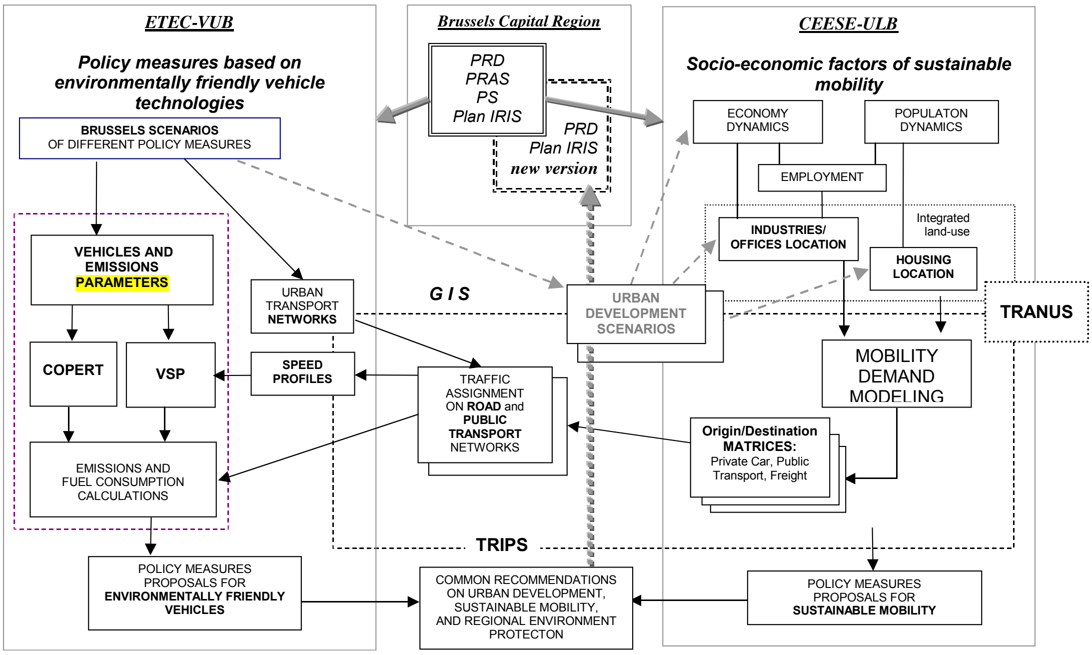

Illustration 1.1Multi-Actor Project "Prospective Research in Brussels –2001": Implementation Diagram

The assessment tool, initially developed for the Belgian federal government and further improved in this 'Prospective Research for Brussels'-project, associates mobility scenarios with vehicle emission and fuel consumption models. The simulation software comprises static models (COPERT/MEET), as well as dynamic models (VSP - Vehicle Simulation Programme). The models are coupled with a traffic assignment model (TRIPS). Several categories of road passenger and goods vehicles are taken into considerationfocusing on the practical situation in the Brussels Capital Region.

Within the first year of the project the first part dedicated to software development has been carried out, improving and updating the software package.

The original project approach was based on a multi-actors project in collaboration with the CEESE-ULB (Dr. Pavel Savonov). The Prospective Research project of the ULB was only accepted one year later however, and very few progress has been made, the researcher having in the meantime left the country. Hence, the research project had to be worked out without input from the ULB through exploiting the existing knowledge at VUB, particularly concerning the available traffic data.

In this framework, the software tool has been evaluated and traffic policy measures have been assessed. Based on the revised software package as developed in the first year, a number of different scenario's have been evaluated on the level of mobility, environment and sustainable development, such as:

- Restrictions on transport in certain areas
- Deployment of automatic rent-a-car systems with innovative vehicles
- Development of goods distribution centres with electric and hybrid vehicles
- Other policy mobility measures with environmental friendly vehicles

The study concludes with an analysis and interpretation of the results and a proposal for new policy measures. These recommendations for a sustainable mobility and measures necessary to reduce air pollution will be a key output of the project, allowing its use as a policy-supporting document.

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2 Policy Relevance

2.1 Project backgrounds and justification

The finite nature of fossil fuel, particularly oil, resources and the geopolitical and economical backgrounds of energy production are necessitating the development of alternative energy sources and the reducing dependency on imported oil. These factors will force us to change our economics completely and the question will not be no longer if, but when, and what problem will be the first to trigger new technologies. As shown in Illustration 2.1[6], critical shifts in the availability of oil will occur the next decades.

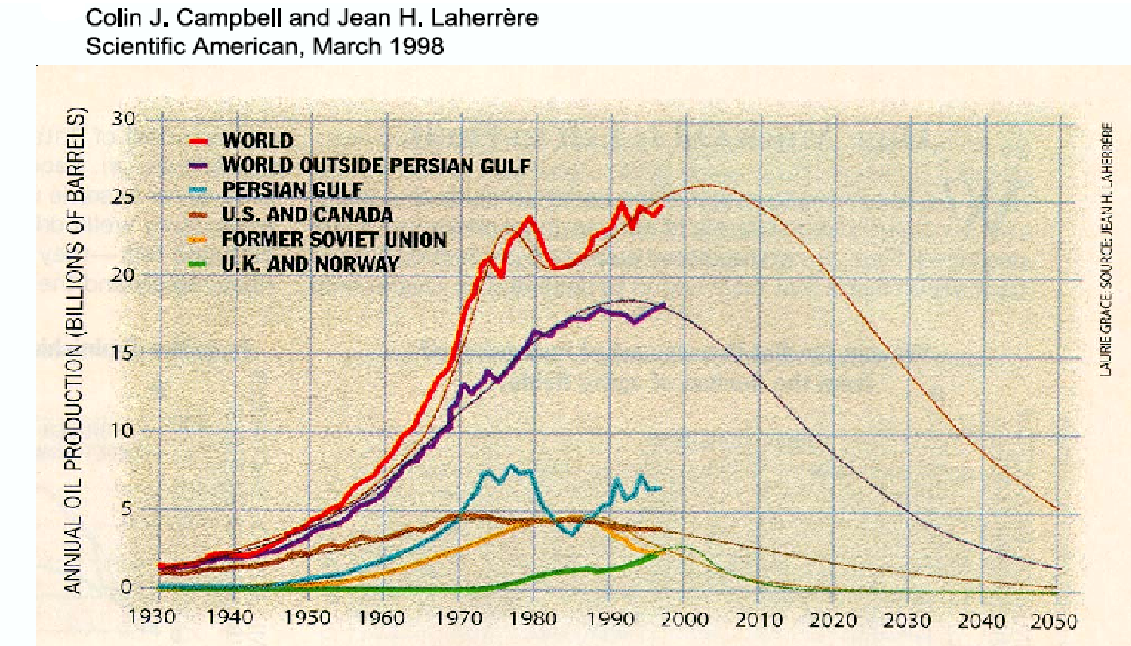

Illustration 2.1: The end of cheap oil

Beside these economical and political aspects, there are some considerable environmental reasons for changing our transport systems. The pollution caused by transport is a heavy burden especially in urban areas, where a large number of pollution emittors (cars) are united with a large number of pollution receptors (people and buildings).

Transport is the cause of large quantities of pollutants in the atmosphere, which have a direct or indirect effect on environmental receptors (people, materials, agriculture, ecosystems, etc.) at global as well as regional or local level. More specifically, road traffic generates large emissions of greenhouse gases (CO_2, N_2O and CH_4), which are held responsible for the climate change; tropospheric ozone precursors (NO_x and VHC) that cause serious damages at regional level, as well as agents causing acid rain (NO_x and SO_2). At local level, emissions of particulates matter, sulphur dioxide or carbon monoxide resulting essentially from the road traffic are the cause of serious damage to the buildings and public health.

If, in recent years, mainly due to a decrease in noxious emissions from industry and building heating, the air quality has improved in big cities with respect to most pollutants – with some notable exceptions such as carbon dioxide that has continuously increased – the damage associated with air pollution has remained at a high level, due to an increase in transport. Recent studies undertaken by the CEESE-ULB have evaluated the annual impact of road traffic in the Brussels-Capital Region at about M€800 in 1996[7] .

The introduction of clean vehicles could provide an interesting contribution towards a significant reduction of harmful exhaust gases, which is a key element of a sustainable transport policy. This can help Belgium to meet its Kyoto targets (abatement of greenhouse gases), to reduce its energy dependence on fossil fuels and to place itself on the path towards a sustainable development of transport.

2.2 Policy Measures

In this chapter, the several policy measures which have been consideredin the research project will be presented. They aim to an increase of the use of hybrid and electric vehicles and a reduction of harmful exhaust gasses.

These policies were selected and implemented in the software tool, allowing to take into account potential traffic policies while developing the software tool.

2.2.1 Restrictions on transport in certain areas

The closing of certain areas of the city centre for particular types of transport is a policy which can be implemented through several measures, the cost of which will vary in functin of their complexity:

- Fully closing of all traffic in the city centre, and make a possible exception for
    - public transport
    - environment-friendly transport (EV and HEV)

    - whether time-dependent or not.

- Discouraging traffic in the city centre through

    - parking tolls for polluting vehicles

    - reserving available parking spaces for EV or HEV

    - road pricing for non-ZEV (Zero Emission Vehicle) when entering the centre.

    Traffic tolls are a classical measure to control road access and use. They have been implemented since many centuries, mainly to provide income to road operating authorities and to pay for road infrastructures. In recent years, toll levying has known novel applications however, with the aim of the toll not being in the first place to provide income, but to limit and control traffic in certain areas in order to relieve congestion and improve mobility through promoting a modal shift. The best known example of such toll is the "congestion charge" which was introduced in London in February 2003 with the aim to:

    - reduce congestion
    - reduce through traffic
    - further encourage use of public transport in central London
    - benefit business efficiency by speeding up the movement of goods and people
    - create a better environment for walking and cycling

    It is worth to note that low-emission vehicles such as electrics are exempted from this congestion charge.
    After six months of congestion charge in operation, the system has led to reduction of traffic load with up to 30% in the zone where the congestion charge is levied.[8]

- Interdiction of traffic in tourist and / or commercial zones in the city centre.

These measures can of course be implemented in combination with each other to obtain a bigger impact.

2.2.2 Car-sharing with EVs

Car-sharing and public transport complement each other; car-sharing, as a system of semi-public transport, maintains the privacy and flexibility of a private car, which are the main advantages of the concept. The reservation of parking space or privileged access to certain areas for the car-sharing vehicles will make the system even more attractive.

Illustration 2.2Automatic rent-a-car station at VUB, Brussels (1980)

The concept of automatic rent-a-car systems in Brussels has been pioneered by the Vrije Universiteit Brussel in the framework of the "Brussels Electric Vehicle Experiment", where 9 vehicles were deployed on 2 stations (at the two VUB campuses) from 1979.

Further applications have been pursued on several sites, one of the most known and successful being the *Liselec* project in La Rochelle, France, where a fleet of over 50 electric vehicles is in use today.

Illustration 2.3: Liselec station in La Rochelle

The implementation of such systems in the Brussels Capital Region has also been considered in this project, with proposed centres, where electric vehicles can be rented, will be located near major transport interchanges. The rent-a-car stations should be located in key strategic areas: the connection with public transport should be easy and a fast access to the suburb area is necessary; there is also the need of enough parking areas at the interchange locations.

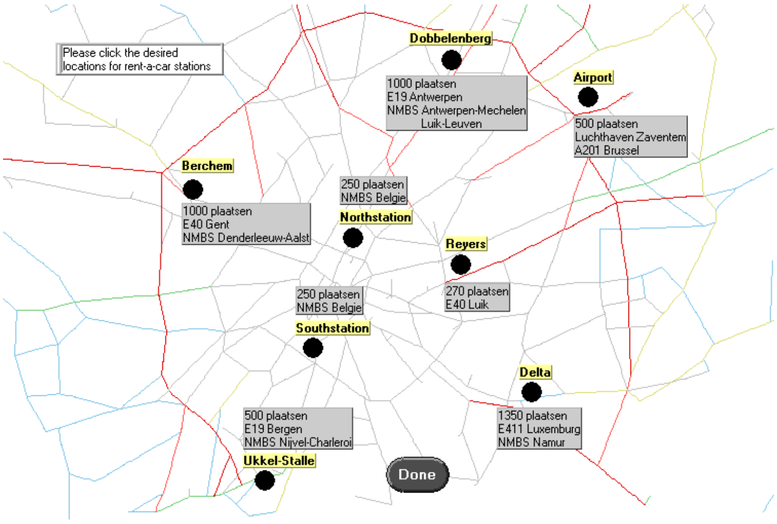

Illustration 2.4 Rent-a-car stations (Part of software interface)

2.2.3 Goods distribution with EV's

Most cities, including the Brussels Capital Region, are confronted with problems regarding air and noise-pollution and congestion caused by motorised road traffic. The evolution of urban logistics in the past decades even worsened that situation, due to an increasing use of heavier goods vehicles in city centres. The nuisance caused by these vehicles to traffic fluidity and the environment is growing and becoming less and less acceptable. Shops and businesses suffer from the poor accessibility of the city, residents and shoppers experience the negative effects of the pollution caused by these vehicles. The economic and environmental viability of cities are negatively effected by this present organisation of urban goods distribution.

Better solutions for urban logistics can be envisaged however by approaching the subject in a dual way, taking into account the interests of all parties involved, in order to set an example for clean and efficient urban distribution in the 21st century:

- By organising urban distribution using quiet and clean (hybrid) electric vehicles, the nuisance caused by distribution activities will be decreased. The improved living climate of the city will benefit residents and shoppers as well as shopkeepers.
- A more efficient organisation of urban logistics is achieved by more efficient routing of the vehicles and the use of urban distribution centres (UDC). This will decrease the number of journeys made by heavy vehicles and increase traffic fluidity in urban areas. The improved accessibility of the city will benefit transport companies, shopkeepers and businesses operating in the city.

These concepts have been tested in a number of cases, one of the most extensive being the EU-funded *ELCIDIS* project (1998-2002)[9], which ran in six European cities, involving a total of 39 electric and 16 hybrid vehicles and where the authors have been involved in evaluation and dissemination.

As main result, the project succeeded in verifying the principal merits of using (hybrid) electric vehicles in urban delivery concepts. *ELCIDIS* has provided indisputable proof that there are no predominantly objections to the use of hybrid and electric vehicles in urban distribution, neither from company managers nor from drivers, and certainly not from local authorities.

Illustration 2.5Loading of an electric van at the ELCIDIS urban distribution centre in La Rochelle, France.

The impact of the use of environmentally friendly vehicles for city goods distribution energy-use and environment is considerable. Electric vehicles present the opportunity to be more energy efficient than their ICE counterparts. This is partially due to their ability in using regenerated energy from braking, but also the much higher energy-efficiency of the electric motor should be considered, as well as the complete absence of energy use during stops.
Operating hybrid and electric vehicles in urban distribution has to be combined with a UDC based approach. For battery electric vehicles, a UDC near the city-centre with “home-recharging” equipment is necessary. For hybrid electric vehicles, the UDC may be located further away from the city, but at a reasonable distance.
From the transport companies point of view, small and large electric vans are applicable for both postal and package deliveries, delivery of large(r) parcels and/or voluminous goods need large electric vans and hybrid trucks.

In order to assess the application of the concept on the Brussels Capital Region, the provision of urban distribution centres has been implemented in the simulation programme, with two options as for the actual location of the centres:

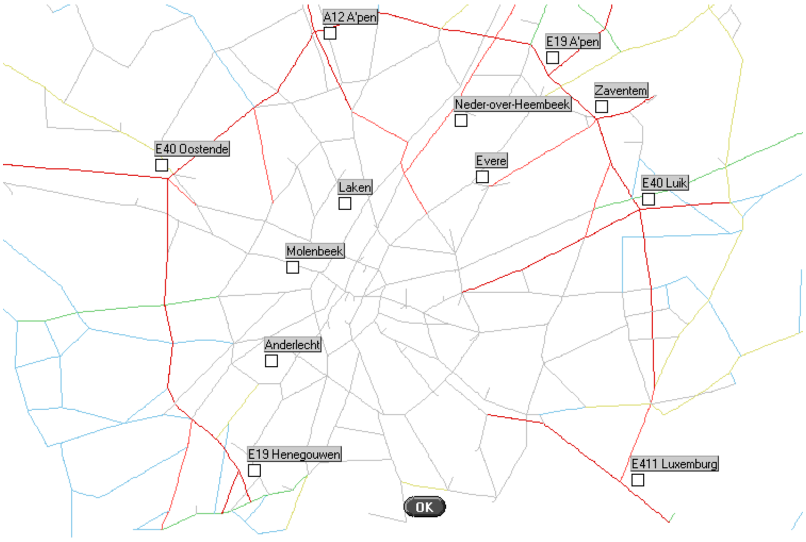

Illustration 2.6Goods distribution centres in the Capital Region (Part of software interface)

- Near the crossings of the outer ring road and the main approach roads to Brussels, at the edge of the Brussels Capital Region. In this way heavy traffic can not only be removed out of the city centre, but also for a big part out of the area within the outer ring road, which is more or less equal to the whole Brussels Capital Region.

- Some of the distribution centres can be located in the industrial zone within the Capital Region. This area roughly encompasses the north-south belt following the canal. This gives the possibility of intermodal transport of goods - through the railways and the canal, as well as a connection to the cargo area of the airport. The opportunity of intermodal transport, which is gaining a growing interest, undoubtedly brings a surplus value for these centres.

2.2.4 Reserved parking for EV/HEV

The introduction of environmentally friendly vehicles which make use of electric power can be promoted by the deployment of parking infrastructure which is reserved for this type of vehicles. As an added incentive, such parking spaces could be provided with charging infrastructure for electric vehicles.

Electric vehicles need access to charging infrastructure; a specific study[10] on the implantation of publicly accessible charging infrastructures in the Brussels Capital Region has been performed by the Vrije Universiteit Brussel. The physical layout of the infrastructure can take different forms, which are defined by international standards[11]:

- Using conventional socket-outlets ("mode 1")

- Using conventional socket-outlets with an in-cable protection device ("mode 2") – the use of this mode is not relevant for Europe.
- Using dedicated socket-outlets for electric vehicles, incorporating additional safety measures such as a "pilot contact" ("mode 3")
- Using an external (fast) charger with d.c. connection ("mode 4")

Charging stations to be deployed on the public highway shall be equipped with a "pilot contact" and thus be "mode 3" (for a.c.) or "mode 4" (for d.c.) only. This mode in fact presents very high safety features: the outlet will only dispense current to an electric vehicle which is correctly connected, and if no vehicle is present, the socket-outlet is dead.

Illustration 2.7: Charging station proposed for downtown Brussels

The network of charging stations may be completed with a limited number of fast charging stations, which can be used in emergency situations, besides offering a psychological support easing the acceptance of the electric vehicle by the user.

Illustration 2.7shows an artist's impression of an electic vehicle charging place in downtown Brussels. The charging column, here pictured in a bright green colour for clarity purposes, is of a type which can be perfectly integrated in the urban landscape, even in the sensitive environment of a historical city centre.

3 Research Progress

3.1 Overview

During the first year of the project, most efforts have been directed at developing the software system allowing combining traffic models with emission and vehicles models.

The original project approach was based on a multi-actors project in collaboration with the CEESE-ULB (Dr. Pavel Savonov). The Prospective Research project of the ULB was only accepted one year later however, and very few progress has been made, the researcher having in the meantime left the country. Hence, the research project had to be worked out without input from the ULB through exploiting the existing knowledge at VUB, particularly concerning the available traffic data.

The main activities performed in the framework of software development and data collection can be summarized as follows:

3.2 Traffic Software Assessment

The ***EMITRAFFIC*** software, developed by the VUB in the framework of this project, makes use of commercial software TRIPS and LabVIEW. In the first task TRIPS was compared with other traffic simulation software to evaluate if in this way an improvement was possible.

TRIPS is a comprehensive transport planning modelling package that is used to build mathematical models of a transportation system. This allows the evaluation of potential scenarios or policy measures using a 'what-if' approach, in order to determine the planning and development of transportation infrastructure for a town, a city, a region or a country.

Modelling such systems can be complex as there is a need to represent accurately both the transportation system itself: the roads, intersections, buses, trains etc and their interactions, and the behaviour of people within these systems. A key requirement for such modelling software is that it should provide the user with the flexibility to describe a wide range of systems with differing characteristics and attributes, whilst providing the analytical framework that allows the planner to specify and address the issues of immediate interest.

TRIPS does this by providing an integrated set of inter-related modules, each focusing on a particular functional aspect of transportation modelling: *Demand Modelling, Public Transport (PT), Highways, Matrix Estimation* and *Survey Analysis and Licence Plate Matching*. Within each module the user has the scope to specify, with an appropriate level of detail, the model structure that is needed to answer their questions.

To help in this task, TRIPS is operated through an intuitive set of graphical tools that have been designed for efficiency and productivity. There are two such sets of tools: *TRIPS Manager*, which is designed to let the user specify a model structure in the form of a 'flow chart', and *TRIPS Graphics*, which provides the user with a powerful set of network editing and reporting tools.

None-the-less, constructing such models can be a time-consuming task, and the investment in a model is only realised through effective understanding and use of its results. TRIPS contains mechanisms for providing detailed output information which may be presented in varied text or graphical formats, and a full range of standard and user-defined statistics can be generated.

At the other hand MODELISTICA sells another software package called *TRANUS*. The advantages of TRANUS should be compared with TRIPS.

TRANUS is an integrated land use and transport model, which can be applied at an urban or regional scale. The program suite has a double purpose: firstly, the simulation of the probable effects of applying particular land use and transport policies and projects, and secondly the evaluation of these effects from social, economic, financial and energy points of view.

For the transport planner, land use and transport integration provides a means of making medium and long-term demand estimates, which are impossible with transport-only models where demand is a given input. The integrated approach can also be very useful as an alternative method for constructing realistic estimates of origin-destination matrices; large surveys can be very expensive, and even with a generous sample size it is very difficult to obtain a complete estimate of the matrices. The alternative is to carry out a much smaller survey and use the data to calibrate an integrated land use and transport model, obtaining complete and realistic matrices.

For the land use planner, whether at an urban or regional scale, integrated modelling makes possible an assessment of the implications of transport policies on the location and interaction of activities. But it is in consistent land use and transport planning that the TRANUS system shows its full potential. However, it is possible to apply TRANUS as a stand alone transport model from given data about demand, should this be required for short term policy appraisal.

It can be concluded that Tranus is more a land-use model, mainly focused to the demand side. Tranus contains a lot of standard tools, however the assignment tools are less advanced than it is the case with TRIPS. TRIPS allows a higher flexibility as a developers tool. However the demand modelling is not standard available and needs to be programmed. The superior assignment tools allows also dynamic assignment inclusive blocking back of queues.

Finally the good support offered by TRITEL (TRIPS software distributor in BELGIUM) is an additional factor to take into account.

Hence it was decided to upgrade the software packet from TRIPS to CUBE. Cube is a family of software products (Trips, Viper, TP+, Tranplan, Accmap, Minutp, Citiquest) that form a complete travel forecasting system providing, easy to use, capabilities for the comprehensive planning of transportation systems. Cube is comprised of Cube Base and add-on libraries of planning functions. A user of Cube has Cube Base and one or more of the functional libraries dependant on their planning tasks. This structure allows the professional planner to add functions as required without the need to learn a new interface and without the need to create multiple planning databases. Cube allows for the easy incorporation of other software including industry standard ArcGIS from ESRI and various Microsoft Office programs. The client's own software may also be readily incorporated into the system.

This upgrade succeeded successfully, allowing to continue the simulations with the current release software.

3.3 Traffic Data Collection

The simulations are performed by TRIPS on the base of mobility data. The area to be considered in TRIPS is divided in *zones*: each vehicle originates in one zone and terminates in another. This defines the *origin-destination matrix*, which quantifies the displacements between the zones (e.g. X vehicles from zone A to zone B, Y vehicles from zone A to zone C, etc.). The area is represented by a network, which is loaded with vehicles by TRIPS. The origin-destination matrix is charged iteratively by choosing the shortest or fastest or cheapest way between origin and destination. At each iteration, the saturation of the road network is checked and corrections made if required. Therefore, speed/flow curves are used, giving the reduction of the speed with increasing traffic flow. After a number of iteration, convergence is obtained and the simulated traffic flow is the result.

The traffic data available at the moment for TRIPS are dating from 1993 (passenger cars) and 1998 (goods transport). The CEESE-ULB expertise of demographic and socio-economic dynamics was foreseen in the multi-actor programme. The Prospective Research project of the ULB was only accepted one year later however, and very few progress has been made, the researcher having in the meantime left the country. Hence, the research project had to be worked out without input from the ULB through exploiting the existing knowledge at VUB and going forward with the existing traffic models.

However, a potential collaboration in this field will also yield to prospective for the time horizons 2005, 2010 and 2020; taking into account recent targets of the Brussels Capital region (IRIS mobility plan; Regional Plan of Development, PRD).

3.4 Vehicle Data Collection

The dynamic vehicle emission calculation is performed with the help of VSP, VUB's Vehicle Simulation Programme, running in a LabVIEW environment.

The basic modelling strategy is the well-tried and trusted method [12,13,14,15,16,17] of dividing the drive cycle into a number of time steps and calculating the characteristics of the vehicle at the end of each time interval. Longitudinal dynamics simulation serves to calculate the time characteristics of several quantities in a vehicle.

The simulator approximates the behaviour of a vehicle as a series of discrete steps during each of which the components are assumed to be in steady state. This allows the use of efficiency or other look-up tables, which are generated by testing a drivetrain component at fixed working points.

For a vehicle simulation typically the following steps are carried out [18].

- Using primary parameters for the vehicle's body shell and chassis (e.g. cumulative mass of powertrain components, payload, body design characteristics, etc.) and route parameters (acceleration, velocity, gradient, wind velocity, etc.), the programme calculates the forces acting on the vehicle and the required tractive effort.
- This tractive effort corresponds with a required torque and speed at the wheels.
- The torque and speed are transformed through the powertrain by the successively intervening system components (such as differential or gearbox) until a prime mover such as a combustion engine or electric motor is reached.
- The prime mover typically uses an efficiency map to predict its energy requirements (f.i. in terms of fuel consumption for an internal combustion engine or power to be drawn from a battery).

This calculation is repeated at each time step during the vehicle cycle.

A component model can be as sophisticated or simple as the programmer's time and budget permits. A good description of the component losses is required. This can be achieved by simulating the behaviour of the component by taking into account the whole map of working points. The components (engine, electric motor, chopper, etc) can be defined by *physical equations* and equivalent circuit (analytical models) or by measured efficiency characteristics (Curve fitting experimental models) fit into look-up tables.

The VSP programme already has an extensive vehicle database available. The database also allows implementing various alternative fuel options; the fast evolution of technology in this domain makes it necessary to have state-of-the-art information.

Next to the extension of VSP's database, the programming environment, LabVIEW, is updated on a half-yearly basis to its current software release.

3.5 Emission Factors Updating

Based on VSP, vehicle dynamics can be simulated on the basis of detailed modelling techniques (speed cycle, gear changing, new technologies, etc.) and the characteristics of the different vehicle components. However, the data available to implement this type of approach are often relatively limited as they require the knowledge of detailed map of the consumption of traction systems. These data are very hard to get since they are anxiously guarded by the manufacturers who consider them as highly confidential, because they reflect their specific know-how in engineering on one hand and because they allow an assessment of the actual performances of the materiel on the other hand.

For the basic default scenario describing the actual status of the traffic in the Brussels Capital Region emission models, based upon statistical emission factors defined in function of an average speed, will be used.

The *average speed approach* is a commonly used method to estimate emissions from road traffic, e.g. Copert[1] . This approach is based on aggregated emission information for various driving patterns, whereby the driving patterns are represented by their mean speeds alone. All this information is put together according to vehicle technology, engine size and model year and a speed dependent emission function is derived. This means that in addition to vehicle type, the average speed of the vehicle is the only decisive parameter used to estimate its emission rates.

In principle, total emissions are calculated by summing emissions from three different sources, namely the thermal stabilised engine operation (hot), the warming-up phase (cold start) and the fuel evaporation. The total emissions are thus expressed as:

$$E = E_{hot} + E_{start} + E_{evap}$$ Eq. 1

In which E_{hot} are the hot engine emissions (g), E_{start} the cold engine emissions (g) and E_{evap} the evaporation emission (g)

The hot emission factors are based on:

- Drive cycles represented by their average velocity only.
- Vehicle technologies (class of engine swept volume and production year).
- Number of vehicles of a certain category.
- Covered distance for each category.

The hot emission factors basically are defined by equation .

$$E_{k,hot} = \sum_i \left(n_i . L_i . \sum_j p_{i,j} . e_{i,j,k} \right)$$ Eq. 2

In which:

- k : type of pollutant
- i : vehicle category
- j : road type
- n_i : number of vehicles in category i
- L_i : covered distance by vehicle of category i (km/vehicle)
- $p_{i,j}$: relative contribution (%) of yearly covered distance on road type j by vehicle category i
- $e_{i,j,k}$: emission factor (in g/km) in function of road type j, vehicle category i and type of pollutant

Correction factors are required to take into account the additional emissions and consumption due to cold start. The ratio of cold start emissions to hot start emissions has been shown to vary between around 1 and 16 according to the vehicle technology, the pollutant, and other parameters [19]. The cold start emissions (E_{start}) are calculated in function of the average velocity, ambient temperature and distance travelled with cold motor.

