Integrated Modelling of the Urban Development, Mobility and Air Pollution Analysis in the Brussels Capital Region:

Policy Measures Based on Environmentally Friendly Vehicle Technologies

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Abstract

The general objective of the described 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 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. The research project integrates transport aspects with energy and environmental aspects.
The various simulations performed in the framework of this project have allowed to assess the potential impact of the introduction of zero-emission vehicles within the Brussels Capital Region (B.C.R.). 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.
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.

Keywords: simulation, environment, emissions, pollution, city trafic

1 Introduction

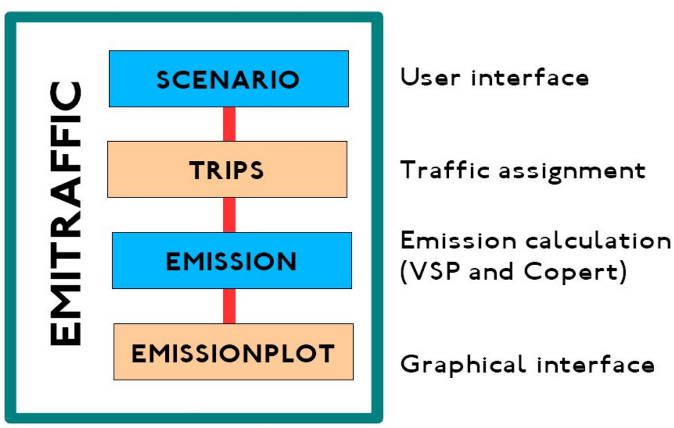

Figure 1: Overview of the simulation tool

The simulations in the framework of this project have been performed with “EmiTraffic”, a package developed at the Vrije Universiteit Brussel which integrates vehicle simulation software (VSP) [1], static emission models (Copert/Meet) [2,3] with traffic simulation (Trips/Cube). An overview of the simulation tool is given in Figure 1. The methodology used is explained in another EVS-21 paper [4], whileas this paper will concentrate on the simulation results.

2 Overview of the current situation

The first part of the simulation took 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.
This scenario is considered the reference scenario
Figure 2 gives an overview of traffic density in the whole region (considering the one hour reference period in the morning peak). 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 (Figure 3) to notice that even within the city proper, large concentrations of vehicles can be discerned in certain areas. The colour code for these figures is given in Table I.

Figure 2: Total traffic, 2003 situation (reference scenario)

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

Table I: Vehicle density chart scale

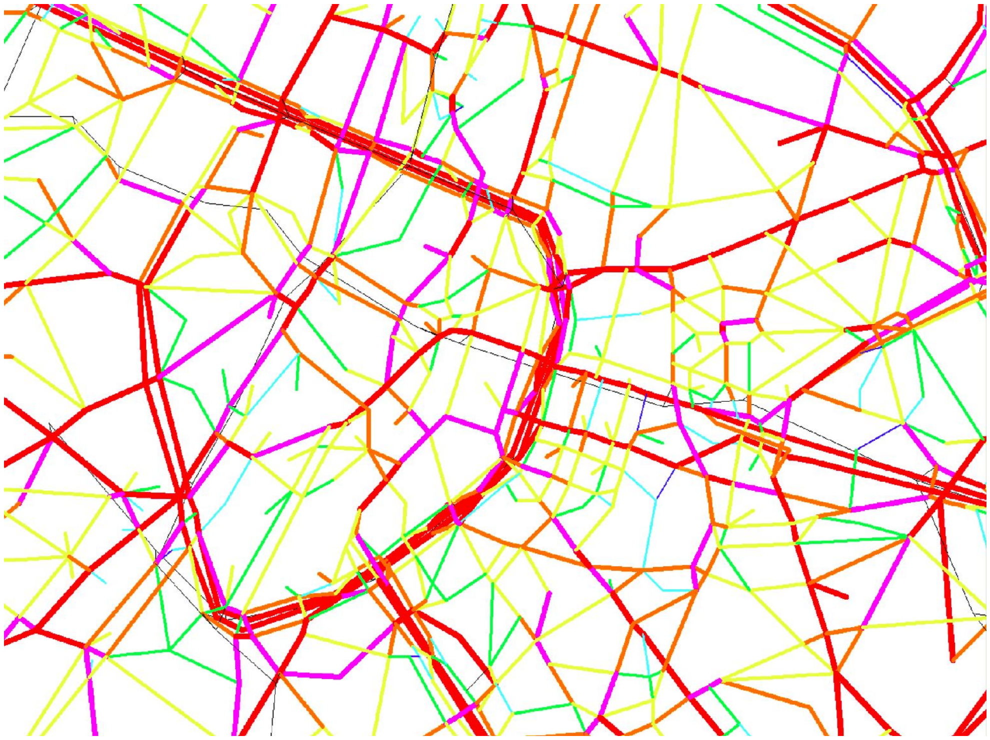

Figure 3: Total traffic, city centre (reference scenario)

In order to calculate the global impact of the emissions on the Brussels environment, one can make a total summation over the whole network, as shown in Table II.

	CO_2	CO	HC	NO_X	SO_2	PM	CH_4
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 II: Global emissions (reference scenario)

The “peak” values correspond with the results as calculated in the 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
* weekends and holidays are discounted, one year emissions equalling 300 working days.

Within these values, the largest impact (e.g. 64,4% for CO_2) will be created by the peripheral and transiting traffic. 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.

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 vehicles which are considered more efficient and environmentally-friendly. Taking the reference scenario and extrapolating for traffic growth towards 2005 and 2010, taking into account forthcoming more stringent emission regulations, one can note the following trends however:

- the CO_2 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.

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

3 Introduction of a share of zero-emission vehicles

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.

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 vehicles driving longer distances driving from out of the region), 95% to vehicles originating in the city centre and the remainder to suburban vehicles (i.e. the B.C.R. area minus the city centre), as to come to an overall 30% ratio. The vans are treated similarly. This scenario is called here the “basic EV scenario”.

One can see in Table III the impact of the deployment of these vehicles compared with the reference scenario..

	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 III: Direct emissions – Basic EV scenario.

The impact on the city centre becomes clear if one visualises the emission reduction.
For the emissions in the city centre, shows the reduction in NO_x emissions in the city centre obtained through this scenario. Scale is as in .