Evaporative emissions occur as a result of fuel volatility combined with the variation in the ambient temperature during a 24-hour period or the temperature changes in the vehicle's fuel system that occur during normal driving.

However this approach is insufficient and additional correction factors are introduced based on statistical data.

$$e_{hot} = e_k . GC . LC . MC . FC . IC$$ Eq. 3

In which:

- e_k :emission factor mostly in function of average speed (in g/km)

- GC :correction factor taking into account the road inclination in function of velocity, type of pollutant, vehicle category and road gradient class (only HDV)
- LC : correction factor taking into account the vehicle load in function of road gradient and velocity (only HDV)
- MC : correction factor taking into account the vehicle mileage in function of pollutant, road type, consumption and mileage. (Emissions are predicted to be up to 3 times higher than the original values for vehicles having travelled for more than 120 000 km).
- FC : correction factor taking into account the effect of improved fuels due to new directives
- IC : correction factor taking into account the effect of the introduction of enhanced inspection and maintenance schemes

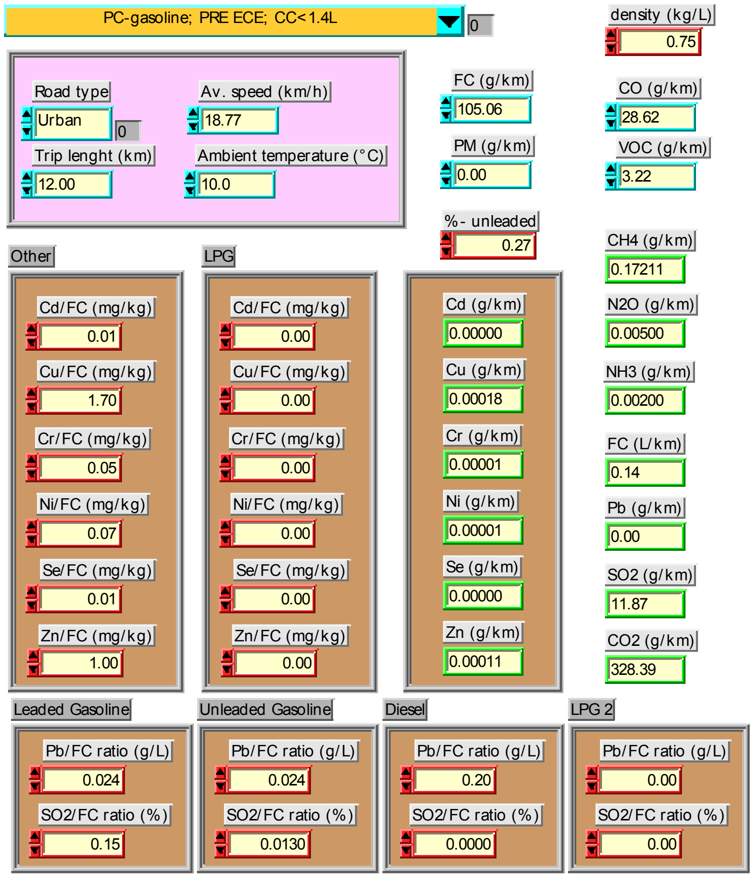

Illustration 3.1 Example of user interface

The latest version, Copert III, was published in July 1999 and make use of the most recent results of the COST 319 action, the MEET report, Auto-oil II programme, inspection and maintenance project and EPEFE project. At the moment a new large European research project is running called ARTEMIS [20]. These up-to-date emission factors were integrated into the software package (developed in LabVIEW), having the most recent data into the software.

For this purpose the *Emission* programme has been rewritten in order to cover different vehicle categories and additional pollutants as described in the latest version of the Copert methodology.

Besides the general user interface (Illustration 4.15), *Emission* gives the user access to its subroutines (called “virtual instruments” in the Labview terminology), which generate Copert emission results for all vehicle categories. An example is shown in Illustration 3.1.

3.6 Dynamic Modelling

TRIPS has particular features for analysing highly congested and time-varying conditions, known as Dynamic Assignment Modelling although it is equally adapt at straightforward assignment. The possibilities and advantages of dynamic modelling was evaluated and this in relation to the vehicle dynamic approach of VSP.

The modelling of dynamic effects is primarily effected in TRIPS through the use of ‘flow profiles’, which express changes in the relative levels of flow during the modelled period. Time is discretised into segments during which flow levels are assumed to be constant. In practice, time segments of 5 to 10 minutes are used. This is entirely similar to that used in the well-known TRL intersection modelling programs ARCADY, PICADY, and OSCADY. TRIPS dynamic assignment also calculates queues and delays in a similar manner to these programs based on time-dependent queuing theory.

The modelling of dynamic effects in TRIPS focuses on flow variation with time as the dominant consideration and, in the interests of practical run times, avoids calculating different routes for different time periods. The dynamic modelling takes places within a conventional ‘Capacity Restraint’ framework, which ensures that multiple sets of routes are generated which give rise to costs which approximate Wardrop Equilibrium conditions to a reasonable degree. The costs associated with these routes are ‘flow weighted’, taking account of the fact of peak delays arising when flow levels are at their highest.

In TRIPS dynamic assignment, the user defines profiles, which are associated with origin zones. These reflect the times at which people want to start their trips. In principle, these flow profiles could be disaggregated to vary by destination zone, but considerations of data availability mean that the implementation simply allows the use to associated flow profiles with groups of origin zones, such as ‘western suburbs’, ‘neighbouring town’, ‘city centre’, and so on.

The standard modelling period in TRIPS is one hour, but facilities exist to link periods together to model several hours, with data such as demand matrices and signal plans able to be altered after each hour. In dynamic modelling, it is necessary for the user to specify for each period a flow profile that is longer than an hour. This is to account for traffic flows already traversing the network when the modelled period starts, that is, trips which started before the modelled period. Flow profiles are therefore typically defined for one and half or two hour periods.

The main mechanism of TRIPS dynamic modelling is to propagate flow profiles from each origin along each path to each destination zones. The passage of time while traversing the route ensures that the flow profiles change from link to link, but the profiles from different paths using at a link interact and give rise to 'link flow profiles', which have shape (profile) which is a composite of the contributing path flow profiles. The link profiles should correspond to flow variations observed on links, and provide a key input to the time-dependent modelling of intersection delays and queues.

Through this mechanism, TRIPS can model the effects of, say, peak flows occurring early in the morning in outer suburbs of a conurbation, but being experienced somewhat later in the city centre where many of the trips terminate.

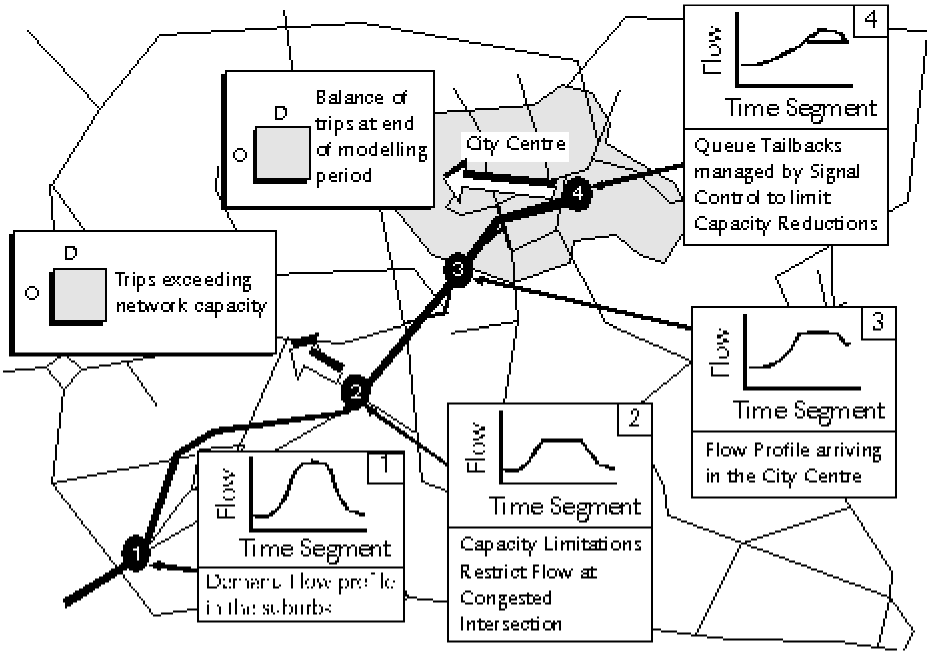

Illustration 3.2TRIPS dynamic modelling

Source: CITILABS (http://www.trips.co.uk/)

Besides the propagation of flow profiles, a key concern of TRIPS dynamic assignment relates to capacities. In dynamic modelling the notion of capacity, which is clear in the case of static modelling, becomes much less obvious. Truly dynamic models are deterministic in nature, which means that flows cannot exceed capacity (as the definition of capacity should imply). TRIPS is not fully dynamic, as the modelling within each time segment is essentially of the static type, and includes a stochastic component, which is also not admissible in totally dynamic models. This means that flows can exceed capacities for transient periods in the modelling, so giving rise to queues on this account.

Another way of viewing this is to observe that the total flow (on a link) may fit within the total link capacity over the modelled period, but at any particular point in time flows may exceed capacity causing queues. TRIPS therefore allows the user to define a 'tolerance to congestion' factor, which is related to the amount of queuing which may be tolerated before the link is considered to be 'over capacity'. Blocking back of queues, resulting in reductions of the capacities of upstream junctions, may give rise to further queues, in a process leading to 'gridlock' in extreme cases.

Dynamic modelling can have advantages of better simulating the traffic and corresponding traffic queues. This dynamic modelling is especially interesting for small network. However in the framework of the large network of the Brussels Capital Region it is will probably not possible to obtain the required data from the demographic and socio-economic analysis of the multi-actor project partner.

However the analysis was of considerable value for the further development of the software tool in the field of the applicability of the tool.

3.7 Speed Profiles

In comparison with other traffic-vehicle emissions software tools, the VUB approach is innovative in that way that it is able to simulate vehicle dynamics and hence it does not use average speed values per link of the traffic network.

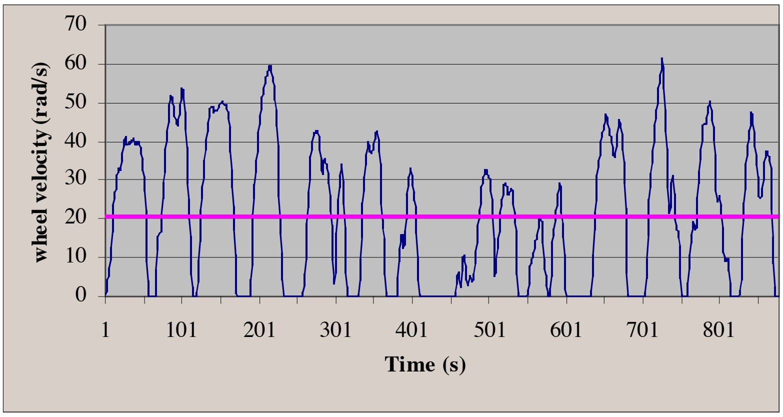

Illustration 3.3Average speed versus Real speed

The software tool starts from the average speed values, calculated in TRIPS, but uses them to define a real speed profile corresponding the path of a considered vehicle while it was driving from its origin to its destination. Hence with these speed profiles not only speed but also vehicle acceleration is taken into account. This is a fundamental consideration when one wants to know vehicle emissions.

One particular feature that has been implemented in the interface between TRIPS and VSP is the construction of the speed cycles. The network generated by TRIPS contains the average speed on every link; wihtin the *Emissions* program, these are converted to more realistic cycles taking into account the type of route, as illustrated in Illustration 3.4.

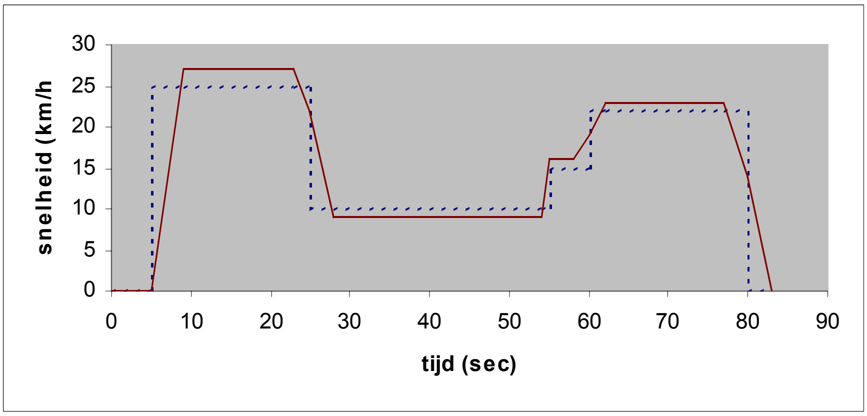

Illustration 3.4: Speed profile adaptation

The influence of driving behaviour, vehicle acceleration, etc on vehicle consumption and emissions is not to be neglected. This issue has been the subject of a specific research project performed by VUB[21]. Based on a research project funded by AMINAL and worked out with as subcontractor TNO the influence of specific vehicle parameters, traffic measures and driving behaviour on fuel consumption was evaluated.

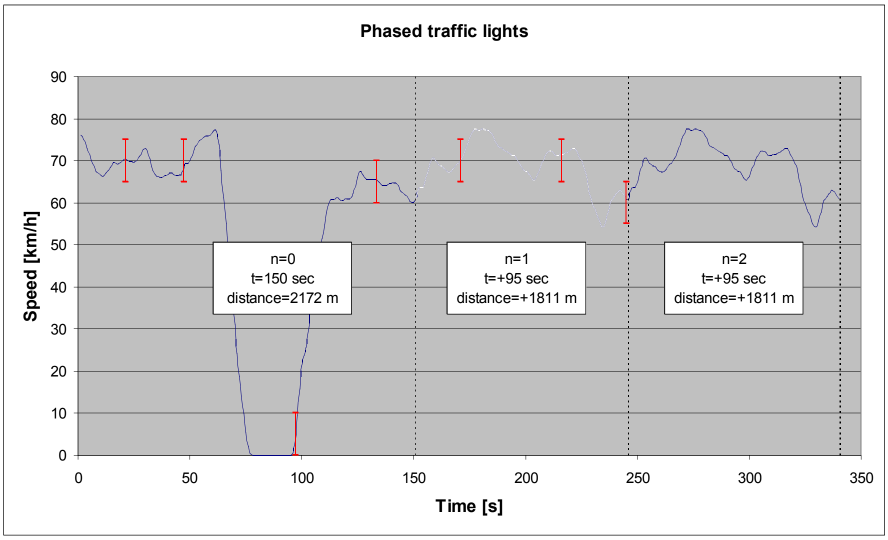

Illustration 3.5Speed profile of phased traffic lights

Experiments were carried out on road and under controlled conditions on a roller bench chassis dynamometer. Traffic data concerning the typical traffic measures like roundabouts, zone 30, speed ramps and green wave (phased traffic lights), were measured by the VUB. During the measurement campaign different drivers drove around in these different traffic conditions while their vehicle speed was measured. Concerning driving behaviour different test persons were instructed with Eco-driving style tips. A certain drive cycle had to be driving, one time before they received the driving tips, one time after. In this way the difference in driving behaviour could be measured. Speed profiles were measured in urban area, in suburban vicinity and on the highway. The number of test persons that interpreted the tips the right way and the number that misunderstood them were evaluated. The on-road measured cycles were reduced to small representative speed profiles that could be driven on a roll benchchassis dynamometer. The results of this study are used for the development of the speed profiles.

4 State of the art of the software tool

4.1 Overview

An overview of the methodology is illustrated in Illustration 4.1. The overall software system is called ***EMITRAFFIC***[22] and is divided in several submodules. Blue squares represent modules written in LabVIEW (a high-level graphic programming language with an user-friendly graphical interface); orange squares represent modules written in Trips/Cube (a commercial software package for transport planning).

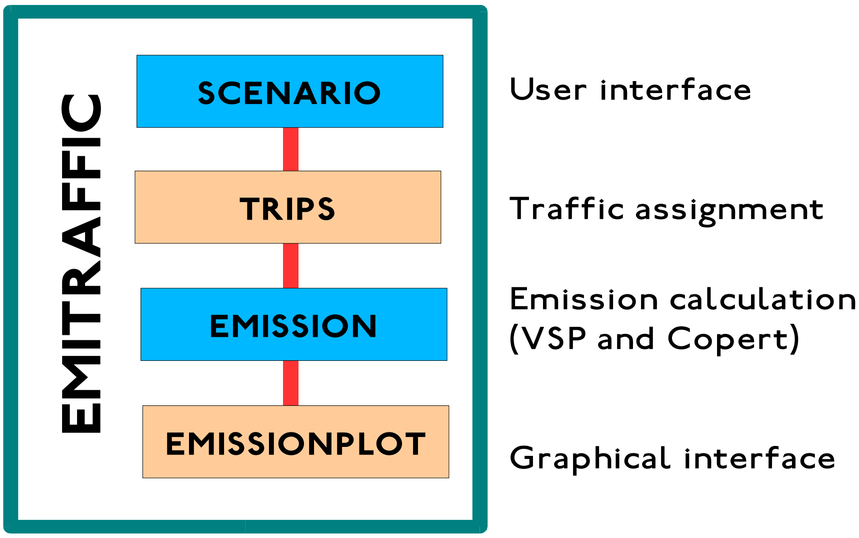

Illustration 4.1: Overview of simulation system

The whole architecture of the system is designed as to present to the user a logical sequence of operation steps.

4.2 Scenario

Scenario contains the main interface with the user, where the parameters of the desired simulation will be defined. ***Scenario***'s default settings correspond to the current traffic situation in the Brussels Capital Region, several submodules are however available to further refine the output of ***Scenario*** through the choice of specific vehicles or the definition of specific policy measures. ***Scenario*** has been entirely developed in Labview, which allows for a user-friendly interface. The main interface screen of ***Scenario*** is shown in Illustration 4.2.

Illustration 4.2: User interface ***Scenario***

At first, the user will want to define the overall traffic scene; this is performed in the module *Traffic*, illustrated in Illustration 4.3.

Scenario uses as input origin-destination matrices for private, freight and public transport. These matrices describe the displacements between different zones (255 zones are considered in this model) of the Brussels Capital Region.

Traffic allows to partition the increase/decrease of traffic (in relation to the reference origin/destination matrix, which represents the average morning peak in the BCR) with three shares of traffic considered:

- the area of the BCR is divided in three concentric zones;
- of all vehicles which depart and arrive within the same zone, thepercentage of electric vehicles can be entered; this division is known as "EV X-Y-Z";
- for those vehicles which depart and leave in different zones:
    - X is used for the percentage of electric vehicles which eather depart or arrive in the city centre (zone A) and thus reflects the number of electric vehicles in the "Pentagon";
    - Y is used for all vehicles arriving as well as departing within zone B;
    - Z is used for all vehicles departing zone C and not arriving in zone A, as well as all vehicles arriving in zone C.
- this whole concept is shown in Illustration 4.4

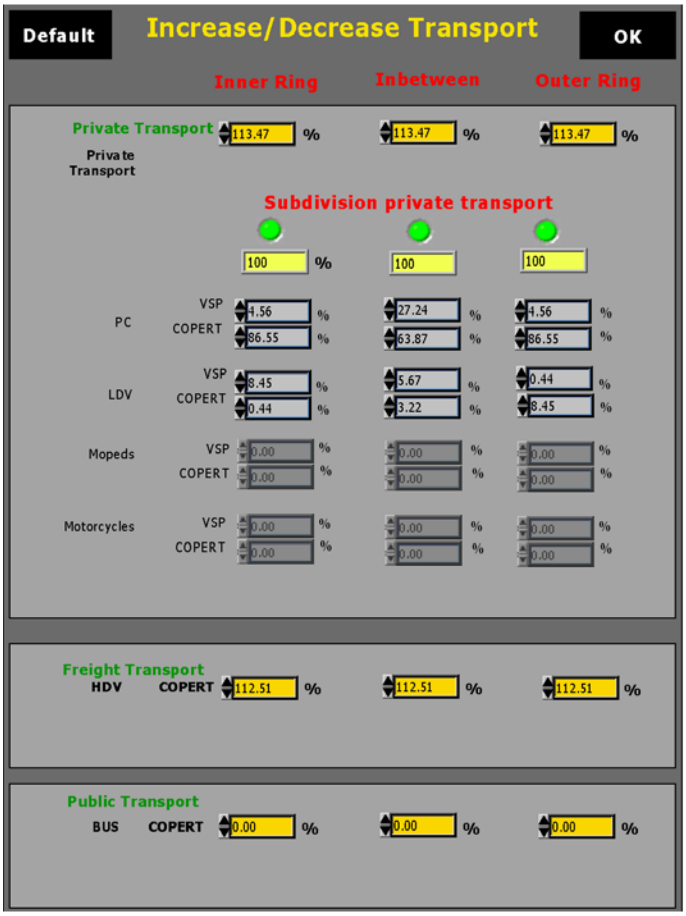

Illustration 4.3: Vehicle selection user interface

This is performed for the different classes of vehicles (private transport, goods transport, public transport). *Traffic* also gives the opportunity to perform specifically targeted simulation taking into account specific zones and/or specific vehicle classes.

Furthermore, for the private transport, the relative share of passenger cars (PC) and vans (LDV) has to be stated, as well as further subdivisions based on the relative number of vehicles to be simulated either based on dynamic emission simulations (VSP) or on static emission simulations (Copert). The software also provides for mopeds and motorcycles, but these have yet to be implemented in the simulations because no origin-destination matrices for these transport modes are available yet.

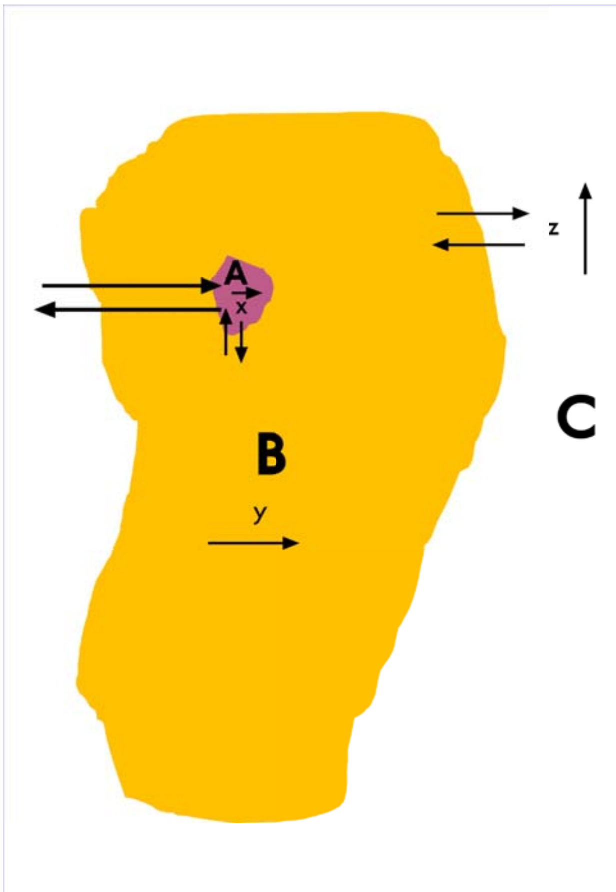

Illustration 4.4: Division of vehicles

The various vehicle classes which are to be simulated can be divided as for their composition. This is done in the modules *Cars, Vans, Trucks, Buses, Mopeds and Motorcycles*. In each case, a two-phase approach is followed:

- first the division is defined for the vehicles to be simulated using static emissions. This makes use of the Copert vehicle classes, of which there are 105 in total. An example (for gasoline cars) is shown in Illustration 4.5.
- then the division is defined for the vehicles to be simulated using dynamic modelling with VSP (Illustration 4.6).

The approach followed is similar for all classes of vehicles; for the two-wheel vehicles (mopeds and motorcycles) however, only static (Copert) data can be selected, as no dynamic models for these vehicles are available as for now. These vehicles are anyway not considered yet in the current simulation, since there exist no origin-destination matrices which take into account two-wheelers. They have been provided however for future expansion of the software system.

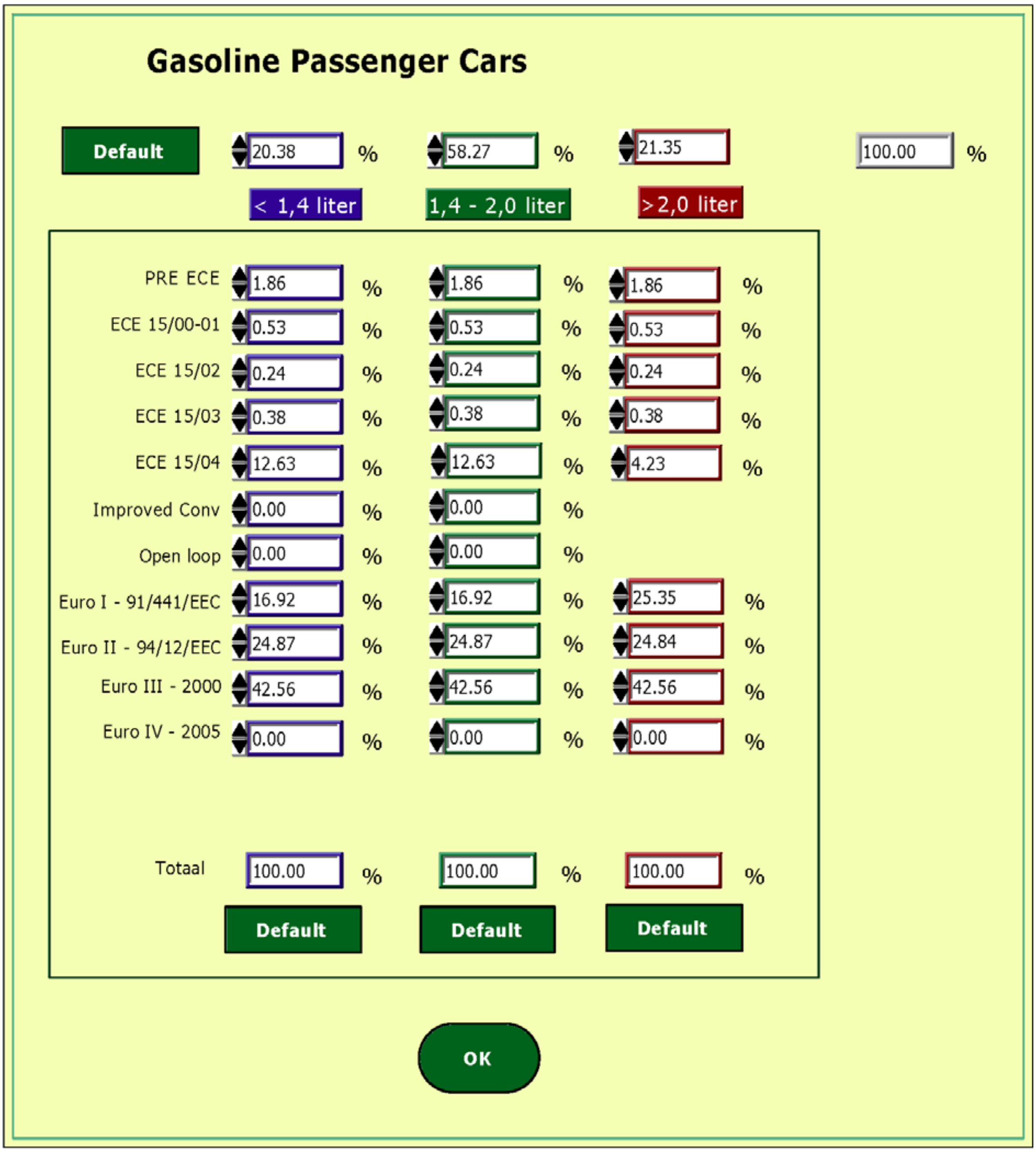

Illustration 4.5: Division of vehicles (Copert)

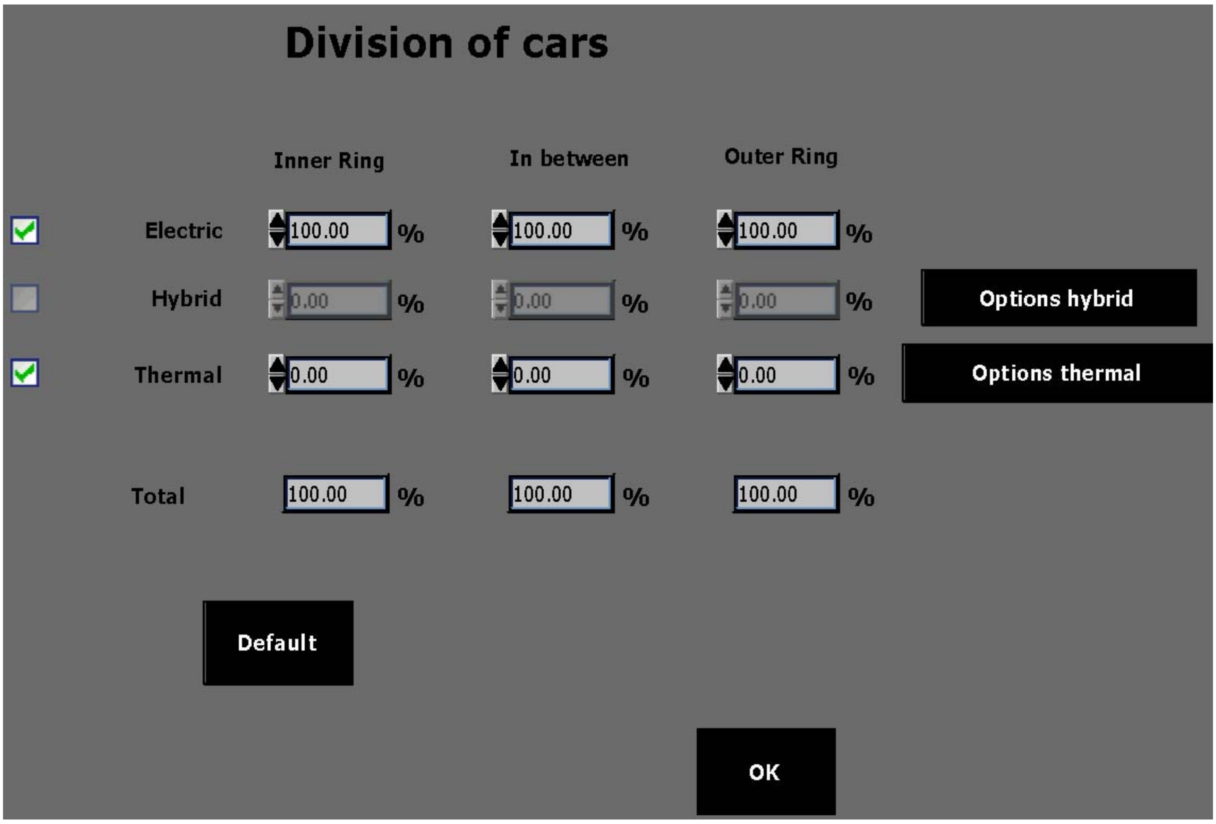

Illustration 4.6: Division of vehicles (VSP)

Having defined the characteristics of the vehicle fleets to be deployed, one can now define the policy measures to be implemented. ***Scenario*** allows to define a number of policies in order to assess their actual impact. These modules include:

- *Traffic restrictions*: this module will allow to simulate traffic restriction measures which will be implemented by influencing the cost functions used in TRIPS (Eq. 5 on page 37):
  - traffic tolls differentiated for thermal or electric vehicles and for within and without the city centre, as well as the closing of the city centre for thermal vehicles.
  - parking tolls specific for particular classes of vehicle (thermal, electric or hybrid) within and without the city centre, as well as the provision of reserved parking spaces for electric vehicles in the city centre (Illustration 2.7); the latter case will result in an increase of the parking cost for the thermal vehicles:

$$PT_R = \frac{100}{(100 - RP_{EV})} \times PT_{NR} \qquad \text{Eq. 4}$$

Where:

- PT_R=parking cost for thermal vehicles with reserved EV spaces
- RP_{EV}=percentage of reserved EV spaces
- PT_{NR}=parking cost for thermal vehicles without reserved EV spaces

- *Automatic rent-a-car-systems*: this module allows for the implementation of automatic rent-a-car stations on an interactive map (shown in Illustration 2.4 above).
- *Goods distribution*: here urban distritution centres can be chosen, making use of two hypotheses as to the allowance of heavy goods vehicles in the centre (cf. Illustration 2.6 above).

All possibilities for implementing these policies in both passenger and goods traffic respectively are illustrated in Illustration 4.8 and . These figures describe the types of paths that can be followed by the different classes of vehicles, as well as the costs to which the vehicles are submitted.

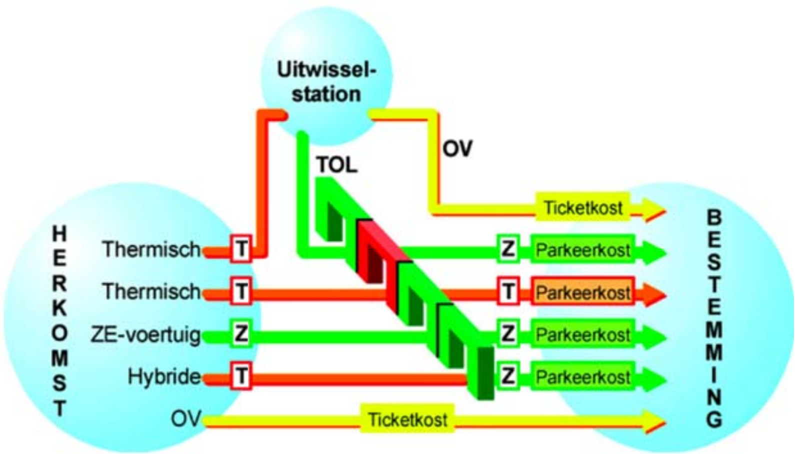

Illustration 4.7: Passenger traffic pathways

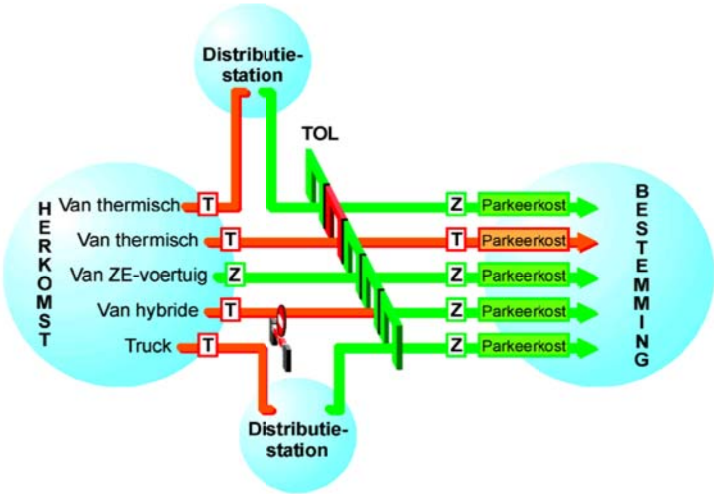

Illustration 4.8: Goods traffic pathways

4.3 TRIPS

TRIPS is a commercial software for transport planning, part of the Cube package marketed by Citilabs Ltd. It allows to perform complex and detailed analysis of different transport systems. Its main function is the assignment of traffic flows (defined by an origin-destination matrix) to an actual network. It consists of a number of modules to be implemented for each specific application. The user interface of the ***TRIPS*** application as used in this project is shown in Illustration 4.9.

Based on the different choices selected in the *Scenario* interface, different origin-destination matrices are created for the different kind of transportation means. ***TRIPS*** will then perform the traffic simulation, assigning the vehicles onto the network, taking into account the details and properties of the network and the desired measures, as defined by the users in ***Scenario***

The assignment and the definition of paths for each vehicle are performed through a generalised cost function for each link:

$$GC = |TCOST \times T| + |DCOST \times D| + |TLCOST \times TL| \qquad \text{Eq. 5}$$

where:
- *T* = time
- *D* = distance
- *TL* = toll
- *TCOST*, *DCOST* and *TLCOST* are weighting coefficients that are set by the user and represent the importance the user gives to the different cost parameters.

As an output ***TRIPS*** releases the different paths from origin to destination, speeds, distances, number of cars, etc. per network link. These parameters are used to calculate emissions, energy consumption and mobility aspects.

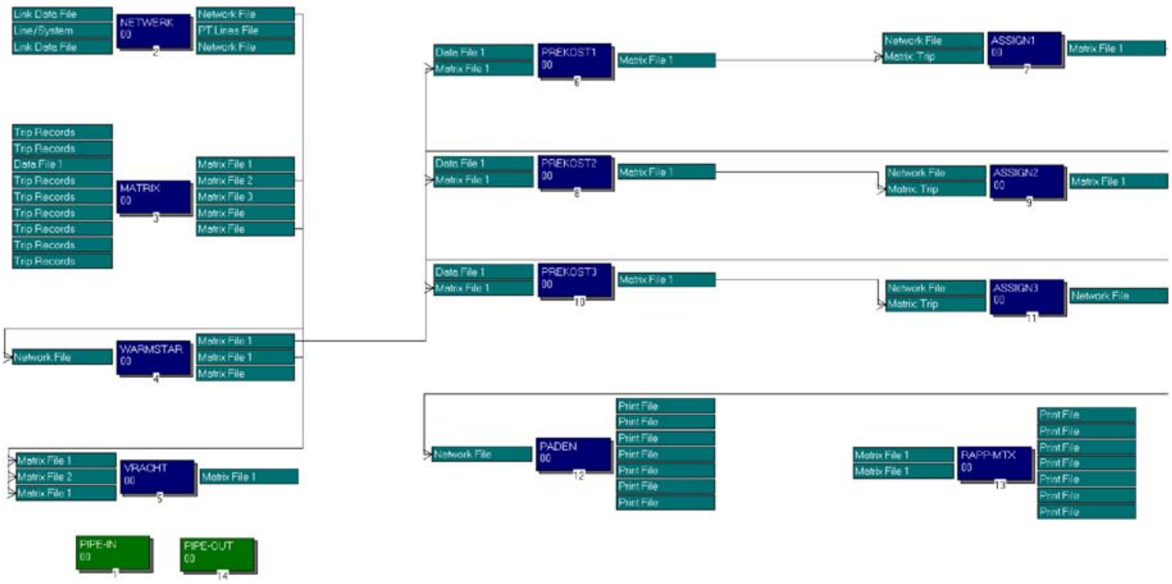

Illustration 4.9: TRIPS programme structure

The actual traffic network on which the displacements are assigned corresponds to the road network in the Brussels Capital Region, which has been simplified in some areas by removing road links with a strictly local interest which have been replaced with feeders from local zones. The network is shown in Illustration 4.11.

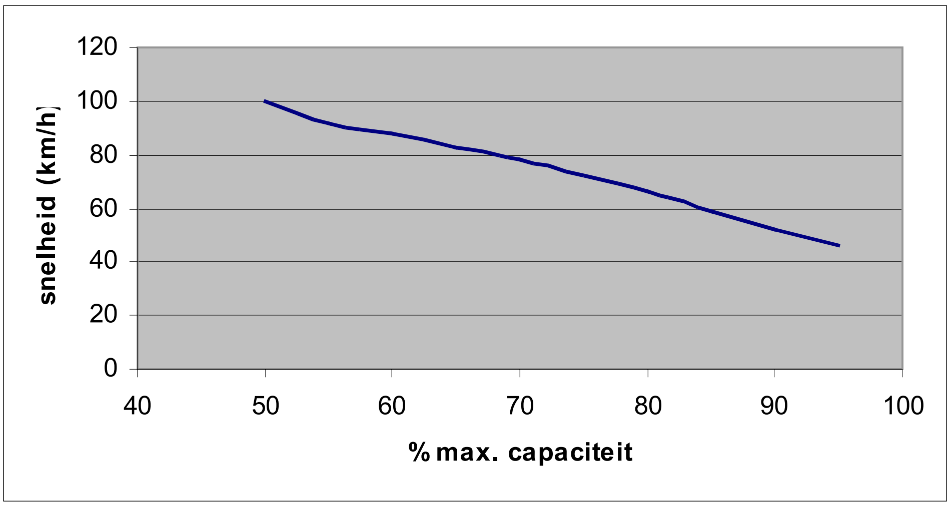

Illustration 4.10: Speed-flow curve

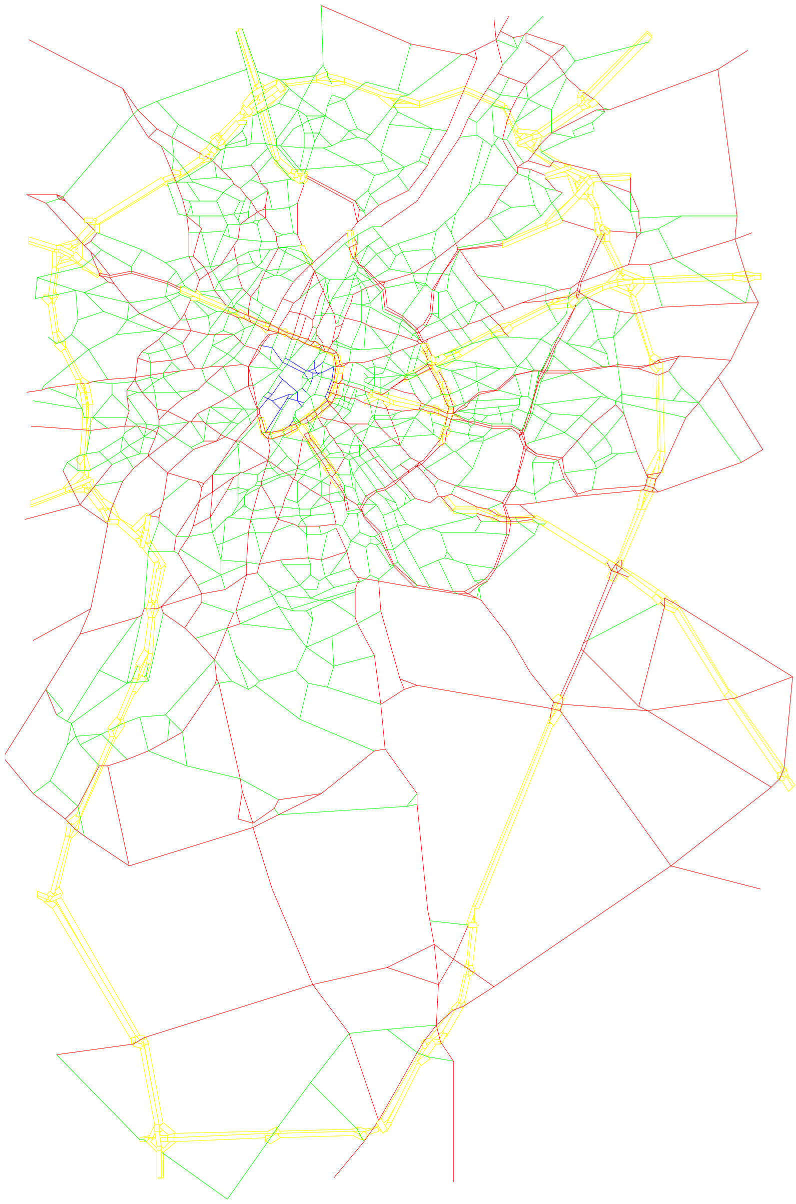

Illustration 4.11: Road network in BCR

TRIPS will assign the displacements to all links in this network, taking into account the load on each link in relation to its capacity to determine the average speed on this link in relation to its reference speed (Illustration 4.10).

After having initialized the network and read the input files (provided by *Scenario*), the program will assign an estimated displacement matrix ("Warmstart" in Illustration 4.9), in order to obtain a more realistic congestion simulation. The actual assignment is performed for both passenger and goods traffic.

Passenger traffic encompasses both private vehicles and buses. The public transport (bus) displacements and the private car displacements which *Scenario* has assigned to electric and hybrid vehicles are retained, since these transport modes are considered sustainable and desirable. The thermal vehicle displacements however are subject to a further decision process as shown in Illustration 4.12.

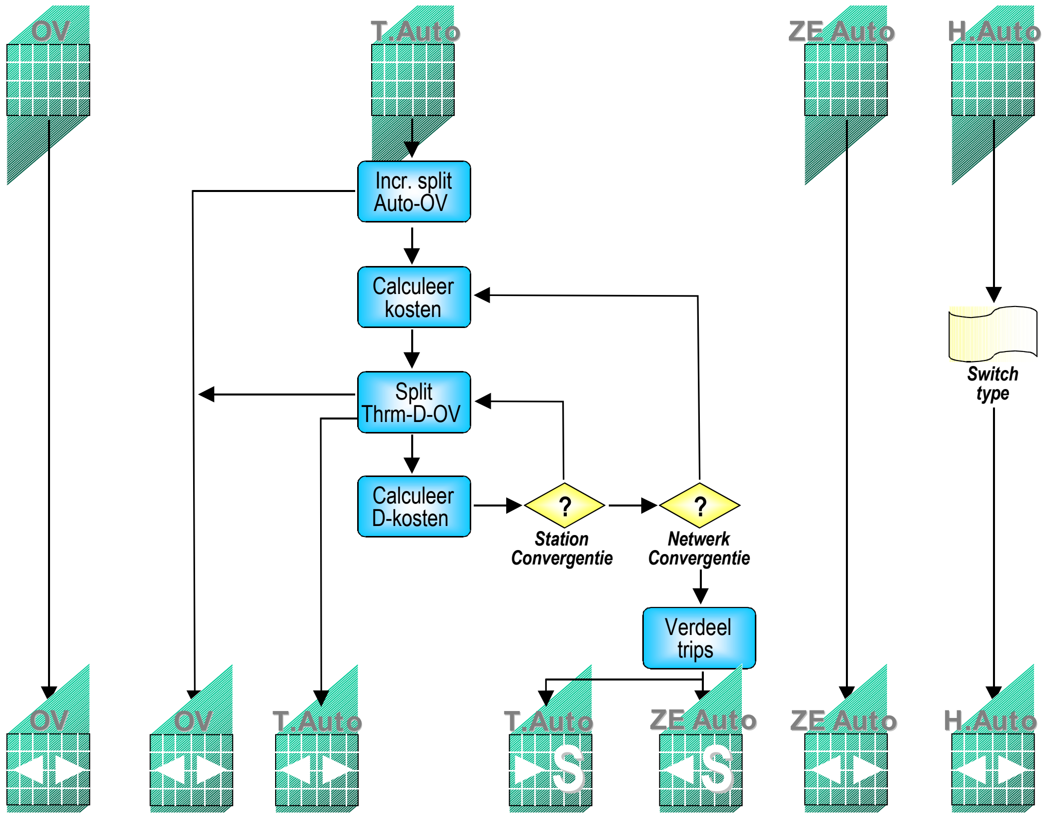

Illustration 4.12: Passenger traffic assignment

This procedure allows for a further modal split based on the calculated cost (Eq. 5) for thermal cars. An incremental mode choice compares the composite thermal car cost with the basic car and public transport cost and modal shift is achieved through an incremental logit procedure.
The next step in the procedure integrates the split between thermal cars, public transport and combined thermal/zero emission (using rent-a-car stations), with two iteration loops ensuring convergence at station and netwerk level. The displacements can then be split between a thermal part to the most appropriate station and an electric part to the final destination.

The approach for goods transport (Illustration 4.13) takes into account four types of vehicles: (thermal) trucks, thermal vans, electric vans and hybrid vans. The *Scenario* data for the two latter types are also unchanged.
For the trucks, restrictions to certain zones are taken into account, trucks not allowed to go to their final destination are assigned to the most appropriate goods distribution centre, through an iteration loop avoiding surcharge on the centres. The displacements are then split between a truck path to the distribution centre and an electric van path to the final destination.

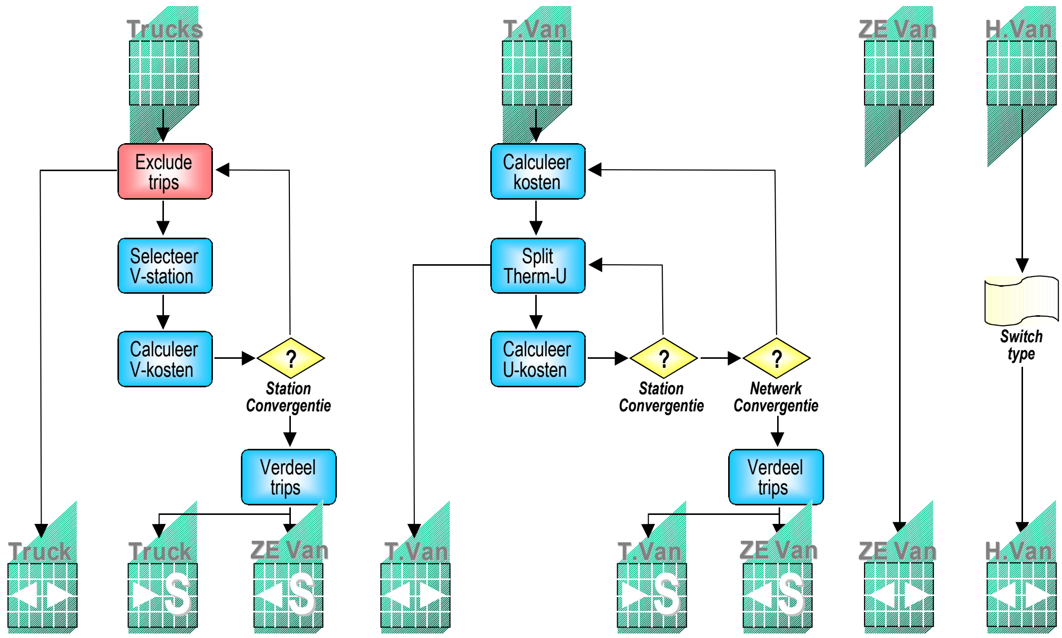

Illustration 4.13: Goods traffic assignment

The thermal vans are not excluded as such from certain zones, their assignment is calculated based on the cost, thermal vans having higher toll and parking rates. This cost difference may lead to the assignment of thermal vans to the distribution centres, with convergence at station and network level being obtained through iteration loops, and the displacements split up where appropriate.

After summing up the different partial displacement matrices, the different types of vehicles are assigned simultaneously with the freight vehicles using a multi-class assignment procedure and a volume average capacity restraint procedure. Sixteen iterations allow to come to a balance, with a convergence delta less than one tenth of a percent.
Output files are then generated for the next application, *Emission*, which will perform the environmental analysis.

4.4 Emission

This module will interpret the traffic assignment as calculated by ***TRIPS*** in order to calculate emission values generated by the vehicles.
To this effect, actual emissions can be calculated using two methodologies: VSP for dynamic emissions and Copert for static emissions.

4.4.1 VSP

VSP, the Vehicle Simulation Programme, is a proprietary development of the Vrije Universiteit Brussel[32]. This programme will calculate the dynamic emissions, based on speed cycles, derived from the output of *TRIPS* and remodelled into real traffic situations (accelerations, stand still, driving behaviour, etc.).

The goal of the simulation programme is to study power flows in drivetrains and corresponding component losses, as well as to compare different drivetrain topologies. This comparison can be realised at the level of consumption (fuel and electricity) and emissions (CO_2, HC, NO_x, CO, particles, ...) as well as at the level of performances (acceleration, range, maximum slope).

The general aim of the simulation programme is to know the energy consumption of a vehicle while driving a certain reference cycle. For thermal vehicle this energy consumption corresponds to fuel consumption and in the case of electric vehicles this is the energy drawn out of the battery. For hybrid electric vehicles fuel consumption as well as energy out of the battery are required. Based on models for battery charging, electricity production and fuel refinery, the primary energy consumption can be simulated.

The theory behind VSP is based on the well-known movement equation defining the traction force:

$$F = Ma + \frac{1}{2}\rho S c_x (v + v_w)^2 + Mgf_r \cos(\alpha) + Mg\sin(\alpha) \quad \text{Eq. 6}$$

Where *M* is the mass, *a* the acceleration, ρ the density of air, *S* the vehicle frontal area, c_x the air resistance coefficient, *v* the vehicle speed, v_w the wind speed, f_r the rolling resistance and α the slope of the road. VSP is able to calculate real-time emission and energy consumption figures for any vehicle (providing vehicle data are available) on any road, following any speed reference cycle and thus taking into account drive cycle dynamism and driving behaviour. Although VSP has been initially designed for full interactive use (its user interface being shown in Illustration 4.14), it is here fully integrated in the Labview environment, running in background being called upon by *Emission* when needed.

VSP offers the possibility to calcualte as output the emissions and the energy consumption for each type of vehicle in each particular part or area of the city. However, to be operated at its full potential, VSP needs to know detailed descriptions of all components of the drive trains of these vehicles; these data are in most cases proprietary to the vehicle manufacturers and not easily available for research.

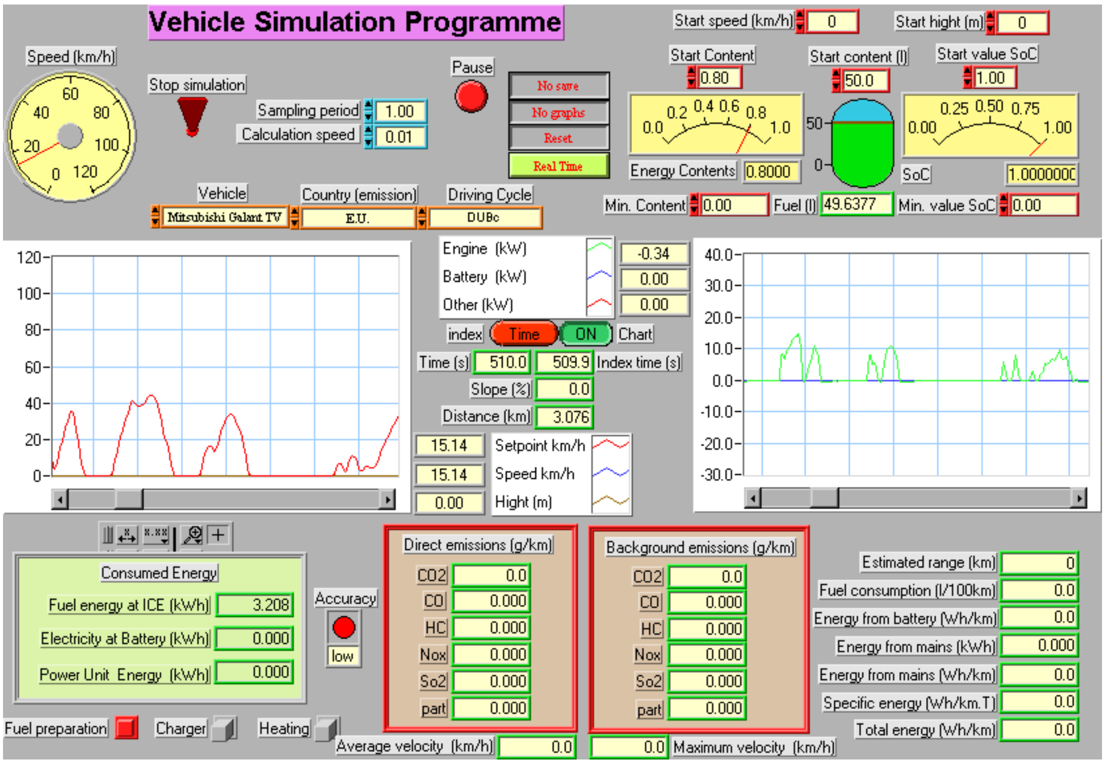

Illustration 4.14: VSP User interface

4.4.2 Copert

If one chooses to use static emissions, the Copert methodology will be applied to calculate emissions and energy consumption, based on the average speed which was calculated in ***TRIPS***. Copert distinguishes 105 classes of vehicles, according to their type, the fuel used and the relevant emission standards (e.g. Euro I, Euro II, ...); for each class of vehicle, it defines mathematical functions (quadratic or exponential) to define selected emissions as a function of the speed.

Although Copert is widely used, it has, contrary to VSP, no provision to take into account the influence of driving behaviour or the introduction of new technologies like electric and hybrid vehicles. However, it offers the advantage of Copert making available comprehensive data for the considered vehicles, and due to its widespread use, to create a frame of references.

Emission will use VSP and/or Copert according to the choices made in ***Scenario.*** It will generate output files for ***Emissionplot***, as well as an overview of all emissions per link in spreadsheet format for further processing by the user.

An overview of the user interface for ***Emission*** is shown in Illustration 4.15.

The module is also written entirely in Labview as to allow an user-friendly interface and a smooth interaction with the VSP module, which is also in Labview and which is called upon by ***Emission.***

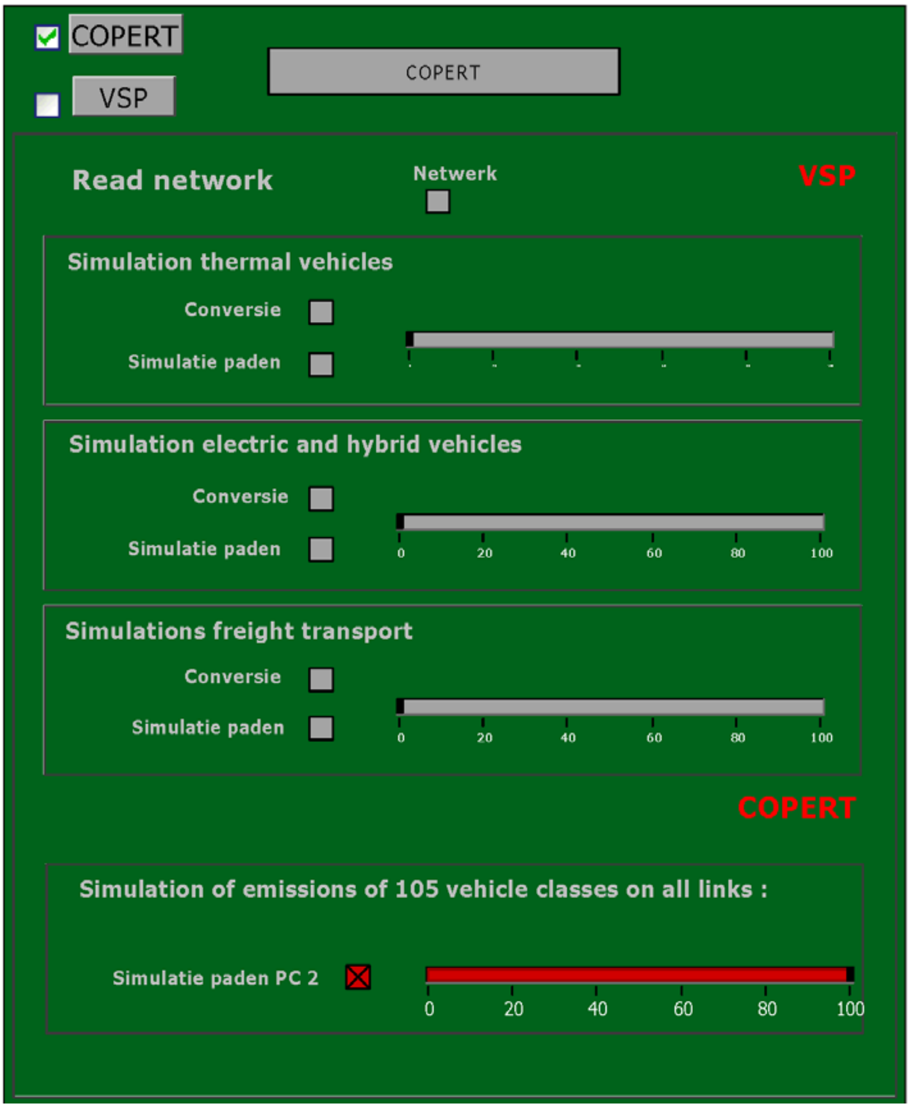

Illustration 4.15: ***Emission*** *interface*

4.4.3 Well-to-wheel emissions

In order to assess the overall impact of vehicle use on the environment, not only the tailpipe emissions of the vehicles have to be considered, but also the emissions associated with energy production, in order to obtain a global "well-to-wheel" impact.