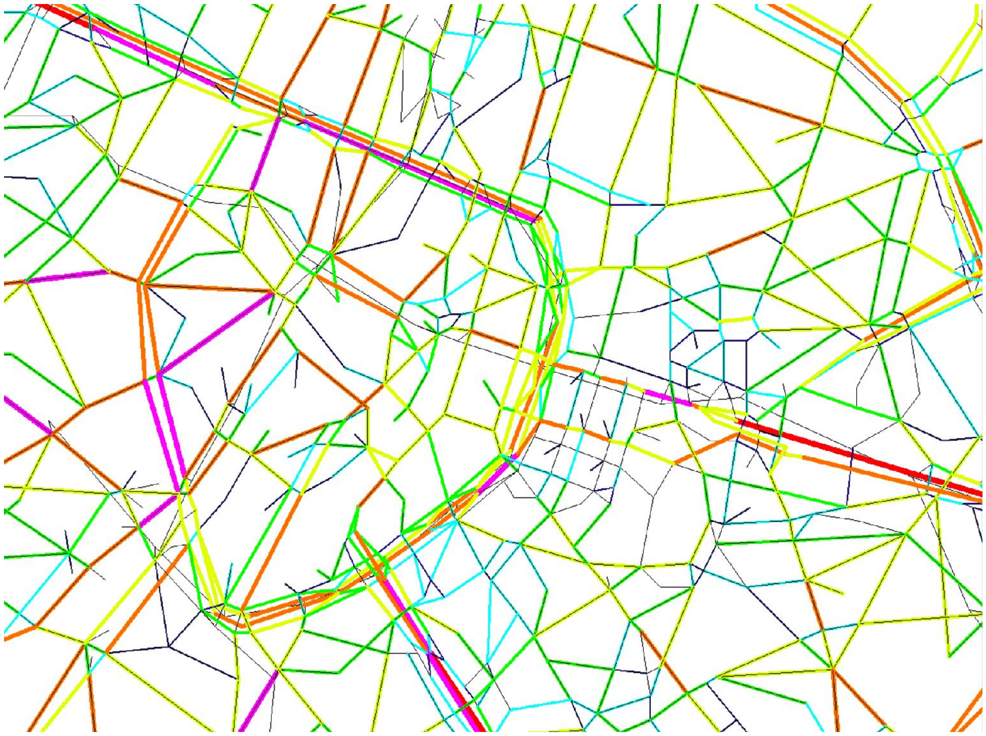

Figure 4: NO_x reduction with basic EV scenario

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

Table IV: NO_x chart scale

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.

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.
One can now assess the influence of these measures on the total emissions produced. Due to the large amount of transiting traffic, the influences will be limited compared with the scenarios without measures (basic EV scenario and reference scenario). One should also note that in some cases outside of the city centre, 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 being 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. 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. In the sensitive area which is the centre these measures do have a considerable impact as is shown in Figure 5 which shows the NO_x emissions as an example, for the case with the city centre closed, and the reference scenario without electric vehicles. The hatched 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 IV.

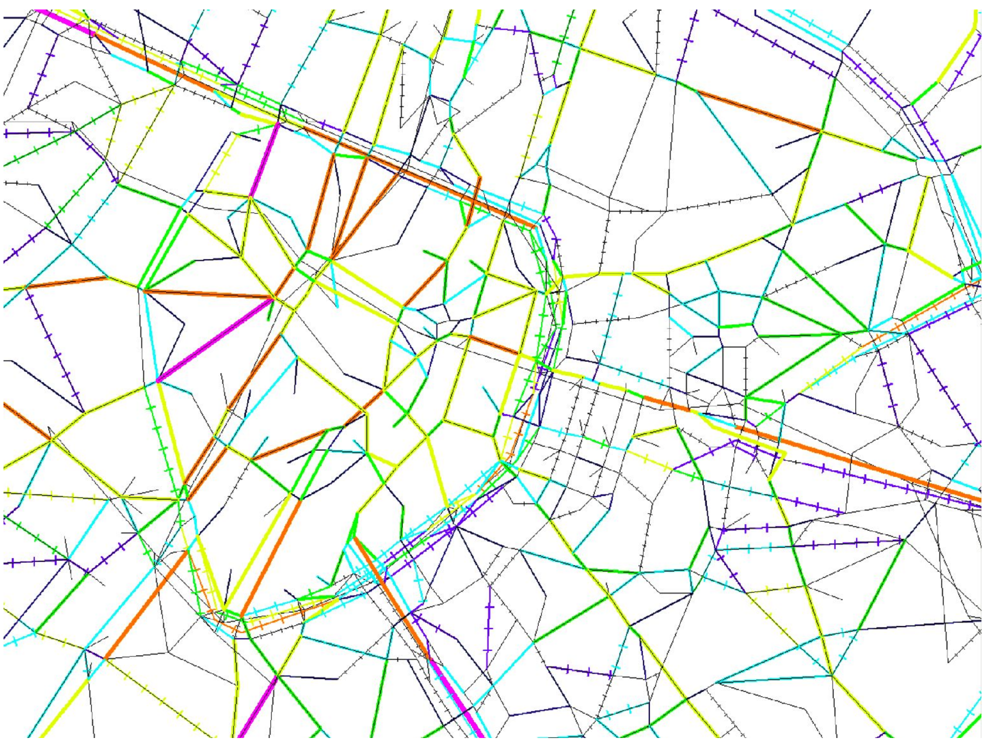

Figure 5: NO_x reduction – City centre closed – Reference scenario

5 Goods distribution

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.