The above paragraph take into account the "tank-to-wheel" emissions; for the "well-to-tank" (or "indirect") emissions the following approach is taken by *Emission*:

- for the vehicles using static emission models, the Copert methodology also provides well-to-tank values (which represent the emissions caused by fuel production, refining and transport)
- for the vehicles using dynamic emission models, VSP takes into account indirect emission values for both thermal vehicles and electric vehicles. In the latter case, where the emissions from electric generating stations have

to be considered, one can choose the electricity production mix (i.e. the share of coal, gas, nuclear, hydro,... in electricty production), for various countries as well as for the E.U. as a whole.

4.5 Emissionplot

Although the ***Emission*** module provides the full information about emissions in its output, it is interesting to present this results in a graphical way, thus creating a much more attractive visual result. This is done by ***Emissionplot***, a module, written under the TRIPS environment.

The graphical information system provided consists of a visualisation of the network (i.e. a map of the Brussels Capital Region), where traffic, consumption and emission data are accessible for each and every link (i.e. street) and can be illustrated in a graphical way, as will be shown below when presenting the simulation results.

5 Simulation results

5.1 Data evolution hypotheses

To assess the actual traffic situation, as of today, and starting from the available data, one should take into account the evolution of traffic on one hand and the evolution of the vehicle fleet on the other hand.

5.1.1 Traffic data

The data available for the Brussels Capital Region, the origin-destination matrices, are based on the 1993 data from the BCR IRIS model , and are to be reviewed for the current situation. Unfortunately we have not been able to access the most recent origin-destination matrices (which had to be provided by the other partner in the multi-actor project).
The general evolution data of traffic are known however[23], and thus have allowed us to define the evolution of traffic levels with 1993 as reference. This evolution is shown in Illustration 5.1.

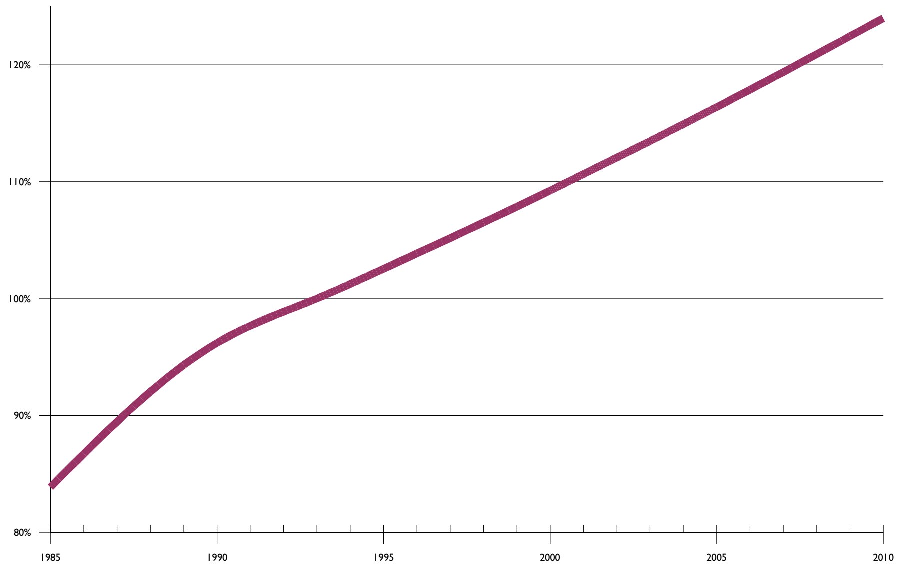

Illustration 5.1: Evolution of traffic in BCR (1993=100)

For the goods traffic, the data go back to 1998, and the adaptation becomes as follows (Illustration 5.2), taking into account the specific mobility data[24] for goods transport. One will note the higher growth rate of the goods traffic in comparison with the private traffic.

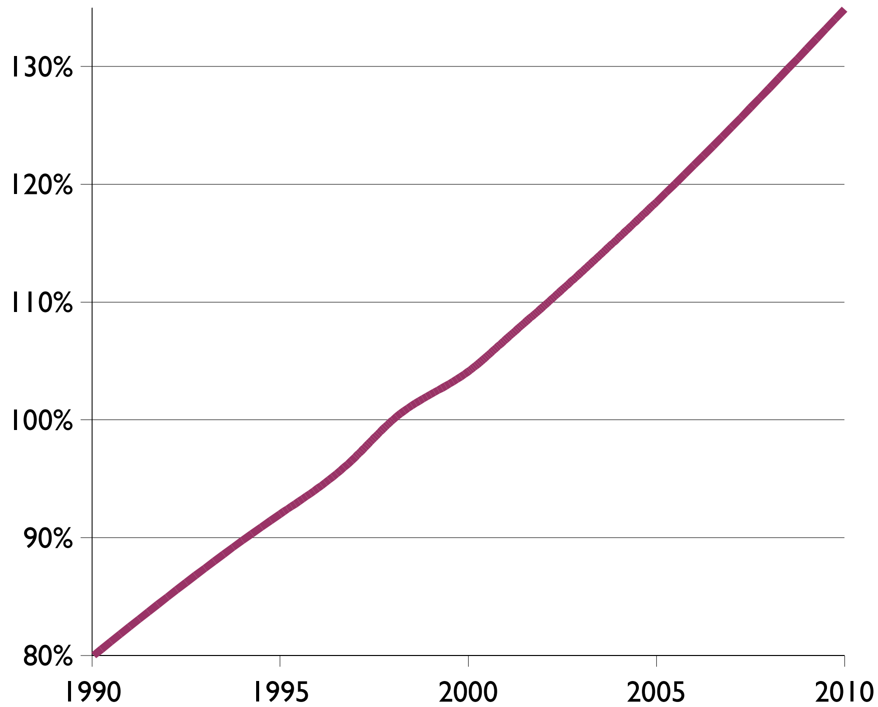

Illustration 5.2: Goods traffic evolution (1998=100)

This approach to traffic growth does not take into account any changes in land use. Land use has an influence in the production and attraction of trips from and towards different considered zones in the transport model. Hence it influences the origin-destination matrices used in the model; this has not been considered here. Additionally the traffic growth does not consider any policies to reduce the traffic demand through specific measures to achieve modal shift (e.g. Regional express rail network). The estimation of the traffic data shall thus be seen as a baseline scenario (called sometimes BAU= "Business As Usual") to which other policy scenarios will have to be compared.

5.1.2 Fleet data

To assess the environmental impact of traffic, the composition of the fleet has to be taken into account, due to the fact that throughout the time, emission regulations have become increasingly restrictive. Particularly for the emission calculation using the Copert methodologies the classes of vehicles have to be known. The emission regulation in vigour, and thus the Copert class, can be derived from the age of the vehicle. A detailed overview of these data is available from Febiac, the Belgian federation of the car and two-wheeler industries, for the fleet in the years 2000 to 2002[25], and trends can be extrapolated for the coming years, as shown in Illustration 5.3 for the case of gasoline passenger cars.
To make reliable use of these data however, one has to take into account some specific phenomena. One can notice for example that the category "pre-ECE", corresponding to vehicles dating prior to March 31, 1973, has a share in the fleet

which is declining only slowly. This is due to the presence in the fleet of classic cars and oldtimers, which are carefully kept by their owners, but which are covering on average more limited distances compared to new cars. All older classes of cars have thus been applied a gradual reduction factor to, and the remainder transferred to the newest technology vehicles.

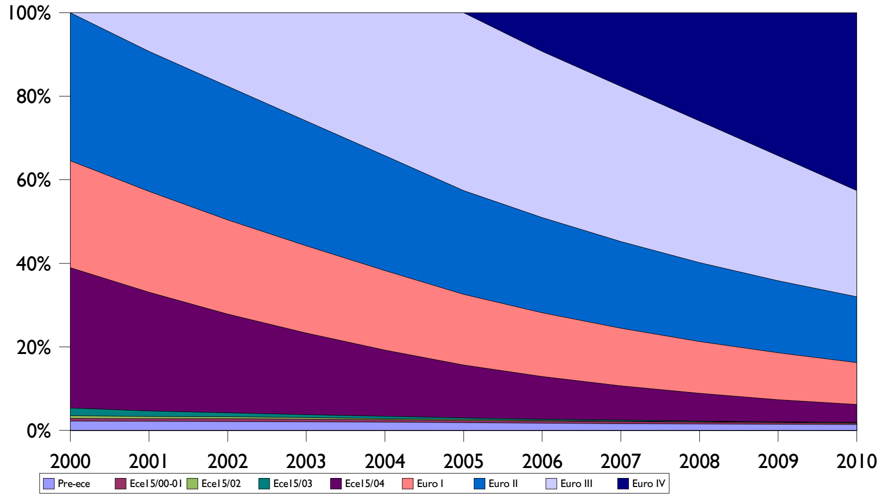

Illustration 5.3: Fleet evolution

Also, the fuel use of the vehicles is derived from Febiac data[26] (Illustration 5.4). The extension of the share of diesel-fuelled vehicles is quite obvious. These curves are an extrapolation of historical data and as such do not consider the emergence of new technologies such as electric vehicles; the simulated scenarios however will take such evolution into account.

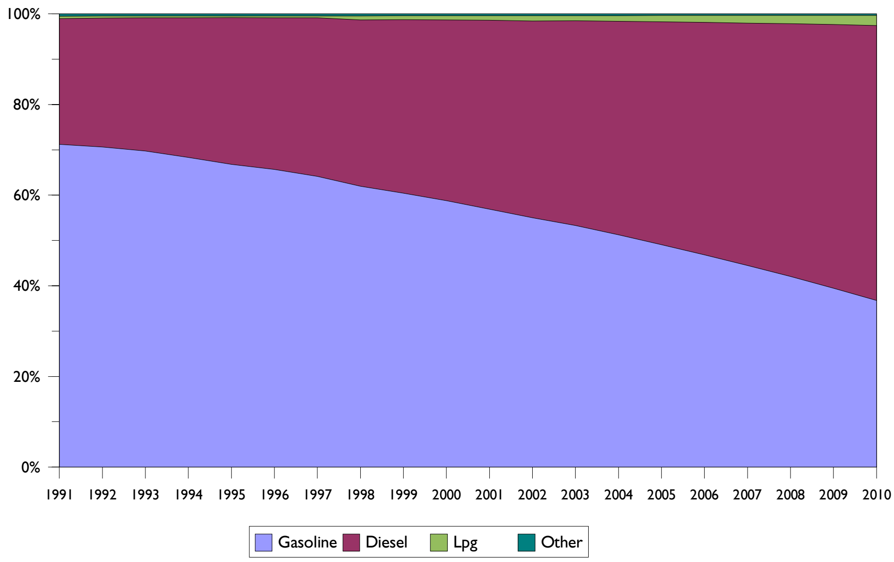

Illustration 5.4: Fuel evolution

Furthermore, one has to consider that there are technological limits of the expanding share of diesel fuel. An incresing share in diesel will cause an increase in the production price; on the other hand, the growth in diesel use for light-duty vehicles is primarily caused by the low taxation of diesel fuel in Belgium, which may potentially be adjusted in the future in order to compensate government revenues. Sources from the petroleum industry[27] state a maximum share of 50% for diesel vehicles in the fleet.

Furthermore, concerning the use of light-duty vehicles, the division between passenger cars and vans must be established. The data from Febiac[28], show that the share of vans is increasing, as shown in Illustration 5.5

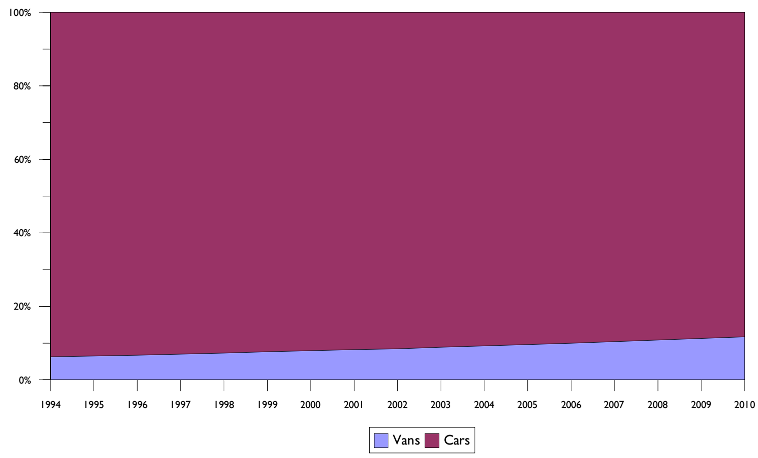

Illustration 5.5 Evolution of light-duty fleet

5.2 Overview of the current situation

5.2.1 Generalities

The first part of the simulation will take into account the current situation and its evolution. This means that only legacy vehicle technologies (internal combustion engines according to emission standards in vigour) will be considered, with the evolution of the mobility as calculated above, and without any policy measures taken. This approach allows to draw a general image of the environmental impact of traffic.

5.2.2 The current situation (2003): traffic

As a reference for further comparison, the data for 2003, taking into account the assumptions above, have been taken. In the following paragraphs, this situation will be extensively described; it will also serve as the reference for all further scenarios. It is called the legacy scenario.

Illustration 5.6 gives an overview of the total traffic (number of vehicles) in the considered scenario, which corresponds to the number of vehicles percoursing the consideed road links during one hour in the Brussels morning peak hour. The legend for this (and for subsequent) vehicle density graphs is given in Table 5.1.

It can be clearly seen that the traffic is concentrated on the outer ring road and on major throughfares. It is interesting however to focus on the city centre (Illustration 5.7) to notice that even within the city proper, large concentrations of vehicles can be discerned in certain areas.

Illustration 5.6: Total traffic, 2003 situation

Color	**Number of vehicles**
Black	< 25
Dark blue	25 – 100
Light blue	100 – 250
Green	250 – 500
Yellow	500 – 1000
Orange	1000 – 1500
Pink	1500 – 2000
Red	>2000

Table 5.1: Vehicle density chart scale

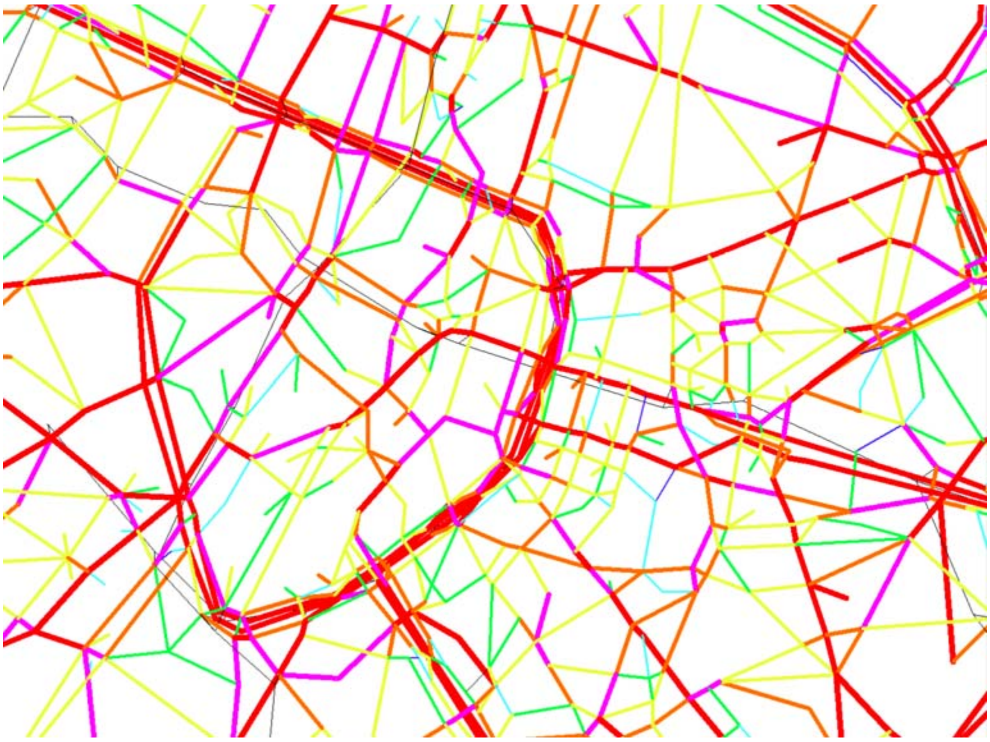

Illustration 5.7 Total traffic, city centre

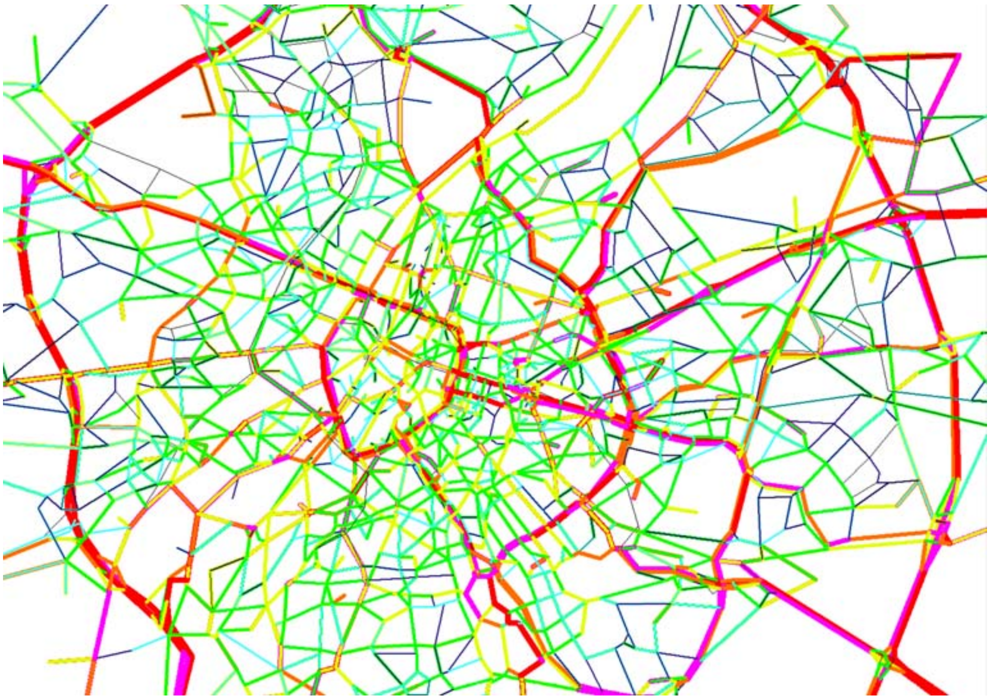

Illustration 5.8: Passenger cars

As shown in Illustration 5.8, the largest share of these vehicles is taken by the passenger cars. The number of vans (Illustration 5.9) is more limited.

Illustration 5.9: Vans

Illustration 5.10: Trucks

Trucks (Illustration 5.10) are mostly to be found on the outer ring road, as well as on a number of penetrating roads.

The total number of vehicle-kilometre covered is illustrated in

Type	Vehicle-kilometre
Passenger cars	3093514
Vans	316515
Trucks	685281
Total	4095310

Table 5.2: Vehicle-kilometres

Within the scenario's to be elaborated, a distinction is made between the three zones A, B and C and the three shares of vehicles X, Y and Z (cf. Illustration 4.4 page 33). The actual impact of these shares is shown in the following figures.

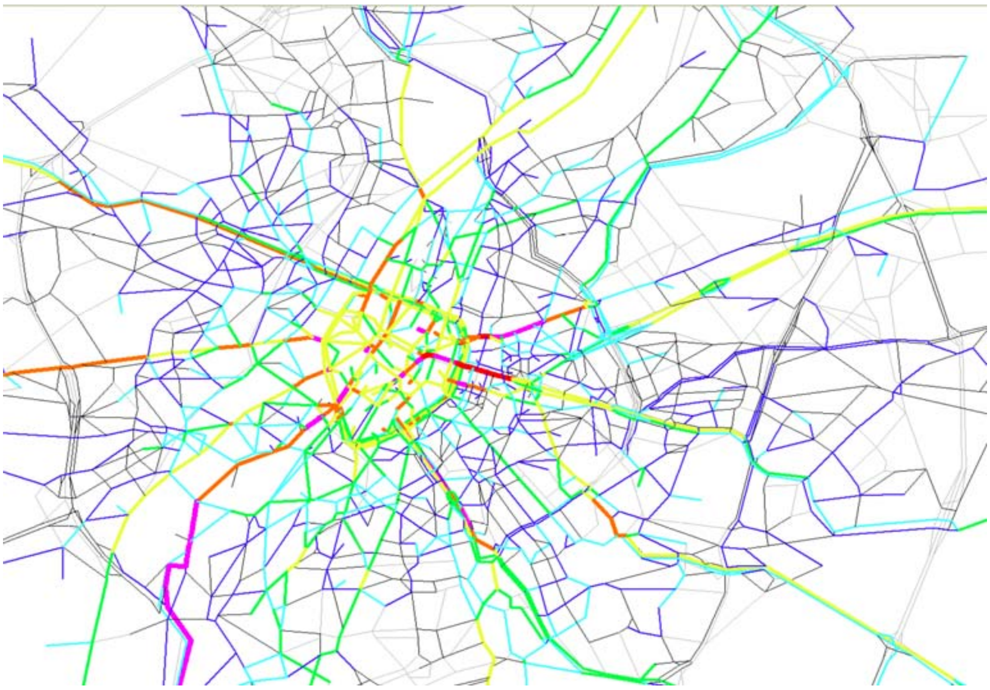

Illustration 5.11 Vehicle share 'X': vehicles having their origin and/or destination in the city centre

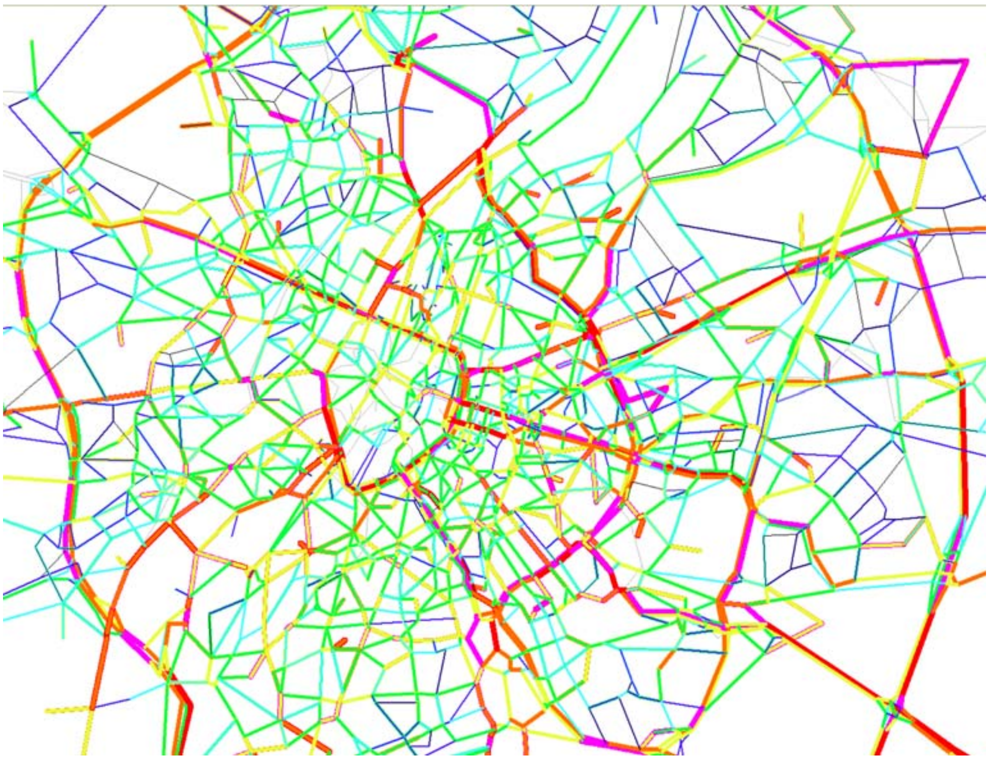

Illustration 5.12: Vehicle share 'Y', having their origin and destination in the BCR area (not city centre)

Illustration 5.13: Vehicle share 'Z': having origin and/or destination outside the BCR, and not in the city centre.

It can be clearly seen that a number of the vehicles in the Y and Z shares do transit the city centre even while they have, strictly spoken, no business there. Measures to influence their route choice will be evaluated.

The number of vehicles in each of the shares for the reference scenario is as follows:

	Passenger cars	***Vans***	***Trucks***
Share X	23015	2246	483
Share Y	118584	11571	776
Share Z	59394	5795	5523
Total	200993	19612	6782

Table 5.3: Number of vehicles in reference scenario

The vehicles of share Z tend to cover larger distances, as they stand for 64% of the total vehicle-km covered (for cars, vans and trucks respectively 58, 56 and 91%).

The average speeds on the network are shown in Illustration 5.14 (scale: Table 5.4). Particularly when considering the city centre (Illustration 5.15), the effects of congestion become clear, with speeds not exceeding 20 km/h evident on many busy streets.

Color	***Speed (km/h)***
Black	< 10
Red	10 – 20
Pink	20 – 30
Yellow	30 - 40
Light blue	40 - 50
Dark blue	50 - 70
Green	70 - 90
Dark green	>90

Table 5.4: Vehicle speed chart scale

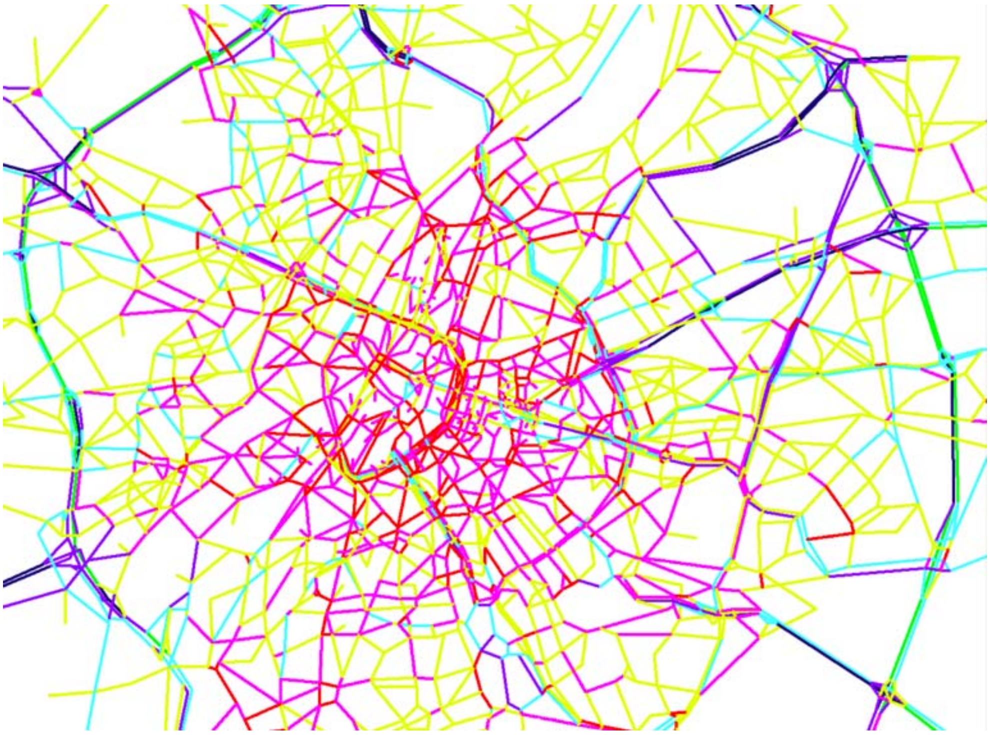

Illustration 5.14:Speed

Illustration 5.15: Speed in city centre

The congestion is due to the fact that the number of vehicles present approximates or exceeds the (theoretical) traffic-carrying capacity of the road (see also Illustration 4.10 above). The percentage of congestion is shown in Illustration 5.16

(scale: Table 5.5). Illustration 5.17 shows the particularly dramatic situation in the city centre.
It is clear that a significant number of roads exceed their capacity, a situation which will be further worsened by the forecast increases in traffic, and which will impose the implementation of major policy measures in order to preserve mobility.

Color	***Capacity used***
Black	< 30 %
Dark blue	30 – 50 %
Light blue	50 – 60 %
Green	60 - 70 %
Yellow	70 – 80 %
Orange	80 – 90 %
Pink	90 – 100 %
Red	> 100 %

Table 5.5: Saturation chart scale

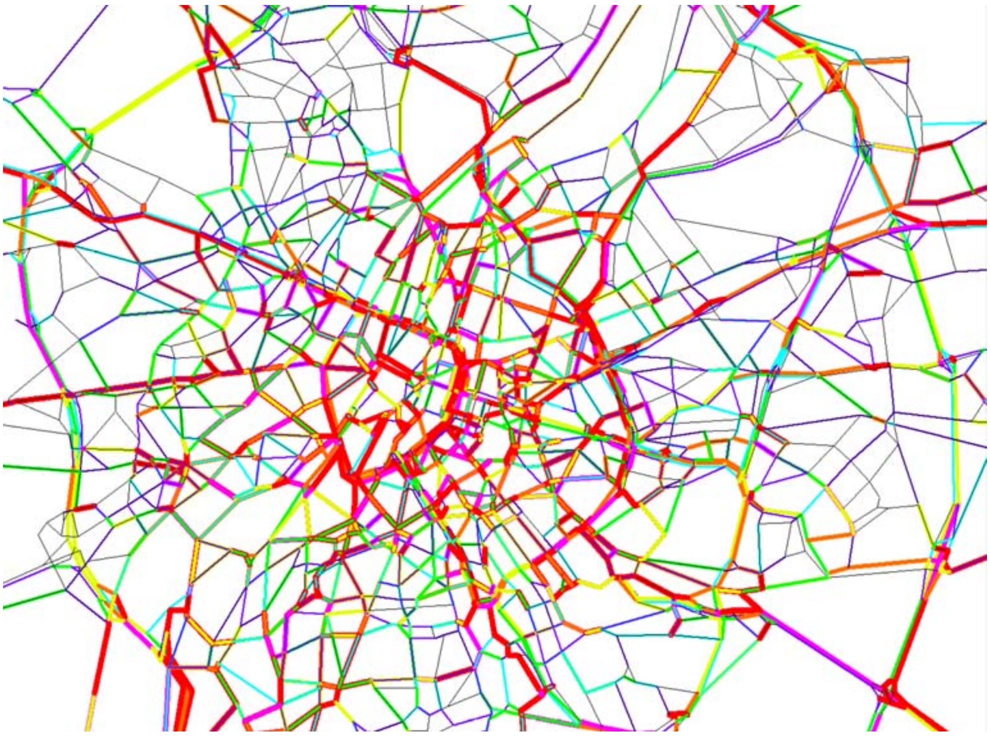

Illustration 5.16: Saturation

Illustration 5.17: Saturation in city centre

5.2.3 Emissions

The calculation of emissions using the Copert methodology based on the average speed of the vehicles on each of the 4286 links (Illustration 5.14) and on the classes of vehicles (Illustration 5.3) can be expressed either on a local scale (graphical illustration on the map) or on a global scale (summing up results for the whole area).

Graphical illustrations for CO_2 emissions are shown in Illustration 5.18 and Illustration 5.19 (scale: Table 5.6); NO_x is shown in Illustration 5.20 (scale: Table 5.7).

It can of course be stated that the CO_2 emissions emissions are also a measure for the energy consumption of fossil-fuel powered vehicles.

Illustration 5.18: CO_2 emissions

Color	***CO_2 (kg)***
Black	< 5
Dark blue	5 - 10
Light blue	10 - 25
Green	25 - 50
Yellow	50 - 75
Orange	75 - 100
Pink	100 - 250
Red	250 – 500
Red (Fat)	500 – 1000
Red (Fattest)	> 1000

Table 5.6: CO_2 chart scale

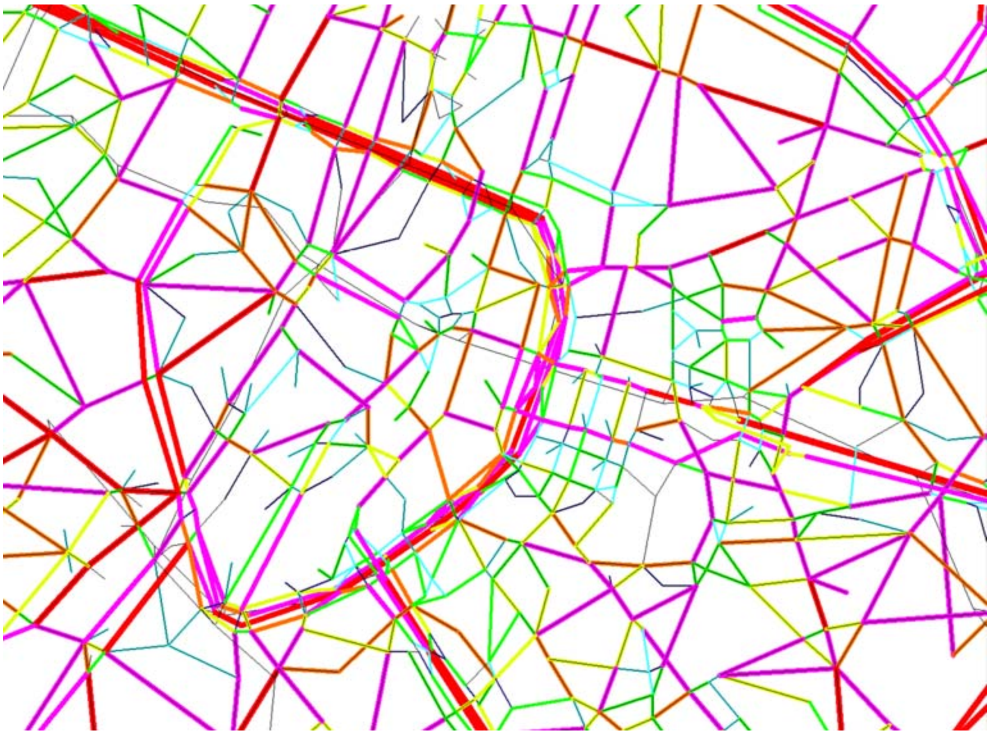

Illustration 5.19: CO_2 emissions (city centre)

Illustration 5.20: NO_x emissions

Color	***NO_x (g)***
Black	< 10
Dark blue	10 - 25
Light blue	25 - 50
Green	50 - 100
Yellow	100 - 250
Orange	250 - 500
Pink	500 – 1000
Red	1000 - 2500
Red (Fat)	> 2500

Table 5.7: NO_x chart scale

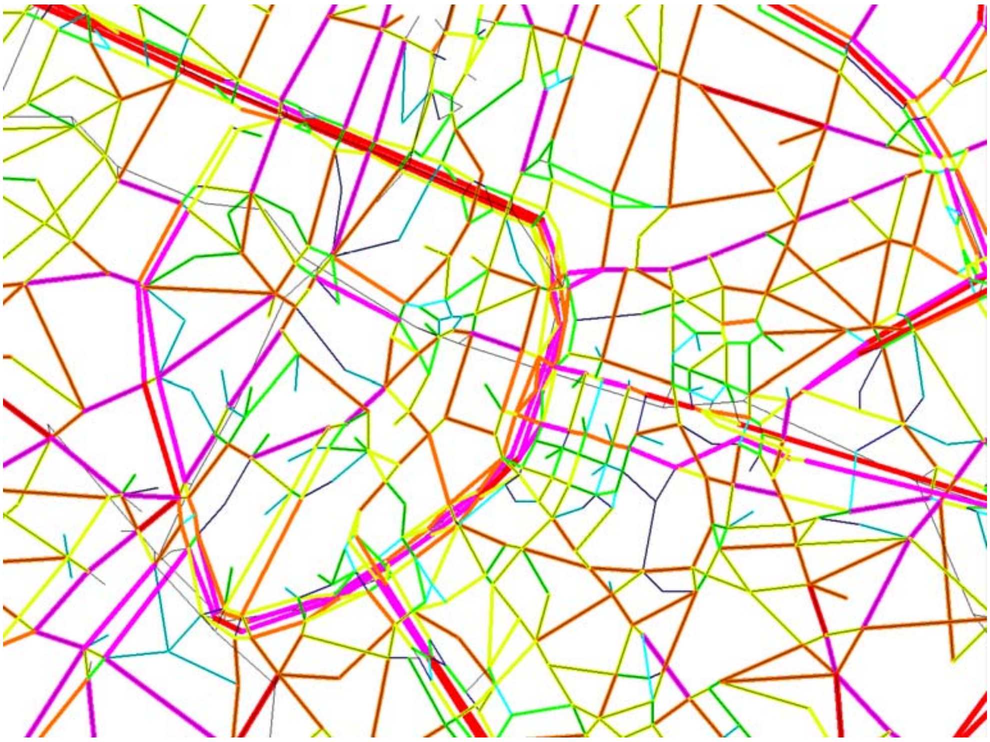

Illustration 5.21:NO_x emissions (city centre)

In order to calculate the global impact of these emissions on the Brussels environment, let's make a total sommation over the whole network. This gives the result shown in Table 5.8.

	CO2	CO	HC	NOX	SO2	PM	CH4
Peak (kg)	847814	6973	876	3467	146	241	71
Day (T)	12209	100	13	50	2	3	1
Year (T)	3662557	30124	3784	14978	629	1043	307

Table 5.8: Global emissions (2003 situation)

The "peak" values corrrespond with the results as calculated in our model. The "day" and "year" values are calculated based on the following assumptions:

- the average traffic density over 24 hour period equals 60% of the peak value [29]
- weekends and holidays are discounted, one year emissions equalling 300 working days.

Within these values, the largest impact will be created by the peripheral and transiting traffic (share Z) as can be seen in Table 5.9. This phenomenon is an inevitable result of the position of Brussels as a central traffic hub in the Belgian and European motorway network. It will also mean that the impact on the environment in the B.C.R. as a whole of traffic policy measures aiming at reducing the pollution in the city centre will be limited; this measures however will remain of paramount value since they will have a major impact on the city centre, the most sensitive environment with a high density of persons (inhabitants, commuters and visitors) and a large number of historic buildings.

	CO2	CO	HC	NOX	SO2	PM	CH4
Share Z	64.4%	55.2%	62.3%	69.2%	67.2%	65.3%	64.1%

Table 5.9: Contribution of peripheral and transiting traffic

It is interesting to compare these results with the outcome of similar recent studies having linked traffic to emissions.

- One model[30] focused on the city of Namur, giving for the morning peak (105 minutes) CO_2 emissions of 50335 kg and NO_x of 383 kg.
- Another study[29] had the Flemish region as subject. It only considered NO_x and PM, giving daily values of 136 T NO_x and 4 T PM.
- Data from the Flemish Enviroment Agency[31], which are calculated using the Copert methodology, give yearly emissions from road traffic for the Flemish region as 15335000 T CO_2, 249797 T CO, 37391 T HC, 70186 T NO_x, 2805 T SO_2, 6029 T PM and 2556 T CH_4.

The results obtained here for the Brussels Capital Region fall in between these two datasets, the B.C.R. being much more extended than the small city of Namur.

Comparing the ratio with the Flemish region which is much more extended of course, one should consider that in the mentioned study considered only a main network of 5753 km, whileas the network as used in this study has a length of 3520 km, including much more urban roads with congested traffic. For the data from the Flemish Environmental Agency however, the ratio between the values is more realistic
The values thus offer a realistic order of magnitude.

Another study about the Brussels Capital Region[32] yielded yearly values of 828776 T for CO_2, 24830 T for CO, 3530 T for HC, 3534 T for NO_x, and 315 T for PM. These values are lower then ours, which can be accounted to the fact that in the underlying model a large share has been included of the peripheral and transiting traffic on the ring road (share Z, see also Table 5.9), which is located largely outside the B.C.R. territory proper. The same applies for a number of areas within the ring road, the division in zones having been selected based on actual geographical layout and not mere administrative boundaries.

One has to remark however that a comparison between several models is not straightforwardly feasible, due to a number of reasons which can be summarised as follows:

- the fleet and the traffic flows being considered, and more particularly the share of peripheral and transiting traffic on the ring road which is taken into account in the regional approach.
- the average occupation per vehicle, when used for calculating vehicle-km from passenger-km, may differ.
- the algorithms used for calculating the emissions: in a number of models the Copert methodology has been applied in a simple way, based on assuming a fixed average speed over all urban roads (thus giving a very rough estimate), whileas the underlying model takes into account the actual traffic flow and its influence on congestion, calculating individual average speeds on each road link (when static emissions are used), and also allowing the use of dynamic speed profiles which are a closer approximation of reality.

It is thus necessary to consider the premisses of each model in order to interprete its result.

5.2.4 Evolution of the situation with legacy technologies

As stated above, it is to be foreseen that the traffic volume within the B.C.R. will continue to grow during the next few years. On the other hand, the composition of the car fleet will also change, with the introduction of more advanced cars which are considered more efficient and environmentally-friendly.

Taking the values for 2003 as reference, one can consider the values for 2005 and 2010 taking into account the assumptions on traffic growth above; however, for 2010, the fleet data for 2005 have been retained, the Copert methodology for the new-generation vehicles (Euro IV and Euro V) being very approximative and not reliable. As such, these results have to be interpreted with a certain reserve. An update of these data will be possible when the results of the European ARTEMIS project[33] will be published.

The results are shown in Table 5.10.

	CO2	CO	HC	NOX	SO2	PM	CH4
2003	100%	100%	100%	100%	100%	100%	100%
2005	103%	85%	81%	91%	105%	93%	85%
2010	113%	92%	90%	101%	116%	104%	93%

Table 5.10: Global emissions (2003 situation)

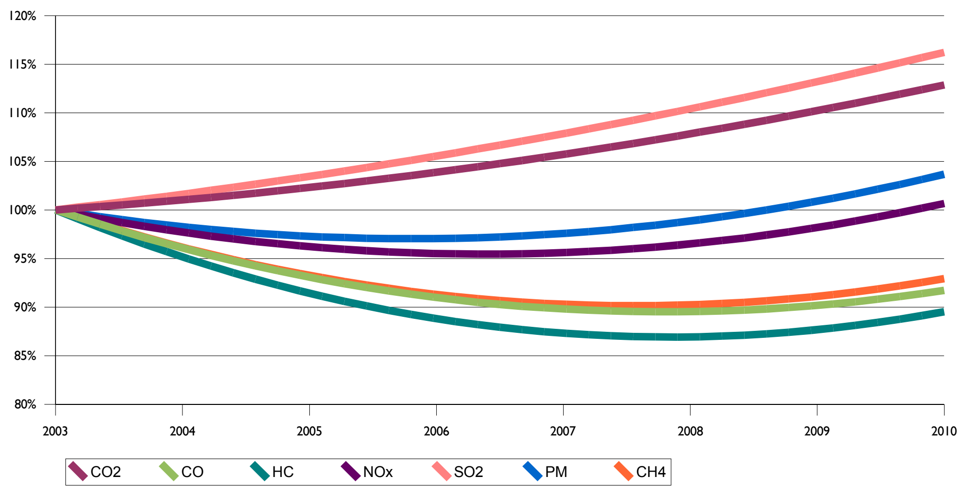

Illustration 5.22: Evolution of emissions

With all the reserves stated above, one can note the following trends however:

- the CO2 emissions (which are proportional to the fuel consumption) are raising at a higher rate than the number of vehicles. This phenomenon is due to increasing congestion.
- the improvement of environmental technology through the introduction of new vehicles, (2005 vs. 2003) technology, although at first reducing emission values, is unable to cope with the growing traffic, leading to an increase in the other emissions too.
- the emission of SO_2 will in reality be likely to increase at a lower rate than calculated, due to the generalized introduction of low-sulphur fuel (which has not been considered in the Copert methodology).

It makes thus sense to consider the introduction of zero- and low-emission vehicles and their impact on the Brussels environment.

5.3 Introduction of zero-emission vehicles

5.3.1 Generalities

In urban traffic, due to their beneficial effect on environment, electric vehicles are an important factor for improvement of traffic and more particularly for a healthier living environment. The electric vehicle makes use of energy sources which make it particularly suitable for use in urban or suburban areas.
It has to be remarked that all conclusions as to the introduction of electric vehicles will also pertain to fuel cell powered vehicles, which are in fact electrically propelled, generating their own electricity through electrochemical conversion of hydrogen, emitting only water into the atmosphere.

5.3.2 Introduction of a share of electric vehicles

In a first scenario, a fixed share of vehicles are being replaced by zero-emission vehicles. This of course will create a straight reduction of the emission values for the vehicle classes concerned.

The case treated here will define the share of the zero-emission vehicles based on technical availability of the technologies. With current zero-emission vehicle technology enabling battery-electric vehicles to cover a distance of about 100 km on one charge, one can state that a reasonable share in the total fleet would be 30% for passenger cars. This figure of course only takes into account technical considerations and not economical ones. For light duty goods vehicles, which in the city context are mostly used for delivery purposes, a share of 50% has been selected. This share is considered for the whole vehicle fleet; one has to take into account however that the battery-electric vehicle is first and foremostly an urban machine, and that the division of the vehicles over the three vehicle shifts has to be done appropriately. With a share of 30% of the overall car fleet, one can attribute a mere 5% of electrics to shift 'Z' (long-distance driving from out of the region), 95% to shift 'X' (vehicles originating in the city centre) and the remainder to shift 'Y', where to come to an overall 30% ratio, the share of electrics will be 29,90%. The vans are treated similarly. This scenario is called here the “basic EV scenario”.

One can see in Table 5.12 the impact of the deployment of these vehicles (Based on 2003 traffic figures, as reference scenario above).

	CO2	*CO*	*HC*	*NOx*	*SO2*	*PM*	*CH4*
Reference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Basic EV	81.3%	75.9%	80.4%	84.1%	83.0%	81.6%	81.95%

Table 5.11: Emissions – Basic EV scenario

This table gives the direct emissions in the B.C.R.; indirect emissions are treated in §5.8.

The impact on the city centre becomes clear if one visualises the number of electric vs. thermal passenger cars in the city centre, shown in Illustration 5.23 and Illustration 5.24.

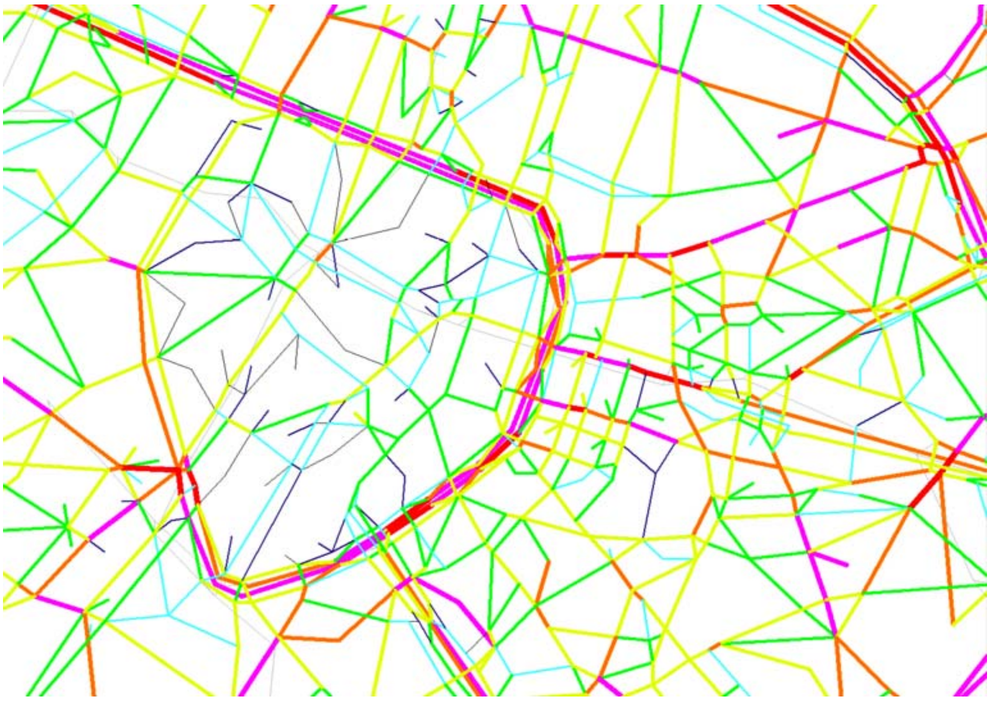

Illustration 5.23: Thermal vehicles in city centre - basic EV scenario

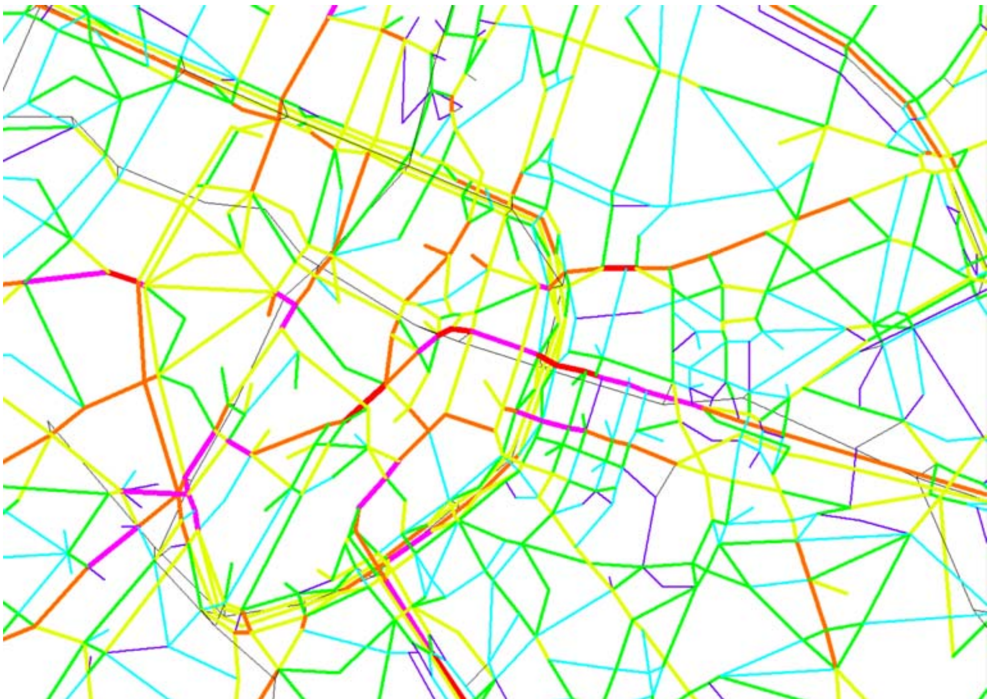

Illustration 5.24: Electric vehicles in city centre - basic EV scenario

For the emissions in the city centre, Illustration 5.25 shows the reduction in NO_x emissions in the city centre obtained through this scenario. Scale is as in Table 5.7.

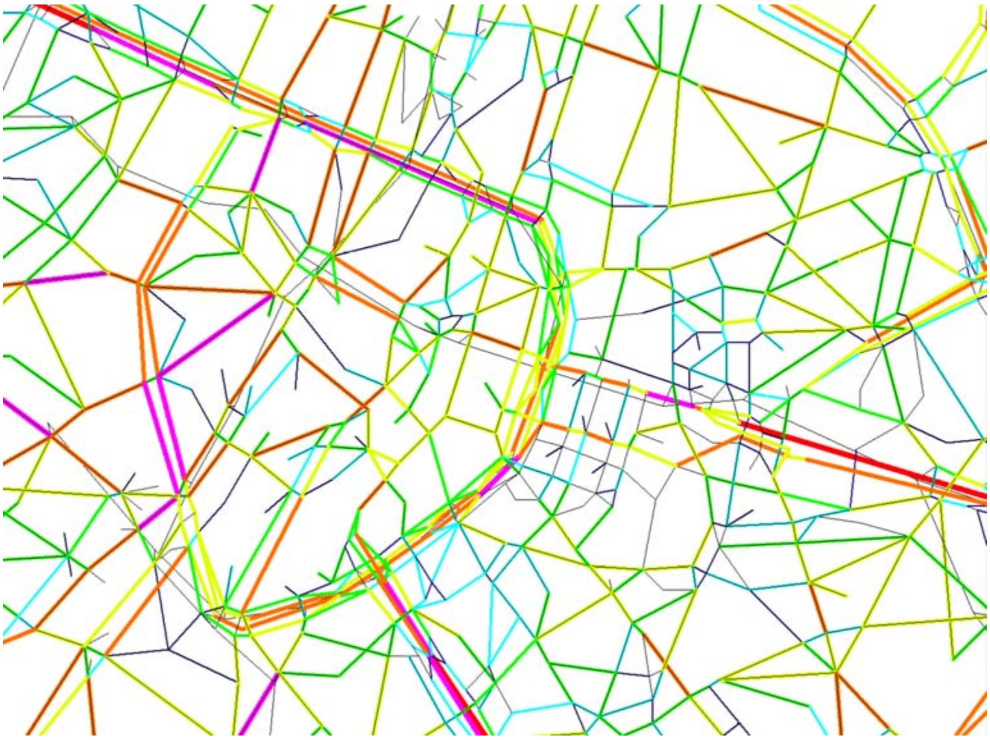

Illustration 5.25: Basic EV Scenario – NOx reduction

It is interesting to have a look at the modal shift due to the introduction of the EV share. Table 5.17 shows that the total share of the electric vehicles, expressed in function of the total vehicle-km travelled, is less than the share of the number of vehicles in the fleet. This is of course due to the fact that the share of electrics is very low in the vehicles in the outer zone (where longer distances are generally covered) and high in the city centre (where distances are usually smaller).
Note that all percentages in Table 5.17 (and in similar tables to follow) are expressed with reference to the total vehicle-km in the reference situation. The electrics take up about 20% of the total vehicle-km.

	Total	***Pcth***	***PCel***	***LDVth***	***LDVel***	***HDV***
Reference	100.0%	75.5%	0.0%	7.7%	0.0%	16.8%
EV Share	100.1%	58.4%	17.0%	5.1%	2.7%	16.8%

Table 5.12: Vehicle distribution

Such a situation however will be difficult to obtain without additional measures aiming at promoting the introduction of zero-emission vehicles. Traffic authorities have a number of tools available to define traffic policies and to control the access and behaviour of vehicles, such as traffic tolls, access limitations and parking tolls.

5.4 Additional measures: traffic access tolls and parking tolls

In the underlying study, traffic tolls have been implemented as an instrument to promote a modal shift from legacy vehicles to zero-emission vehicles.
The toll can be levied on two levels: for entering the city centre (pentagon) and for entering the whole Brussels Capital Region. In each case, toll rates can be set separately for thermal en electric vehicles.
Furthermore, thermal vehicles can be outrightly banned from the city centre. (This ban is implemented in the program by simulating an extremely high toll rate.)
These tolls are levied when entering the city centre; another way to charge access to the area is to raise parking costs for vehicles in the city centre, whilst providing reserved parking (with charge facilities) for electric vehicles.

If these measures are applied to the city centre, one sees a clear diminution of the number of thermal vehicles in the city centre, and hence of emission values. The following figures show the impact on the number of thermal passenger cars in the city centre, applied on the basic EV scenario as defined above.

All these figures have to be compared with Illustration 5.23 which shows the share of thermal cars in the same conditions, but without any tolls or restrictions.

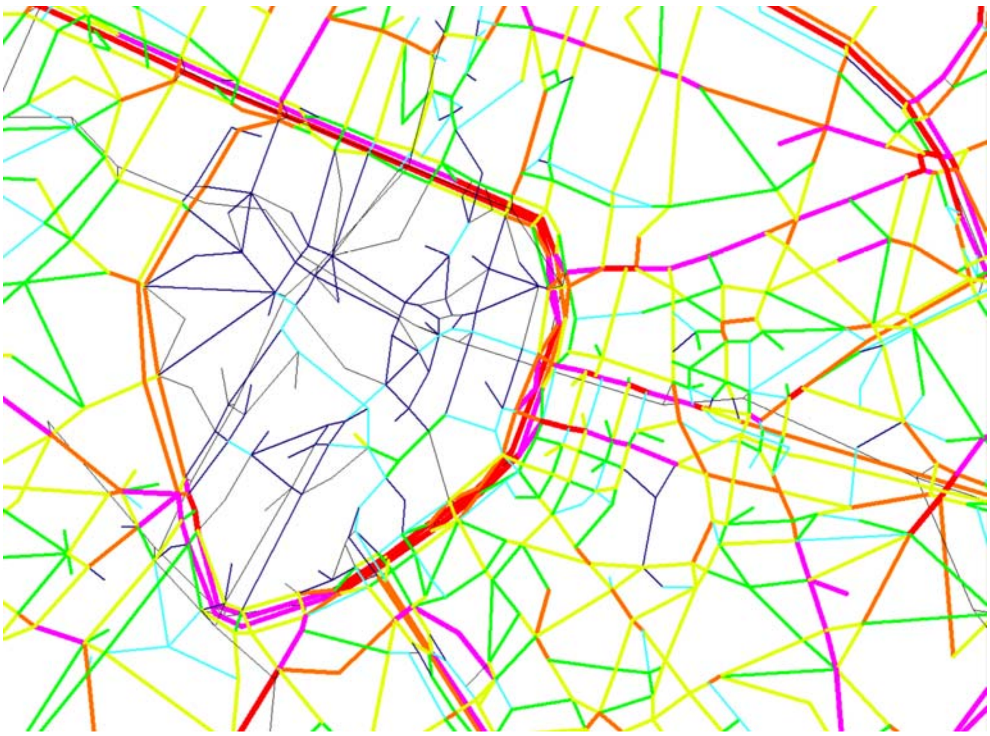

Illustration 5.26 - Thermal vehicles – Toll in basic EV scenario

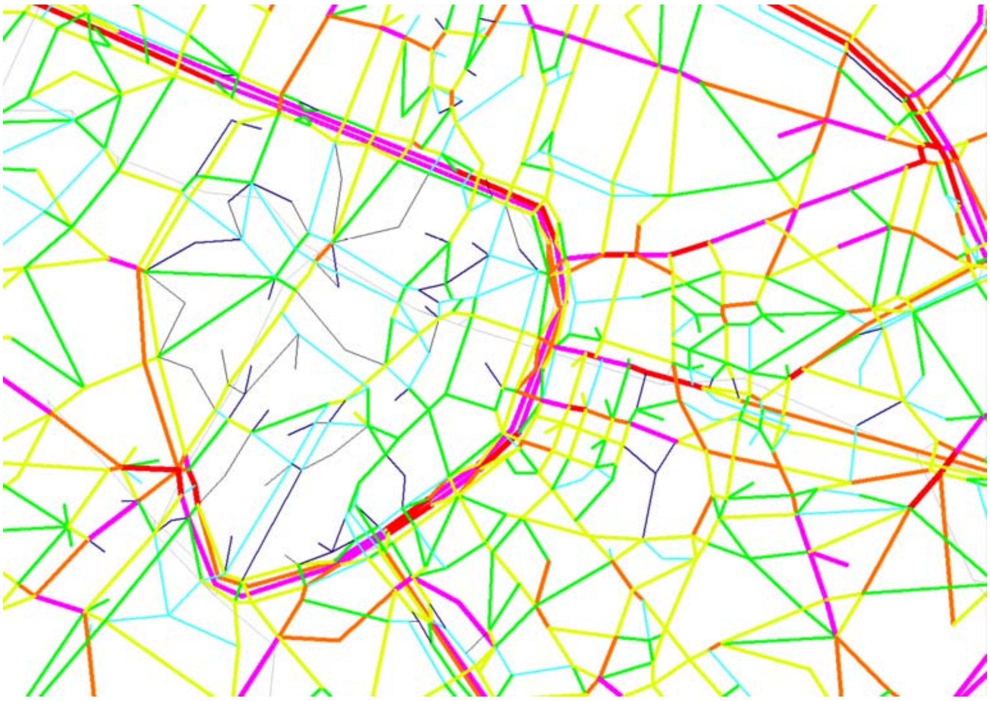

Illustration 5.27: Thermal vehicles – Parking toll in basic EV scenario

In the case of Illustration 5.26, a toll measure has been applied to the city centre, giving a higher reduction than in Illustration 5.27, where an equivalent amount is applied as parking toll for thermal vehicles.

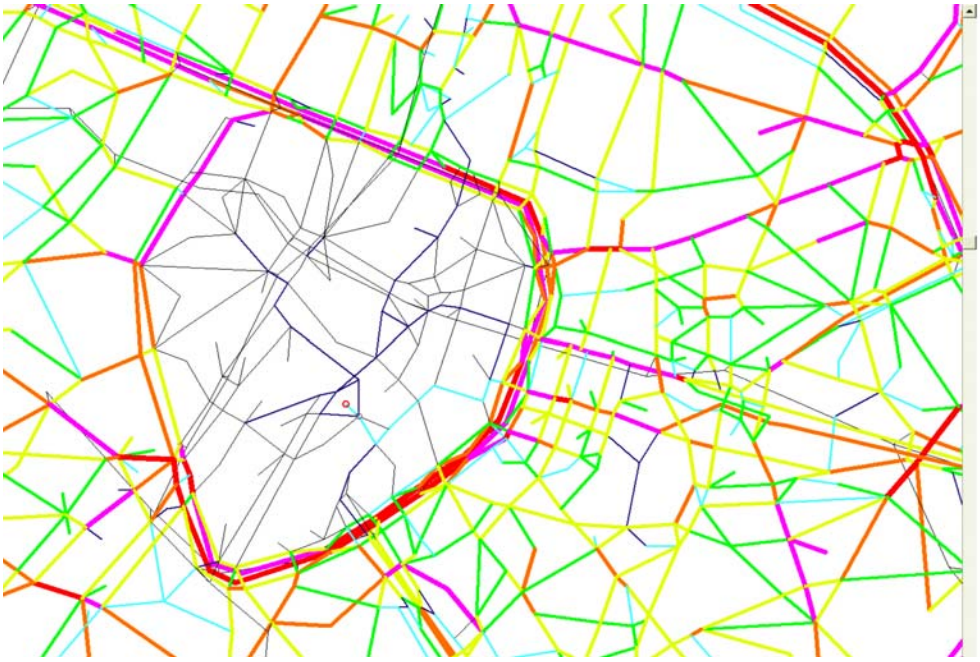

Illustration 5.28: Thermal vehicles – Centre closed – Basic EV scenario

The most drastic reduction one becomes when closing the city centre for thermal vehicles. This is shown in Illustration 5.28; the few vehicles still left correspond to the thermal vehicles of share “X” with trips originating in the centre.
One can of course also introduce toll measures on the reference scenario, i.e without a pre-defined share of zero-emission vehicles. Illustration 5.29 shows the effect of such measure.

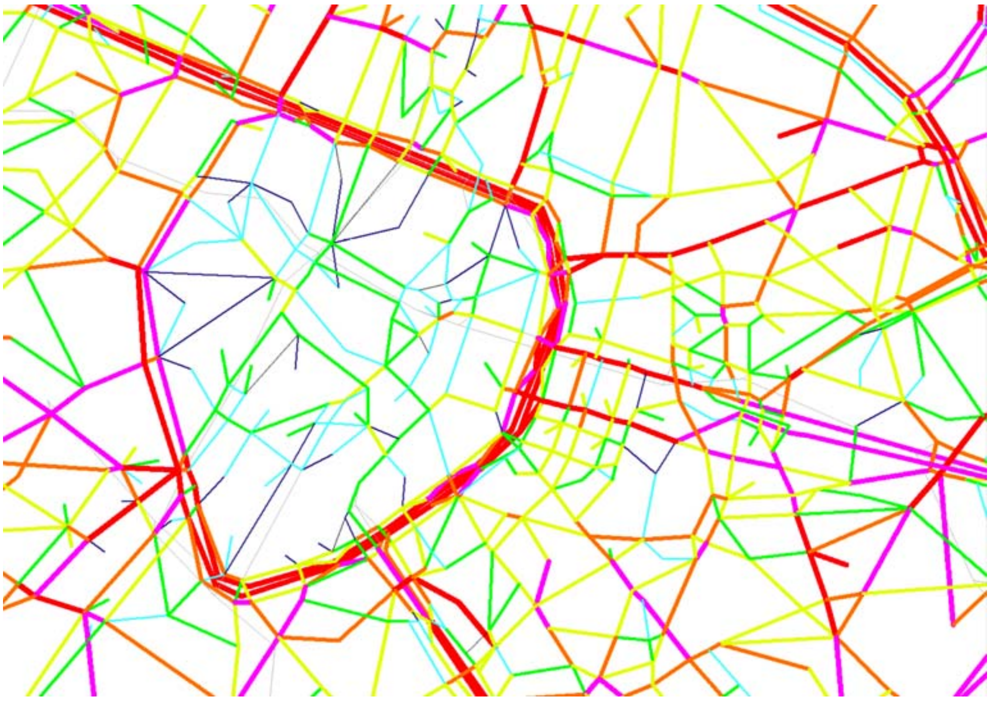

Illustration 5.29: Thermal vehicles – Centre closed – Reference scenario

The thermal vehicles still shown in the city centre, which in principle is closed are the trips of share “X” originating there; all transiting traffic being diverted.
The influence of these toll measures is clear: they discourage through traffic in the city centre. This will have some effect on saturation, as can be seen in comparing Illustration 5.30 (which refers to the situation of Illustration 5.29) with Illustration 5.17 above.

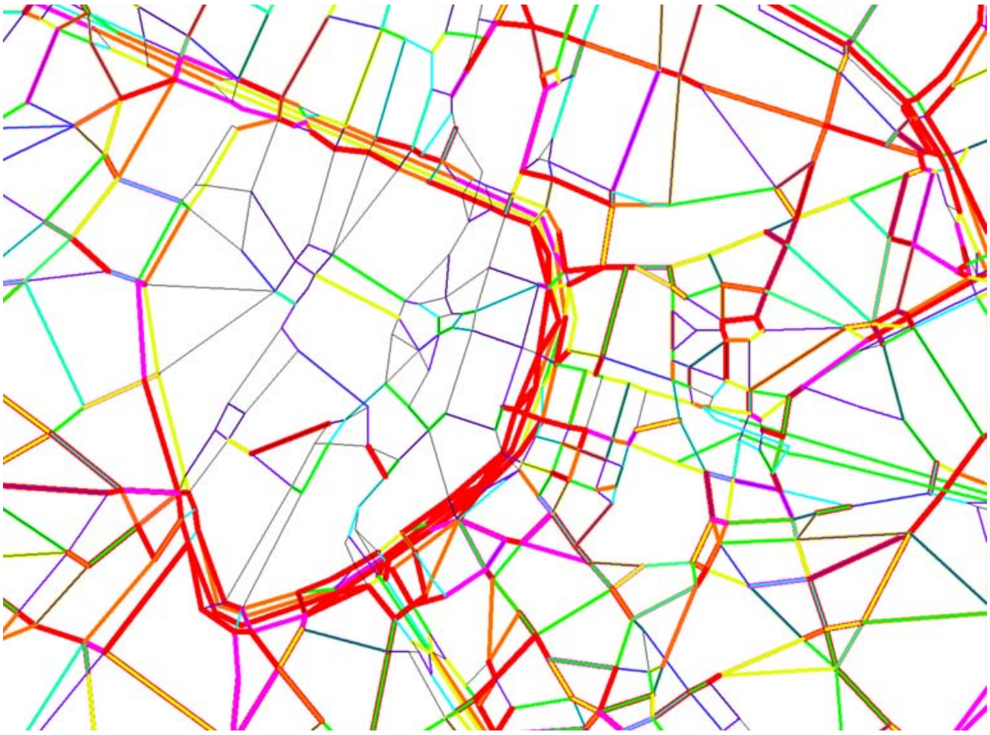

Illustration 5.30: Saturation in city centre (closed) – reference scenario

For the scenarios where zero-emission vehicles are deployed, there will be a higher level of saturation in the city centre of course, since these vehicles are not affected by the toll and restraint measures. remains at a considerable level (Illustration 5.31), although somewhat reduced from the reference situation through the diversion of transiting traffic.

This saturation however will be mainly caused by zero-emission vehicles which are much less a burden on the environment as to noxious exhaust gases and to noise.

Another option is to levy toll for entering the whole BCR area; this will influence vehicles entering the area ("share Z" and part of "share X") but not the vehicles of "shareY" (corresponding with vehicles having both their origin and destination between the inner and outer ring road) make up the largest part of the traffic in the current model; the influence of such measure will thus be less outspoken.

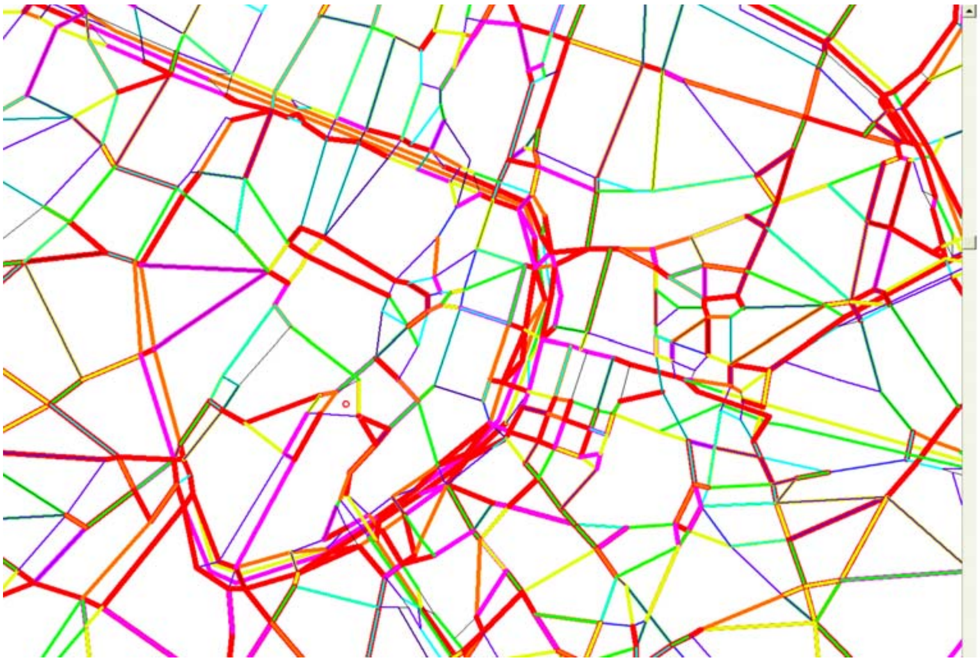

Illustration 5.31: Saturation in city centre, with EV, closed for TV

One can now assess the influence of these measures on the total emissions produced. These results are shown in Table 5.13. It turns out from the simulations however that this influence, considered over the whole region, is quite small compared with the scenarios without measures (basic EV scenario and reference scenario).
One should note that the difference is an actual slight increase, corresponding to an equivalent increase in distance covered, due to vehicles making detours to avoid the tolls in the city centre. The small differences however can be considered not to be of a significant order of magnitude.
A main exception however is the situation of the reference scenario with the city centre closed for thermal vehicles – in this case, a significant reduction can be witnessed, due to trips towards the city centre which are diverted to public transport (as shown in Illustration 4.12 on page 40). This highlights the function of the toll system as a means to obtain modal shift, relieving congestion and reducing emissions in the city centre. With a large share of electric vehicles present in the city centre, the differences will be of course less outspoken since these vehicles are not affected by the toll.

Considered over the whole region, the differences may not seem significant indeed, but in the sensitive area which is the centre these measures do have a considerable impact as is shown in Illustration 5.32 which shows the NOx emissions as an example, for the case with the city centre closed, and the reference scenario without electric vehicles. The crossed lines show links where the emission values increase, which is due to a higher traffic load on this links because thermal vehicles are diverted to avoid toll measures; colour codes are the same as shown in Table 5.7.

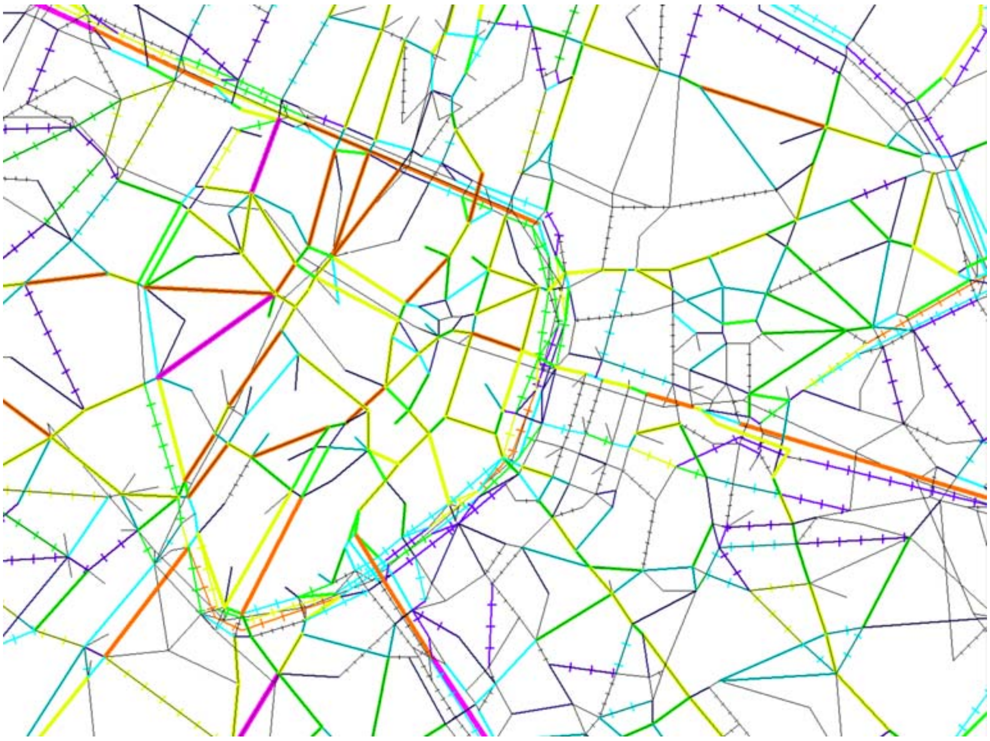

Illustration 5.32: NOx reduction – City centre closed – Reference sc.

	CO2	CO	HC	NOx	SO2	PM	CH4
Reference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Toll centre + region, no EV	100.4%	100.9%	100.7%	100.3%	100.3%	100.4%	100.6%
Centre closed, no EV	93.4%	90.7%	92.6%	94.5%	94.3%	94.3%	93.2%
Basic EV	81.3%	75.9%	80.4%	84.1%	83.0%	81.6%	81.9%
Toll in centre,EV	81.3%	76.0%	80.5%	84.1%	83.0%	81.6%	82.0%
Toll in region,EV	82.2%	79.9%	83.3%	84.7%	83.7%	82.3%	83.0%
Parking toll, EV	81.3%	75.9%	80.4%	84.1%	83.0%	81.6%	81.9%
Toll centre + region, EV	82.3%	80.0%	83.4%	84.7%	83.8%	82.4%	83.1%
Centre closed, EV	81.6%	76.7%	81.1%	84.2%	83.2%	81.8%	82.5%

Table 5.13: Emissions – Toll measures

For the situation with the city centre closed and the basic EV scenario (as in Illustration 5.28), the results are shown in Illustration 5.33 (actual emissions) and Illustration 5.34 (reduced emissions).

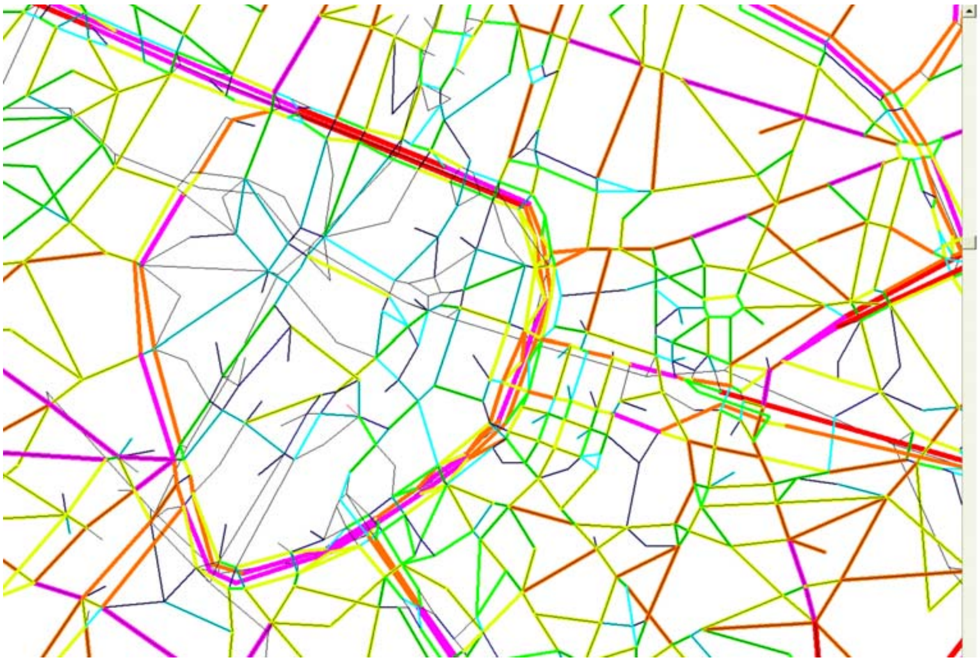

Illustration 5.33 - NOx in city centre – closed for TV – basic EV sc.

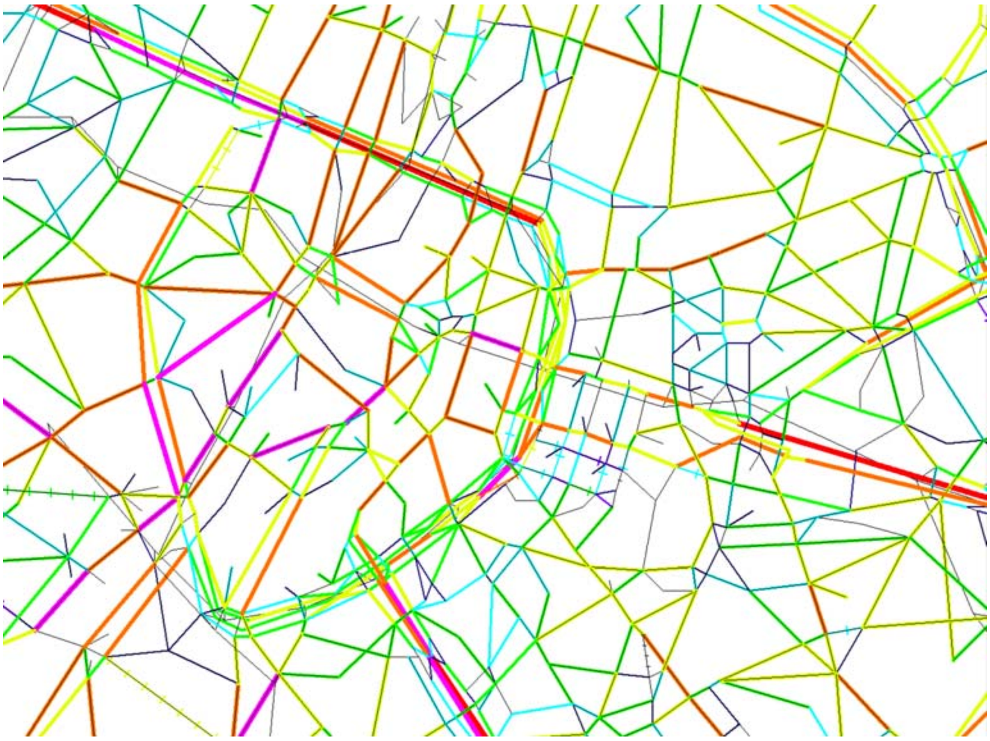

Illustration 5.34 - NOx reduction – closed for TV, basic EV scenario

All these scenarios involving zero-emission vehicles take into account the existence of the zero-emission share as part of the light-duty vehicle fleet (M1 and N1, passenger cars and vans). It is clear that the realisation of such a share of electrically propelled vehicles will have to gradually develop in function of the vehicle and energy market.

Some specific applications however exist for which electrically propelled vehicles excel, such as goods distribution and automatic rent-a-car systems, and which can be suited to introduce the technology with a significant impact on the local environment. This will be the subject of the following paragraphs.

5.5 Goods distribution

5.5.1 Generalities

The zero-emission vehicle scenarios described above take into account an existing share of zero-emission vehicles, they do not consider the heavy goods vehicles however for which, with today's technology, no zero-emission versions are on the roads. The implantation of goods distribution centres, where goods destined to the city are transborded to zero-emission distribution vehicles, can be implemented to further improve air quality in the city. In this framework, a number of locations for distribution centres have been selected (see Illustration 2.6 on page 16), and two approaches can be implemented:

- closing off the city centre for heavy goods vehicles, and implementing goods distribution centres on all (12) locations
- closing off the whole BCR area for heavy goods vehicles, and implementing goods distribution centres along the outer ring (7 locations).

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5.5.2 Distribution scenarios

At first, the goods distribution systems will be implemented on the reference scenario, where only legacy technologies are used and . The model will introduce zero-emission vehicles for the distribution trips in all cases where it deems that the "cost" of the trip (Eq. 5 page 37) can be minimized this way (cf. Illustration 4.13 page 41), through avoiding, by the transbordment to an electric vehicle, the toll cost which the thermal goods vehicle would have to pay. The same princple is used dealing with thermal vans, part of which will be displaced too.

At first, the distribution centres can be developed without imposing any further access restrictions or tolls. In this case (Illustration 5.35), the number of zero-emission vehicles appearing is already considerable. This scenario bans a maximum of thermal heavy duty vehicles from the BCR area and has seven distribution centres along the outer ring.

To enhance the participation in the scheme, toll measures for thermal vehicles (analogous to the paragraph above) have been implemented in order to provide the incentive for the goods transportation vehicles to transfer to a zero-emission vehicle.

This is shown in Illustration 5.36; the scenario illustrated in Illustration 5.37 however has twelve distribution centres, adding five more in the canal area which is the traditional industrial belt of the Brussels region.

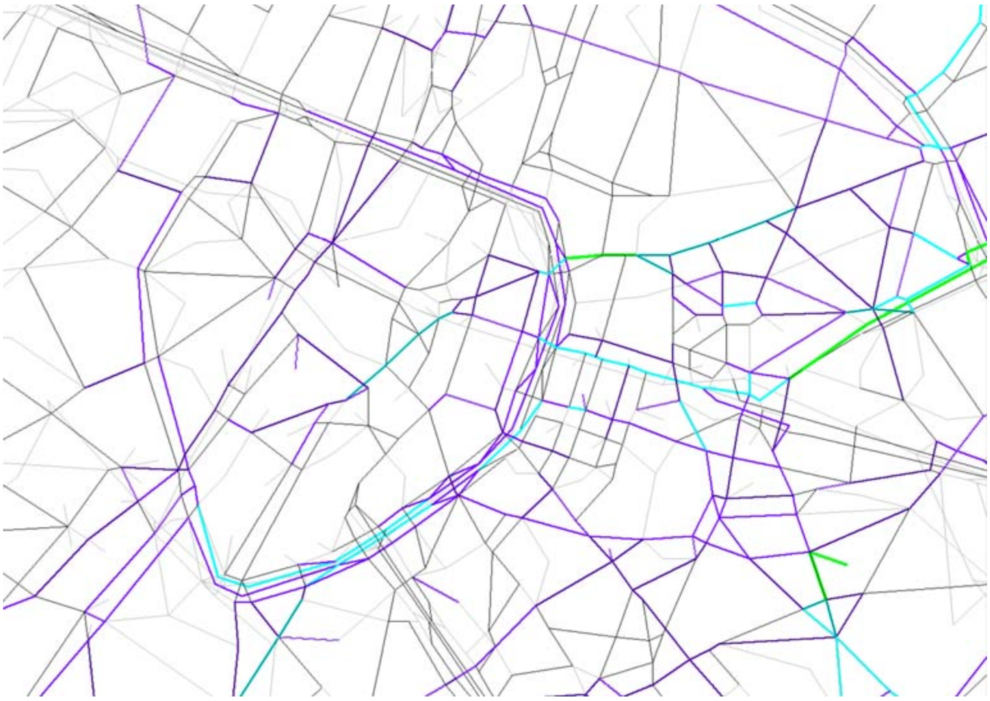

Illustration 5.35: Electric distribution vehicles (7 centres) - no tolls

Illustration 5.36: Electric distribution vehicles (7 centres) - tolls

Illustration 5.37: Electric distribution vehicles (12 centres) - tolls

The scheme has a local impact on emissions, by removing polluting vehicles from the city centre, as can be seen in Illustration 5.38, which shows the reduction compared with the reference scenario in Illustration 5.39. These figures refer to particulate emissions; similar results are found for the other pollutants. The color scale for this chart is given in Table 5.14.

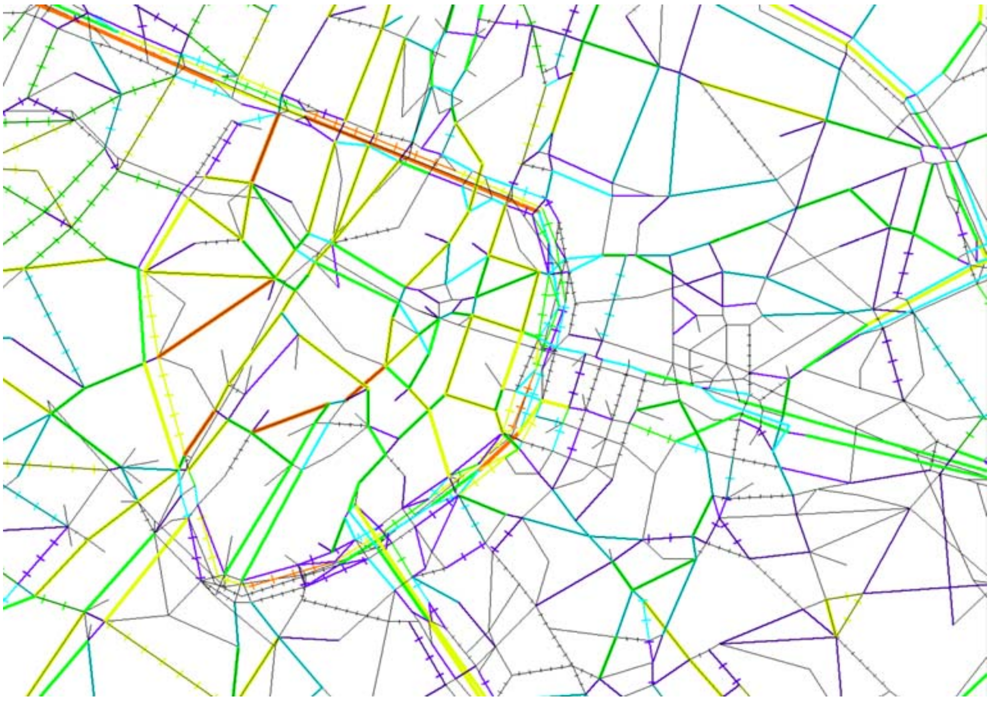

Illustration 5.38: PM emission reduction (12 centres) - tolls

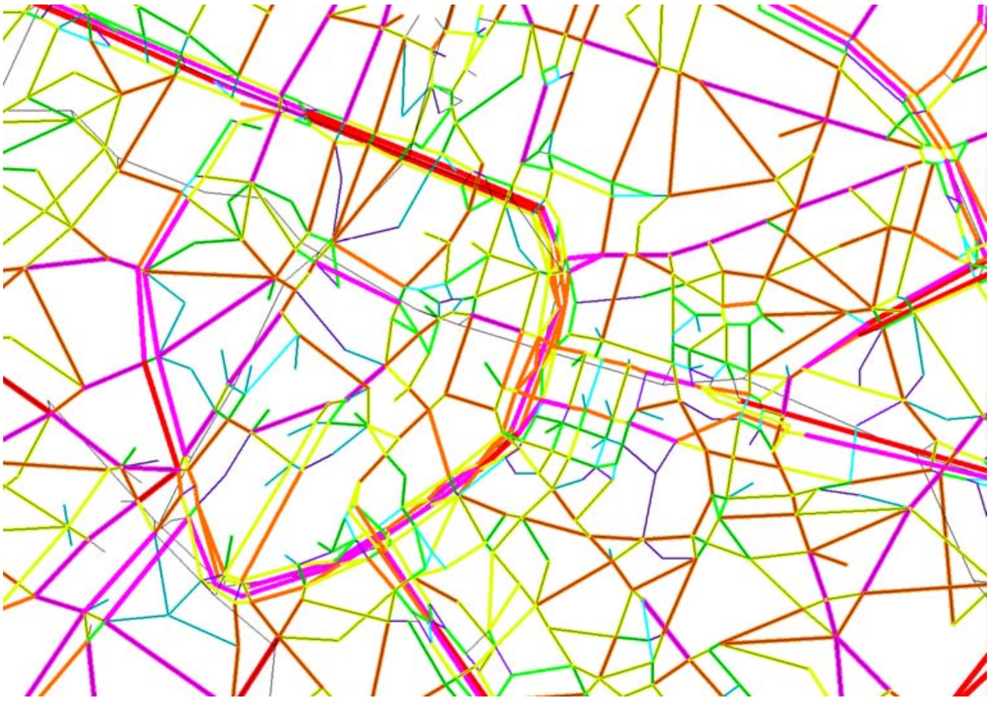

Illustration 5.39: PM emissions (Reference scenario)

Color	**PM (g)**
Black	< 1
Dark blue	1-2,5
Light blue	2,5 - 5
Green	5 - 10
Yellow	10-25
Orange	25 - 50
Pink	50 – 100
Red	100 – 250
Red (Fat)	> 250

Table 5.14: PM chart scale

The impact on the mobility and overall emissions can also be assessed. For the overall region, the impact on the emissions (and on the fuel consumption) is rather limited, considered over the whole region as can bee seen from Table 5.15. This is due to the large significance of peripheral and transiting traffic on the whole region.

	CO2	CO	HC	NOx	SO2	PM	CH4
Reference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
7 Centres, no toll	99.5%	99.9%	99.4%	99.1%	99.3%	99.2%	99.7%
7 Centres, toll	99.2%	100.1%	99.8%	98.7%	98.9%	98.3%	100.1%
12 Centres, toll	99.3%	100.3%	99.9%	98.9%	99.0%	98.5%	100.2%

Table 5.15: Emissions – Distribution centres – Reference scenario

Table 5.16 shows the distances (expressed in thousand vehicle-kilometers) covered by the vehicles. Furthermore, distances taken over by the zero-emission vehicles are partially offset by the additional approach traject and by the extra distances covered through detours to avoid the tolls.

x1000	Total VehKm	Pcth VehKm	HDV VehKm	LDVth VehKm	LDVe VehKm
Reference	4095.3	3093.5	685.2	316.5	0.0
7 Centres, no toll	4114.3	3093.5	675.7	312.7	32.4
7 Centres, toll	4124.3	3105.2	683.0	278.7	57.3
12 Centres, toll	4125.3	3106.2	683.8	279.7	55.6

Table 5.16: Distances – Distribution centres – Reference scenario

(PC=passenger cars; HDV=heavy duty vehicles, LDV=light duty vehicles,th=thermal vehicles, e=electric)

The actual number of zero-emission distribution vehicles appearing in these scenarios is:

- 3320 in the case of 7 centres, without toll, i.e. 17% of the number of thermal LDV
- 7022 in the case of 7 centres with toll, i.e. 36% of the number of thermal LDV
- 9481 in the case of 12 centres with toll, i.e. 48% of the number of thermal LDV

It is clear that the impact of these measures will once again be concentrated on the local level (city centre) where the vehicles are actually deployed. To have a considerable impact on a global scale, it will be necessary to deploy the zero-emission vehicles also on a wider scale.

The concept of goods distribution system can of course also be superimposed on the situation with a share of electric vehicles, in order to further displace remaining polluting vehicles from the city centre. Illustration 5.40 shows the PM reduction compared with reference scenario, with 12 goods distribution centres integrated in the basic EV scenario.

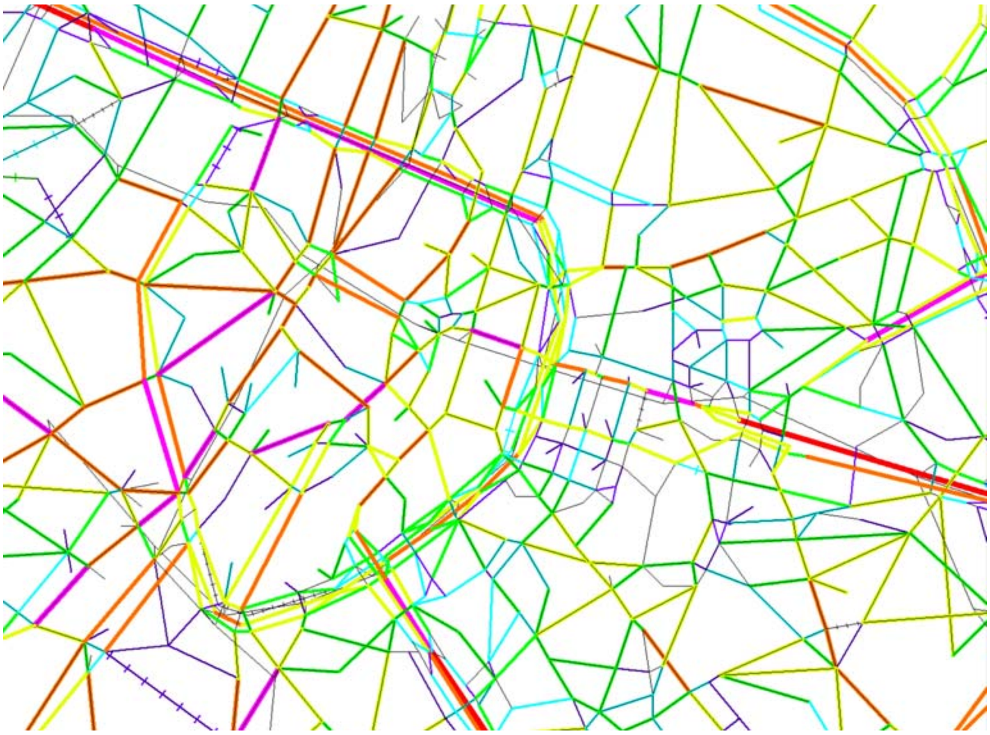

Illustration 5.40: PM reduction – EV scenario with goods distribution

This scenario gives the results in Table 5.17 and Table 5.18.

	CO2	CO	HC	NOx	SO2	PM	CH4
Reference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Basic EV	81.3%	75.9%	80.4%	84.1%	83.0%	81.6%	81.9%
12 Centres, EV, toll	81.1%	76.3%	80.6%	83.7%	82.6%	81.0%	82.2%

Table 5.17: Emissions – Distribution centres – Basic EV scenario

The impact of the emissions are similar to what happens in the reference scenario. As for the distances covered, it is clear that the share of the electrics increases, as is shown in Illustration 5.41.

VehKm x1000	Total	Pcth	PCe	HDV	LDVth	LDVe
Reference	4095.3	3093.5	0.0	685.3	316.5	0.0
Basic EV	4098.7	2394.7	696.8	685.4	210.2	111.7
12 Centres, EV,toll	4106.9	2404.0	696.2	683.7	195.7	127.3

Table 5.18: Distances – Distribution centres – Basic EV scenario

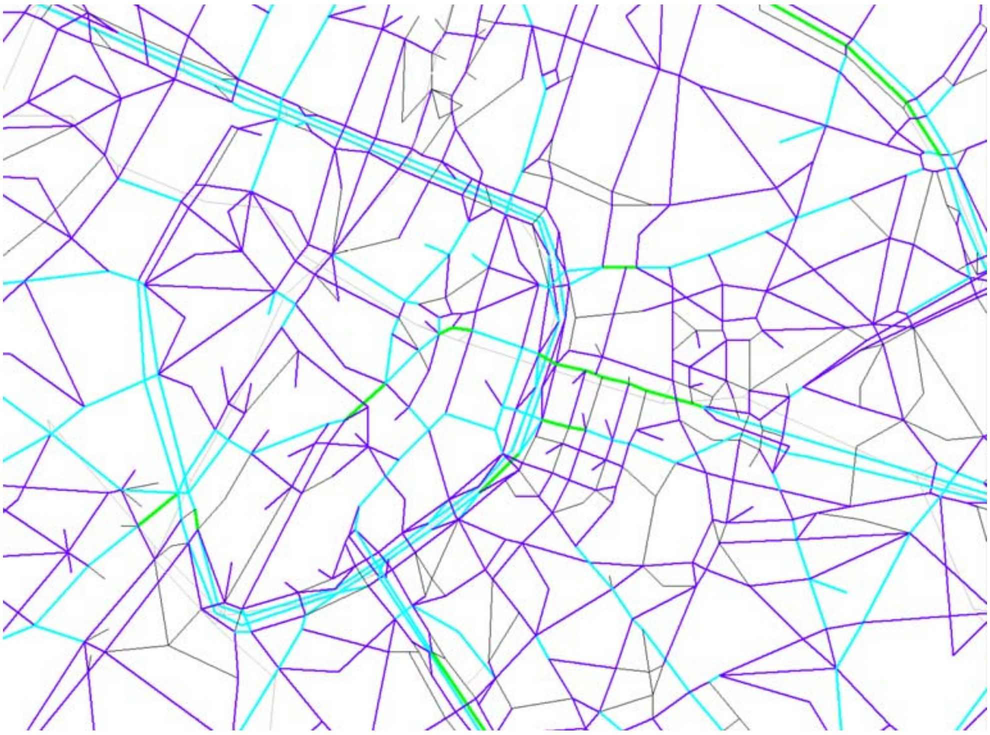

Illustration 5.41: Electric distribution vehicles in EV scenario

5.6 Renta car stations

5.6.1 Generalities

Another concept that can be implemented to deploy zero-emission vehicles are the automatic rent-a-car stations. These can be considered a kind of semi-public transport, and, in combination with other traffic management measures such as toll systems, can contribute to the improvement of the distribution of vehicles and the air quality in the city centre.

In this framework, a number of locations for rent-a-car stations have been selected (see Illustration 2.4 on page 14), and two approaches can be implemented, a limited one considering only three stations adjacent to the downtown area, and a larger one considering five additional stations spread over the whole BCR area.

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5.6.2 Scenarios

At first, the rent-a-car systems will be implemented on the reference scenario, where only legacy technologies are used. The model will introduce zero-emission vehicles for the passenger car trips in all cases where it deems that the “cost” of the trip (Eq. 5 page 37) can be minimized this way (cf. Illustration 4.12 page 40), through avoiding, by changing to an electric vehicle, the toll and parking cost which the thermal car would have to pay.

If no additional measures such as tolls are implemented, zero-emission vehicles take a share as shown in Illustration 5.42.

The number of vehicles participating into the system vehicles can be further enhanced by implementing tolls to enter the city centre. This is shown in Illustration 5.43 for the scenario with three stations and in Illustration 5.44 for the scenario with eight stations. In the latter case, the number of zero-emission vehicles is visibly higher, which is due to the larger number of vehicles available at the stations.
Furthermore, one can clearly see the concentration of zero-emission vehicles emanating from the station locations (e.g. North station).

The introduction of these vehicles into the city centre will of course reduce local emissions, one can compare Illustration 5.45 and Illustration 5.46 showing the reduction compared with the reference scenario in Illustration 5.47. The increase on some links is due to diversion of traffic and due to the approach trajects to the stations.

The color scale for these CO charts is shown in Table 5.19.

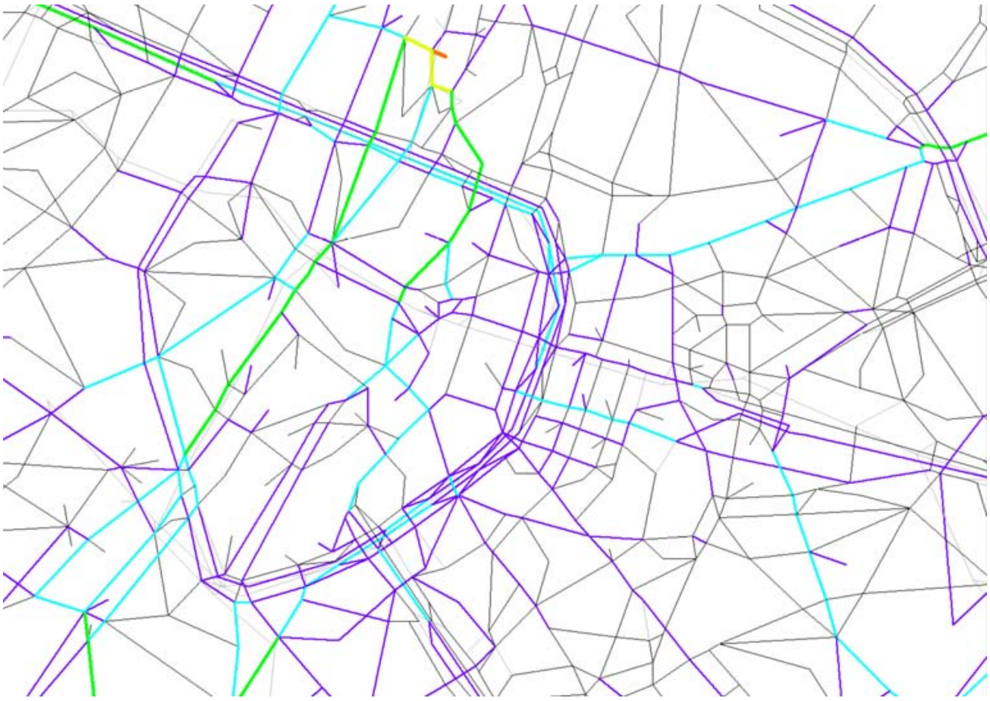

Illustration 5.42: Electric vehicles (8 RAC stations) – no tolls

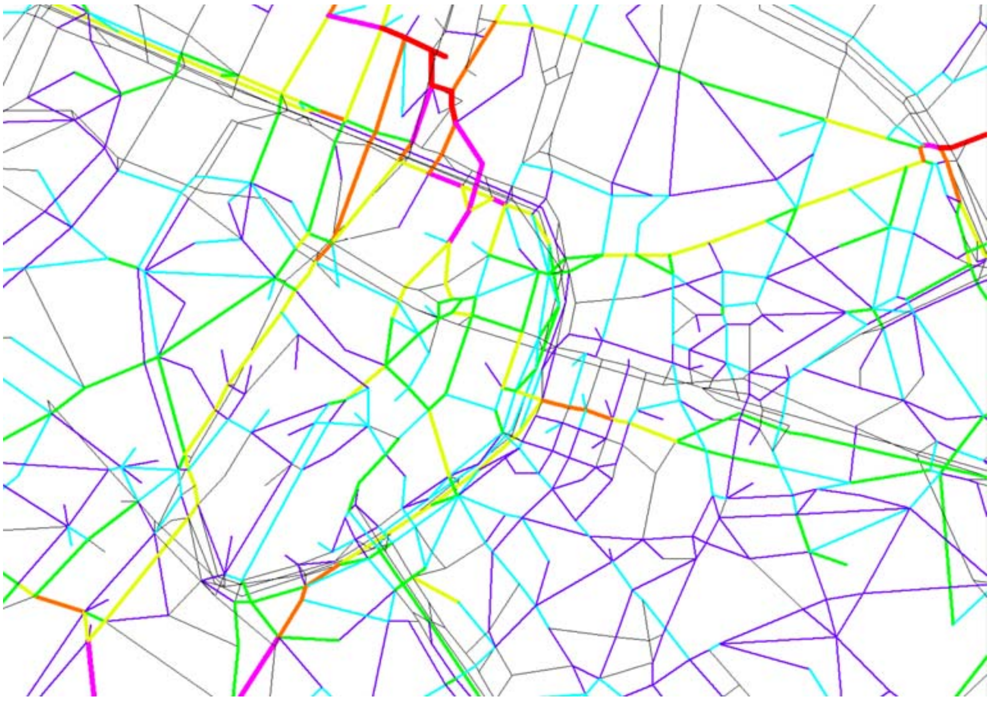

Illustration 5.43: Electric vehicles (3 RAC stations) - tolls

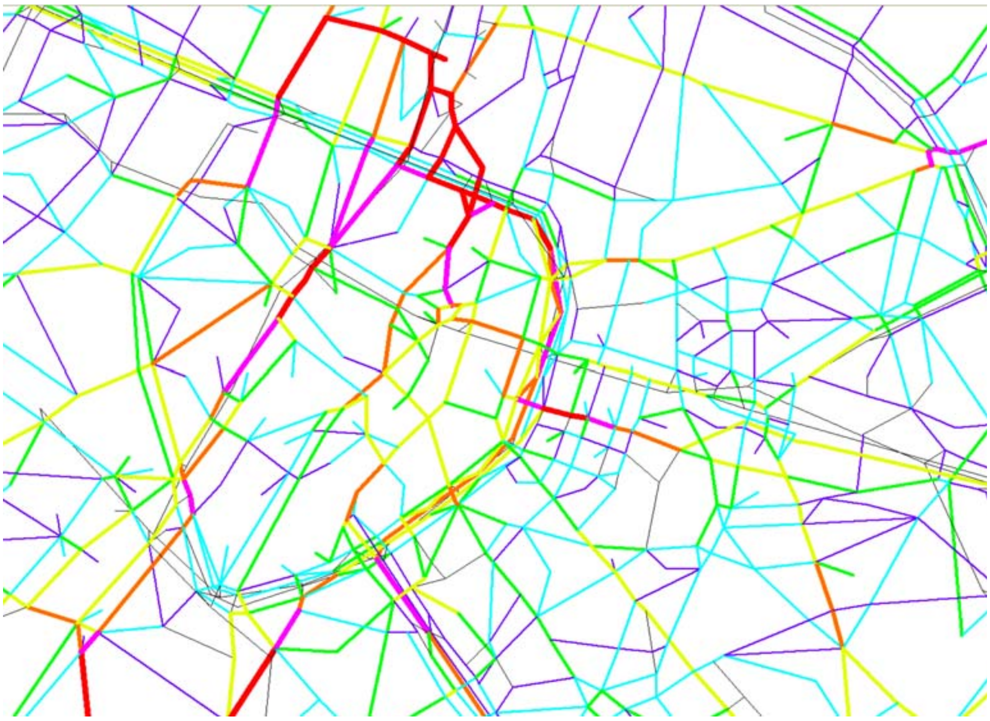

Illustration 5.44: Electric vehicles (12 RAC stations) - tolls

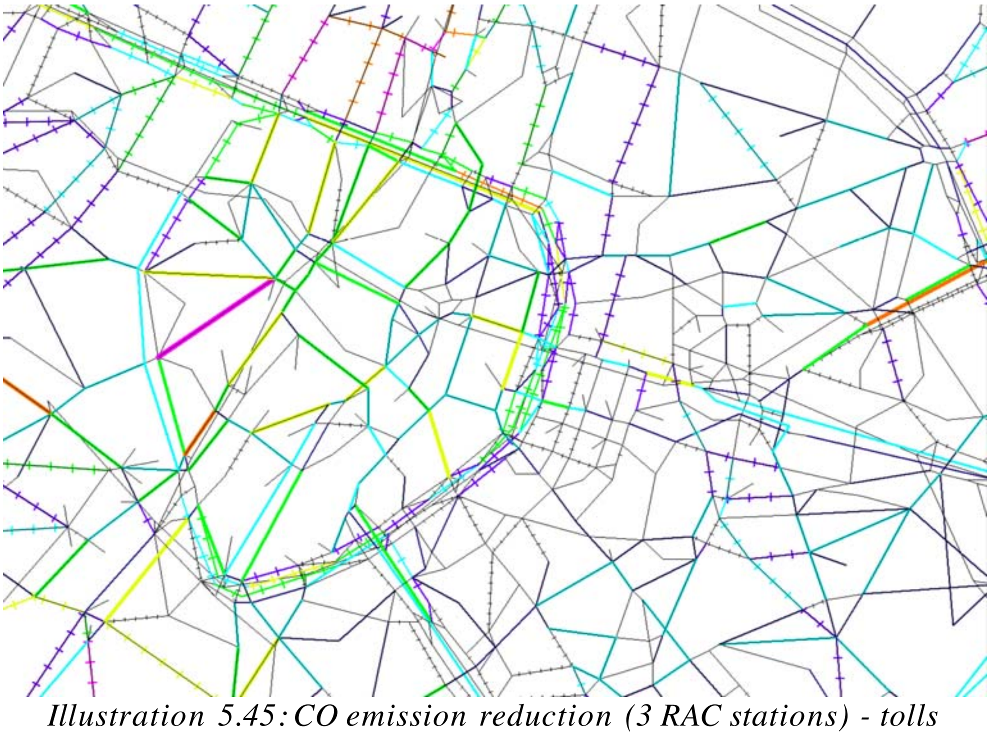

Illustration 5.45: CO emission reduction (3 RAC stations) - tolls

Color	*CO (g)*
Black	< 100
Dark blue	100 - 250
Light blue	250 - 500
Green	500 – 1000
Yellow	1000 - 1500
Orange	1500 - 2000
Pink	2000 - 2500
Red	2500 - 5000
Red (Fat)	> 5000

Table 5.19: CO chart scale

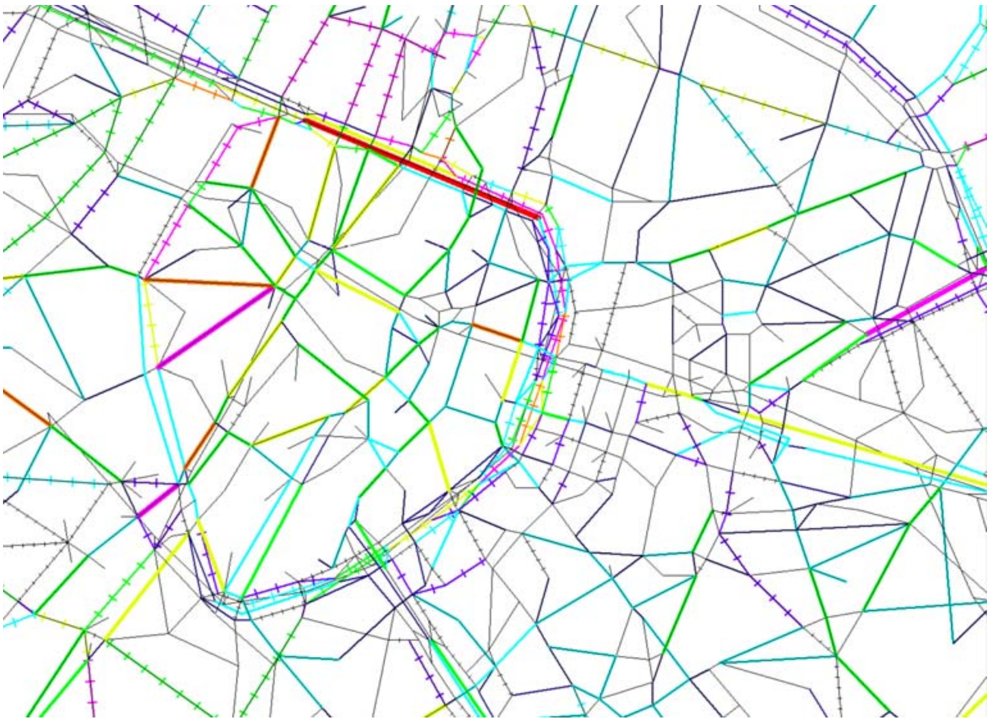

Illustration 5.46: CO emission reduction (8 RAC stations) - tolls

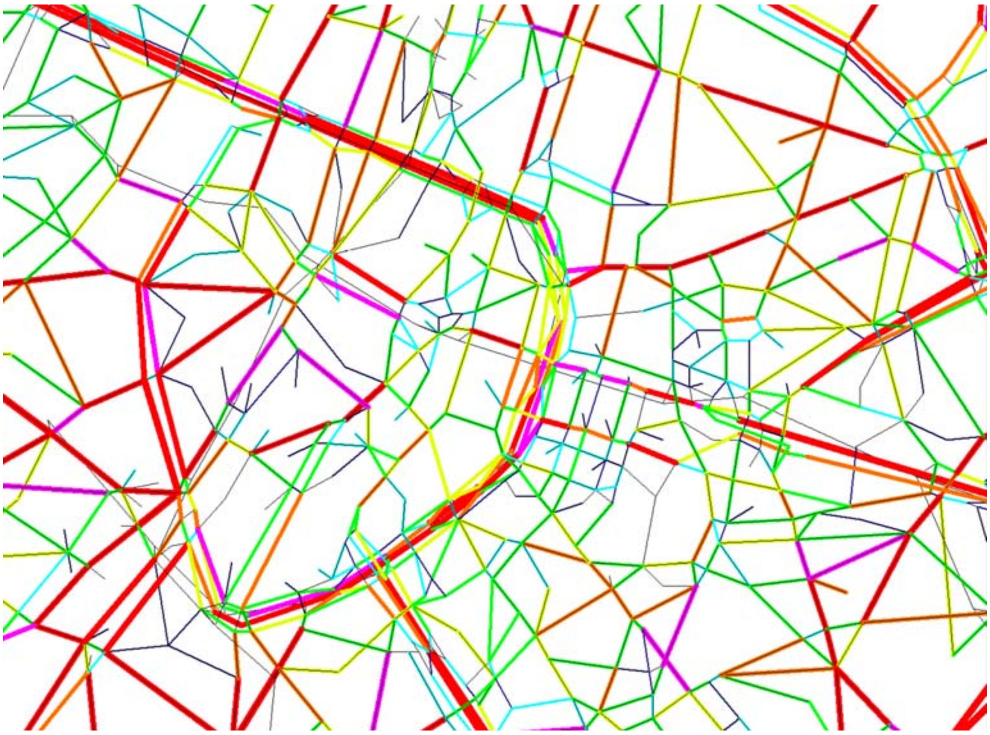

Illustration 5.47: CO emissions (reference scenario)

The impact on the mobility and overall emissions can also be assessed. For the overall region, the impact on the emissions (and on the fuel consumption) is rather limited, as can bee seen from Table 5.20.

	CO2	***CO***	***HC***	***NOx***	***SO2***	***PM***	***CH4***
Reference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
8 Stations no toll	99.0%	98.8%	99.0%	99.2%	99.2%	99.20%	99.0%
3 Stations toll	99.9%	100.7%	100.4%	99.8%	99.9%	100.2%	100.3%
8 Stations toll	98.7%	99.0%	99.0%	99.9%	98.9%	99.2%	98.9%

Table 5.20: Emissions – RAC stations

Table 5.21 shows the distances covered by the vehicles. The new distances introduced by the zero-emission vehicles are larger than the distances driven less by the thermal cars; this is due to the influence of the approach trajects to the stations. The small differences for the goods vehicles are due to changes in assignment in the TRIPS programme due to a changed overall vehicle situation. Local changes in the number of vehicles on each link (which will for example occur in the vicinity of the stations) will in fact lead to different congestion values which may cause different paths for the goods vehicles to be calculated by TRIPS.

x1000	Total VehKm	Pcth VehKm	PCel VehKm	HDV VehKm	LDVth VehKm
Reference	4095.3	3093.5	0.0	685.2	316.5
8 Stations no toll	4104.1	3043.6	58.6	685.4	316.6
3 Stations toll	4176.8	3069.8	105.6	685.5	315.9
8 Stations toll	4244.9	3020.2	223.3	685.6	315.8

Table 5.21: Distances – Rent-a-car stations

The following number of electric vehicles are introduced by the system:

- 6872 in the case without toll (i.e. 3% of the total car fleet)
- 22375 in the case with 3 stations and toll (i.e. 11% of the total car fleet)
- 38508 in the case with 8 stations and toll (i.e. 19% of the total car fleet)

Once more, it is clear that the main impact of these measures will be located in the city centres.

The concept of rent-a-car systems can of course also be superimposed on the situation with a share of electric vehicles, in order to further displace remaining polluting vehicles from the city centre. Illustration 5.48 shows the CO reduction with 8 rent-a-car stations integrated in the basic EV scenario, combined with a toll measure. The reduction of emissions in the city centre becomes very expressed.

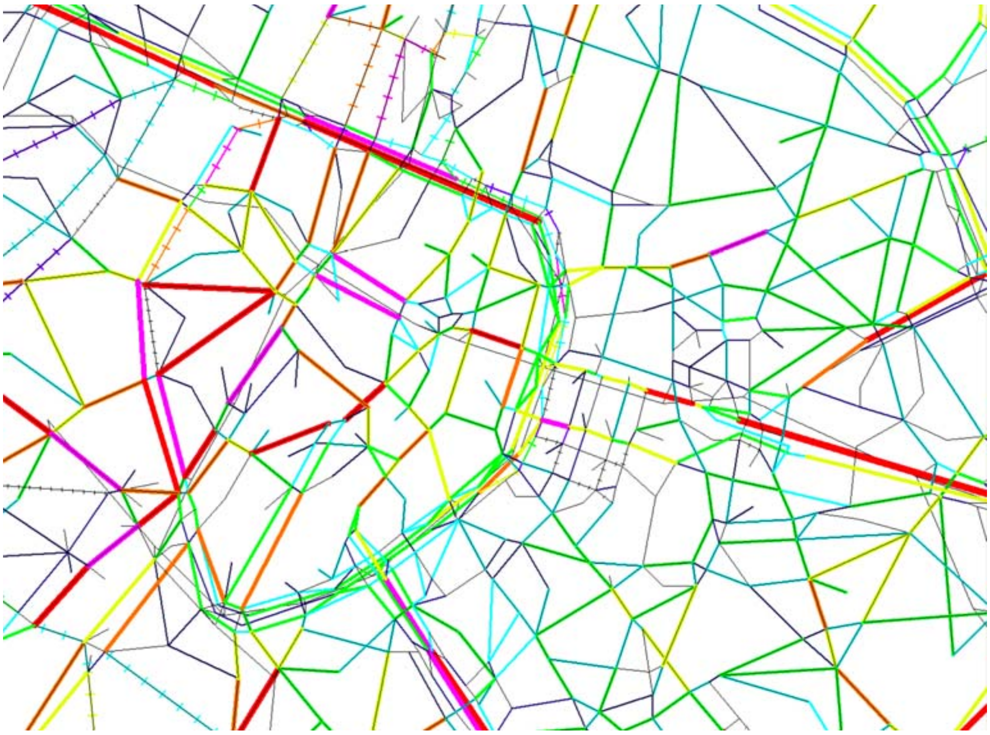

Illustration 5.48: CO reduction – RAC (8 stations) with EV scenario

This scenario gives the results in Table 5.22 and Table 5.23.

	CO2	CO	HC	NOx	SO2	PM	CH4
Reference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Basic EV	81.3%	75.9%	80.4%	84.1%	83.0%	81.6%	81.9%
8 stations, EV, toll	80.3%	75.2%	80.0%	83.3%	82.1%	81.0%	81.2%

Table 5.22: Emissions – Rent-a-car stations with EV scenario

The impact of the emissions are similar to what happens in the reference scenario.

VehKm x1000	Total	Pcth	PCel	HDV	LDVt	LDVe
Reference	4095.3	3093.5	0.0	685.3	316.5	0.0
Basic EV	4098.7	2394.7	696.8	685.4	210.2	111.7
8 stations, EV,toll	4194.6	2335.0	861.2	685.4	209.7	103.4

Table 5.23: Distances – Rent-a-car stations with EV scenario

5.7 Combined measures

5.7.1 Generalities

It has been shown that both goods distribution centres and automatic rent-a-car systems can have a beneficial impact on the emissions in the local city centre environment, as has been shown on the emission plots above. It becomes now interesting of course to combine the two measures, addressing both goods and passenger vehicles through the replacement of legacy with zero-emission technologies.

5.7.2 Scenarios

In a first approach (Illustration 5.49), goods distribution centres (7 centres) are associated with automatic rent-a-car systems (8 stations), without additional toll measures. The impact on the emissions can be clearly seen; for this example, hydrocarbon emissions have been illustrated, the chart scale for which is shown in Table 5.24.
For the city centre, further improvements can be obtained by enforcing toll measures, this is shown in Illustration 5.50. Both figures have to be compared with the reference situtation with only legacy vehicles (Illustration 5.51).

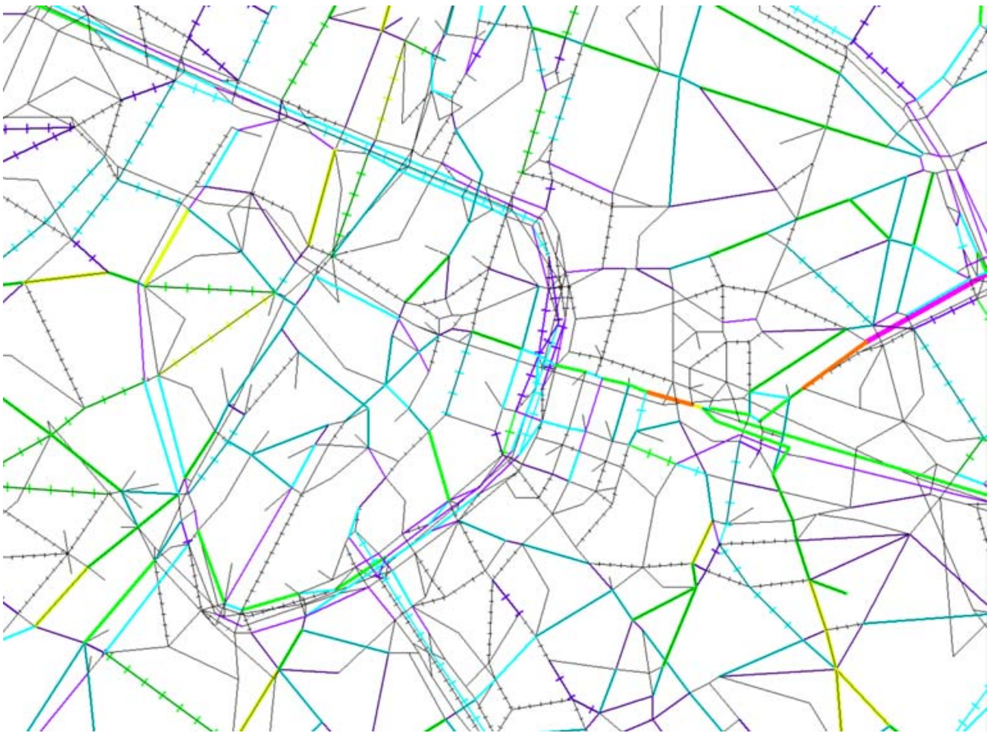

Illustration 5.49: HC reduction – Goods distribution and rent-a-car, reference scenario, no toll

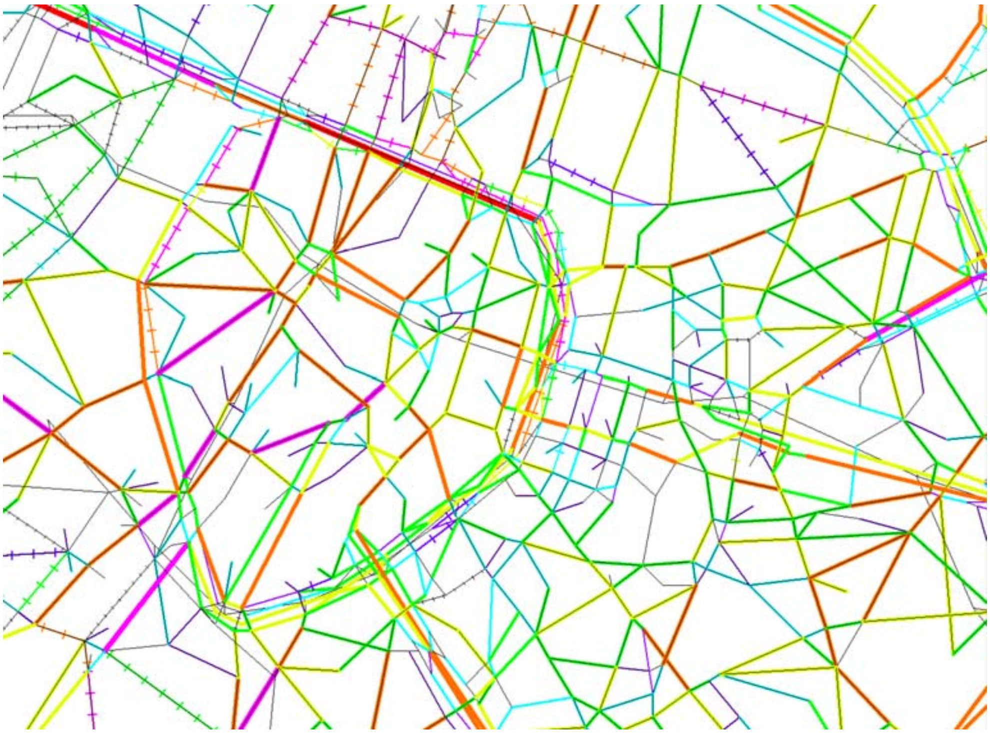

Illustration 5.50: HC reduction - Goods distribution and rent-a-car, reference scenario, toll

Color	***HC (g)***
Black	< 5
Dark blue	5 – 10
Light blue	10 – 25
Green	25 – 50
Yellow	50 – 100
Orange	100 – 250
Pink	250 – 500
Red	500 – 1000
Red (Fat)	> 1000

Table 5.24: HC chart scale

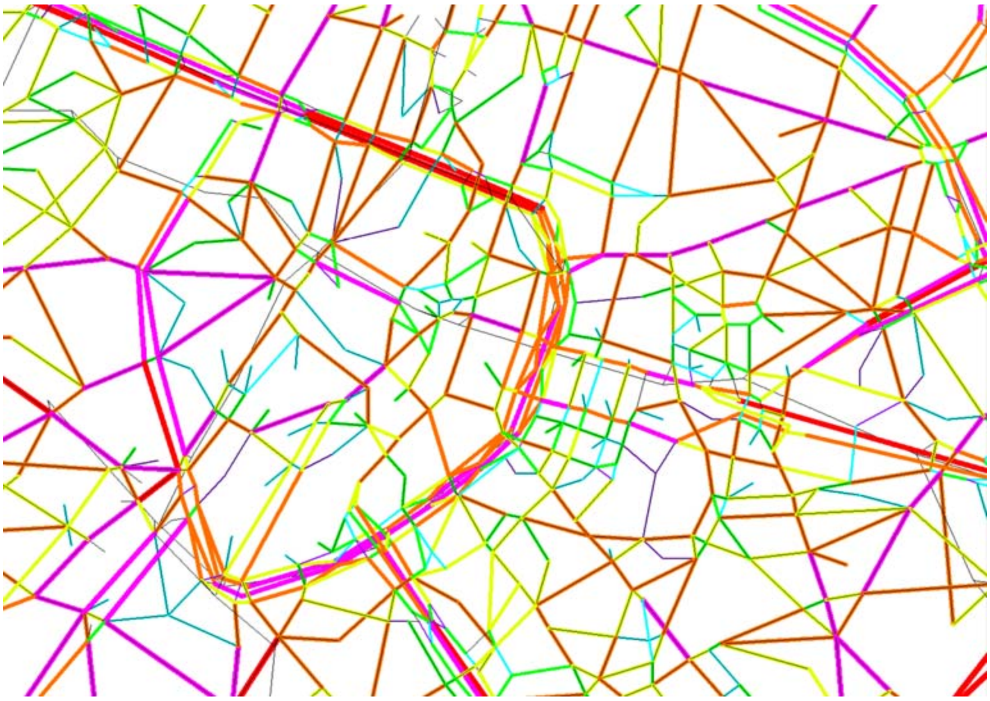

Illustration 5.51: HC emissions (Reference scenario)

The impact on the overall emissions is as follows:

	CO2	CO	HC	NOx	SO2	PM	CH4
Reference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Combined no toll	98.6%	98.6%	98.4%	98.4%	98.6%	98.5%	98.8%
Combined with toll	97.1%	98.1%	97.7%	96.8%	97.0%	96.6%	98.2%

Table 5.25: Emissions – Combined centres and stations with reference scenario

The final scenario to be presented combines goods distribution centres and rental stations with the basic EV scenario and toll measures, allowing a maximum penetration of electric vehicles.

Illustration 5.52: Combined scenario – Thermal cars

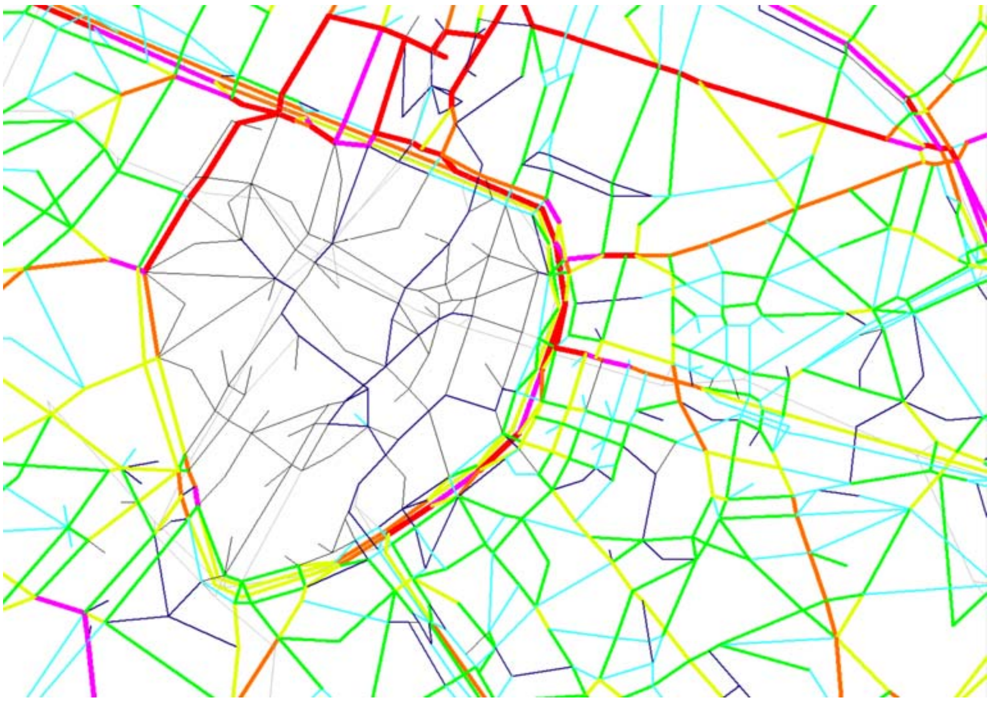

Illustration 5.53: Combined scenario – Thermal cars – city centre

The presence of thermal vehicles is greatly reduced in both the region and the city centre, as shown in Illustration 5.52 and Illustration 5.53, which should be compared with the reference scenario in Illustration 5.8 on page 52.
Emissions are also greatly reduced, as shown in the examples of Illustration 5.54, which shows a clearly reduced CO_2 emission over the whole region, to be compared with Illustration 5.18 on page 59; the eliminated CO_2 emissions are shown in Illustration 5.55. This reduction in CO_2 will of course be reflected in an equivalent reduction in fossil fuel consumption.

Illustration 5.54: Combined scenario – CO_2

The reduction is of course also valid for the other emissions and is particularly obvious within the city centre area, as shown in Illustration 5.56 which shows the reduction in CO. The mutual comparison of the emissions (Table 5.26) shows how the different measures applied together (EV share, tolls, goods distribution, rent-a-car) lead to a synergy which brings down emission levels even further.

	CO2	***CO***	***HC***	***NOx***	***SO2***	***PM***	***CH4***
Reference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Basic EV	81.3%	75.9%	80.4%	84.1%	83.0%	81.6%	81.9%
Combined	71.9%	64.5%	70.7%	75.8%	74.5%	73.2%	73.0%

Table 5.26: Emissions – Combined measures scenario

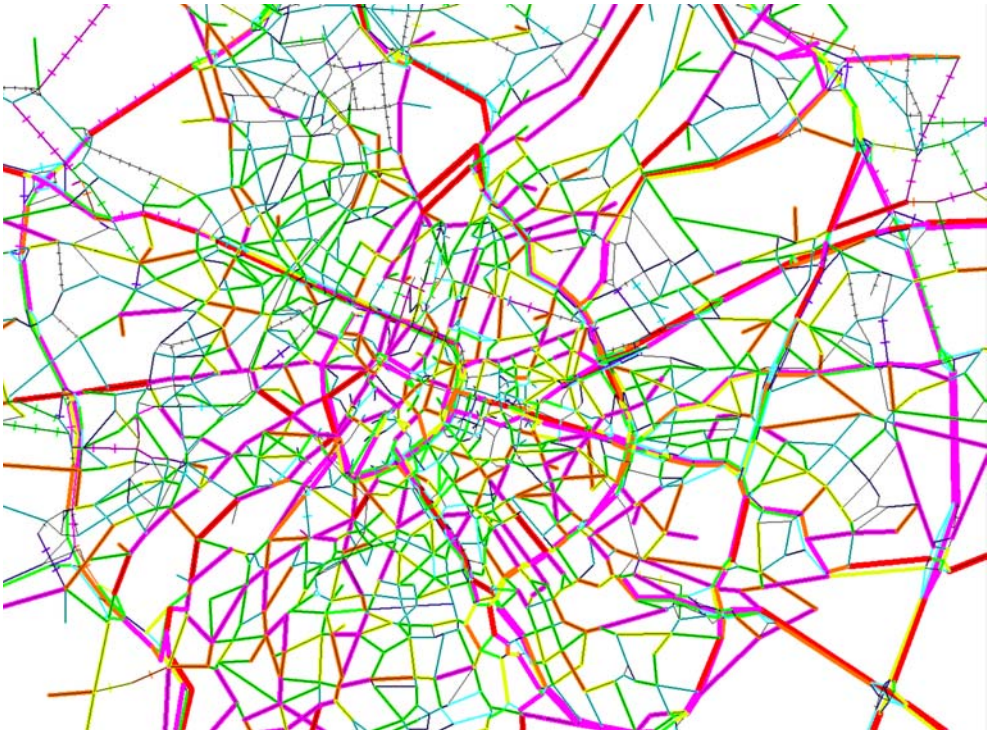

Illustration 5.55: Combined measures scenario – CO_2 reduction

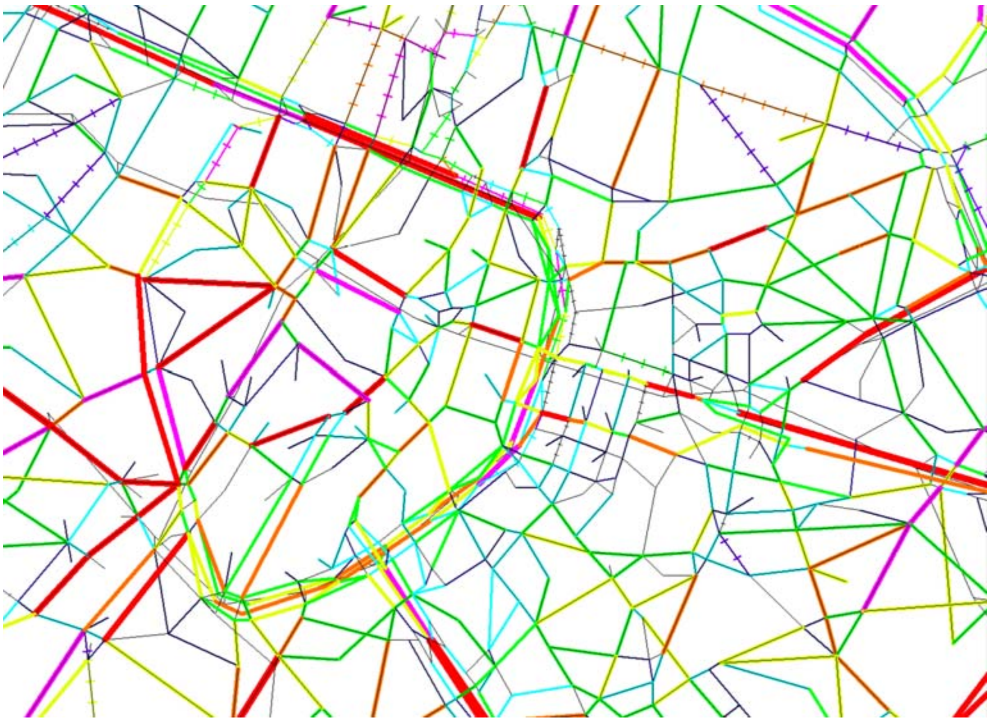

Illustration 5.56: Combined measures scenario – CO reduction

5.8 The problem of the indirect emissions

All statements made in these paragraphs about the environmental benefits of electric vehicles taking into account the local environmental effects on the Brussels Capital Region: the electric vehicles are of course emission-free, and their introduction will eliminate a share of the noxious emissions of thermal vehicles within the territory of the Region, and thus make a considerable contribution to the improvement of air quality. The emissions generated by the use of the vehicles, taken into account up to now, are known as the "tank-to-wheel" or indirect emissions.
To allow a global approach, one should also consider the "well-to-tank" or indirect emissions which are related to energy generating and processing.

For the thermal vehicles, the indirect emissions come from petroleum exploitation, refining and transport. Values for indirect emissions are also generated by the Copert/MEET methodologies.

For the electric vehicles however, the indirect emissions have to be related to the electric generation stations. The actual emissions of these stations vary: some power stations have none (hydro, wind, nuclear), some have few (advanced combined-cycle plants), and some have many (obsolete coal plants). The VSP application has been designed to take into account a varied production mix reflecting the situation in the different European countries and thus allows to relate the electricity consumption of the electric vehicle with emission values from the power stations. One should always take into account however that it is not a straightforward process to link a consumer of electricity to a specific generation plant, in order to make a precise calculation of primary energy consumption and emissions, due to the interconnection on the electric distribution grid.
In this framework, the ongoing liberalisation of the European electricity market offers interesting opportunities, since this allows the consumer to specifically purchase "green" - i.e. zero-emission - current, making the operation possible of vehicles which are zero-emission over all levels.

For the purpose of this study, the current production mix of Belgium has been chosen. It is to be foreseen that the emissions from this mix will decrease during the coming years, due to the replacement of end-of-life thermal stations with state-of-the-art combined cycle plants which have a very high efficiency. The influence on emissions of the planned decommissionning of Belgian nuclear plants will have to be evaluated in function of the future evolution of the energy and fossil fuel markets, which will ultimately decide on the options to be chosen.

In order to make a valid comparison between direct and indirect emissions, it is interesting to consider a hypothetical scenario, where on the same traffic model assignment one one hand a fleet of 100% thermal vehicles and on the other hand 100% electric vehicles are compared. The assignment is the one of the reference scenario, albeit without trucks (for which no zero-emission equivalent is available), and with all private vehicles .

The results of these calculations are given in Table 5.27.

(kg)	*CO2*	*CO*	*HC*	*NOx*	*SO2*	*PM*	*CH4*
Thermal							
Direct	591036.2	5237.7	631.0	2058.0	87.1	138.1	48.4
Indirect	74057.9	46.5	1436.4	358.2	526.5	16.4	151.2
Total	665094.1	5284.2	2067.4	2416.2	613.6	154.5	199.6
Electric							
Direct	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indirect	172350.7	19.2	40.3	247.3	246.7	26.1	4.6
Total	172350.7	19.2	40.3	247.3	246.7	26.1	4.6
%	25.9%	0.4%	1.9%	10.2%	40.2%	16.9%	2.3%

Table 5.27: Direct and indirect emissions

It is clear from this table that, over the whole level, the electric vehicles are responsible for much less pollution, direct as well as indirect, as their thermal counterparts. The use of these vehicles is thus a premier way to make the transition towards sustainable mobility.

6 Conclusions

6.1 Policy Statements

The various simulations performed in the framework of this study have allowed to assess the potential impact of the introduction of zero-emission vehicles within the Brussels Capital Region. First, it has to be made clear that the electric vehicle, besides being effectively zero-emission at the location of its use, presents a net environmental benefit even taking into account the production of electricity. Each and every electric vehicle brought out into the streets will thus contribute to a clean environment.

The evaluation of policy measures to be applied has to take into account the division of transiting and peripheral traffic on one hand, and destination traffic on the other hand, the latter being the prime subject of control measures in the urban area.

Effective control policies will accompany the technological transition to environmentally friendly technologies and will have to be implemented as an incentive to promote their development. The shift away from fossil-fuelled vehicles which will be an inevitable result of the future disavailability of these fuels, can be made a smooth transition through appropriate policies which will prepare the path for sustainable mobility.

For sensitive areas such as city centres, access control measures such as tolls clearly prove their value to relieve the city centre from polluting vehicles.

The principal aim of any policy for the long term will be the promotion of a modal shift from conventional technology vehicles to zero-emission vehicles, the latter taking the principal and preferably exclusive share of the traffic in the most sensitive areas.

One main issue to be addressed is the organization of goods transport and urban distribution, where the environmental ill-effects of heavy goods vehicles can be tempered through the deployment of zero-emission vehicles for the final distribution stage. The concept of urban distribution centres has shown its effect in the underlying study and merits to be expanded further taking into account the full concept of intermodality also encompassing fluvial and rail transport modes.

The largest number of vehicles on the streets remain the passenger cars however, and policies in this field of application will have to promote a modal shift away from the combustion-engined car. The deployment of efficient public transport is the prime policy measure to be taken – the availability of zero-emission vehicles in automatic car rental systems presents however an interesting complementary measure, as it constitutes a kind of “semi-public” transport that can address specific transport needs not covered by existing networks. In order to also address the congestion problem however, the modal shift from thermal vehicles towards other modes of transport, i.e. public transport as well as two-wheel vehicles, is also to be addressed.

Besides their zero-emission capabilities, the ability of electrically propelled vehicles for silent operation is to be mentioned as a particular advantage to improve the quality of the urban environment.

In urban traffic, due to their beneficial effect on environment, electric vehicles are an important factor for improvement of traffic and more particularly for a healthier living environment. The electric vehicle makes use of energy sources which make it particularly suitable for use in urban or suburban areas. As this study has clearly shown, the introduction of zero-emission vehicles brings a considerable improvement to the environmental situation in the Brussels Capital Region by reducing the environmental impact of traffic and the amount of noxious emissions released into the Brussels atmosphere. If Brussels wants to take its role as the “Capital of Europe” with appropriate dignity, it has to set an example for the rest of Europe and for the world in providing its denizens and visitors with a clean environment whilst preserving mobility. The deployment of zero-emission vehicles is an essential step in this direction, becoming not a mere policy measure but a moral duty.towards the future of humanity, which can not rightfully be evaded.

6.2 Research Opportunities

The underlying research project has allowed to develop a powerful instrument to analyze the influence of different kinds of vehicles on urban traffic and more particularly on the urban environment. The chosen approach, making use of both a well-proven and widely used traffic simulation package and a proprietary vehicle simulation programme has allowed for a close integration of all aspects.
One of the most powerful features of the software is the opportunity to simulate in an easy way a variety of scenarios, both considering the composition of the vehicle fleet and considering the implementatios of various policy measures.

The instrument suits itself for further development in the field. Particular issues for further development include:

- The precision and the relevance of traffic simulation depends primarily on the available traffic data. A revision of the origin-destination matrix for the Brussels Capital Region would allow to update the model. A further specialization of this matrix (considering different transport modes and vehicle types) would allow to extend the flexibility and power of the model.
- The methodology has been proven and can be implemented on any location, providing the availability of origin-destination matrix and network data. The

widespread use of the TRIPS software package for traffic planning application is a further advantage in this field.

- Static emission data can be updated when new information from European research programmes such as ARTEMIS comes available.
- The integration of other transport modes would enhance the comprehensive approach of the model. Two-wheelers have already been provided for in the software and can be implemented when appropriate origin-destination matrixes are available. As for public transport, the software has already provisions for describing buses (with different kinds of drive train), and it could also take into account other modes like tram or metro in order to allow the assessment of different modal shifts. The same approach can be taken for goods transportation, where the concept of intermodality enjoys a growing attention.
- A performant package for vehicle simulation has been developed. Its operation however is strongly dependent on the availability of suitable data about drive train topologies and about their components. It is foreseen to further develop the model to include new topologies such as fuel cell vehicles and advanced hybrids, both of which can contribute to significantly lower transport emissions. One of the greatest challenges in this field is the gathering of suitable data about component efficiencies.

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See next page

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