At first, the goods distribution systems were implemented on the reference scenario, where only legacy technologies are used. The model will introduce zero-emission vehicles for the distribution trips in all cases where it deems that the “cost” of the trip can be minimized this way. The same principle is used dealing with thermal vans, part of which will be displaced too.

By developing distribution centres without imposing any further access restrictions or tolls, a number of zero-emission vehicles is already appearing, the cost difference mainly due to reduced congestion by heavy vehicles. To enhance the participation in the scheme, toll measures for thermal vehicles have been implemented in order to provide the incentive for the goods transportation vehicles to transfer to a zero-emission vehicle. Figure 6 shows the penetration of the electric distribution vehicles, with seven distribution centres in use, and tolls applied to thermal vehicles. (Colour code as in Table I)

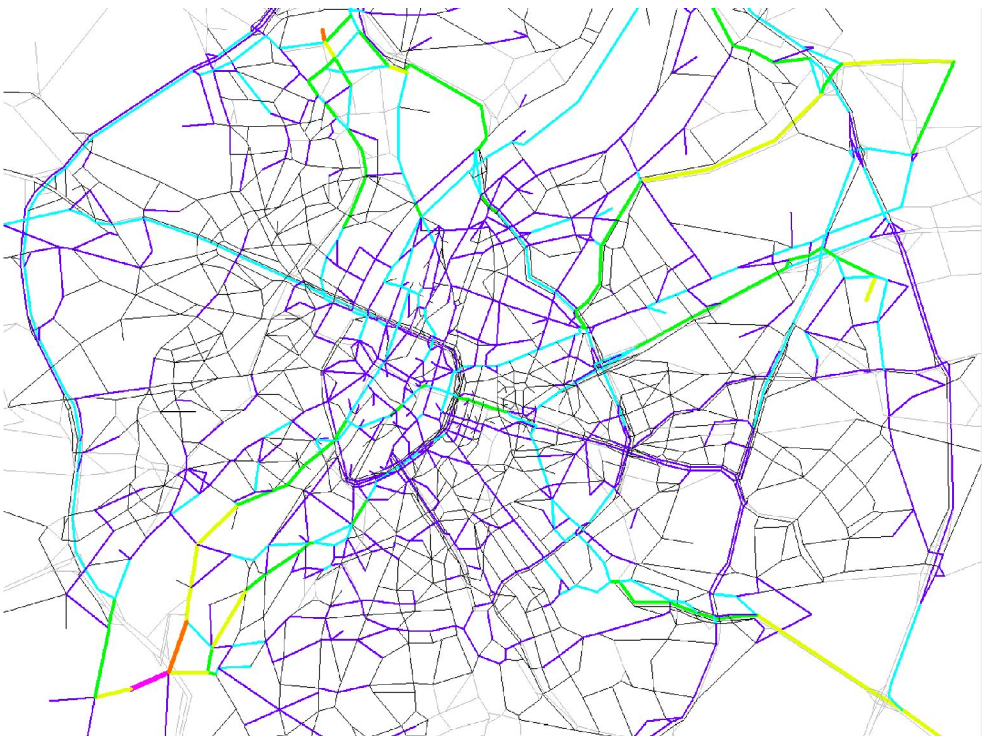

Figure 6: Electric distribution vehicles – 7 distribution centres – tolls applied

The scheme has a local impact on emissions, by removing polluting vehicles from the city centre. For the overall region however, the impact on the emissions (and on the fuel consumption) is rather limited, considered over the whole region. This is due to the large significance of peripheral and transiting traffic on the whole region.

6 Rent-a-car stations

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, 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 B.C.R. area.
At first, the rent-a-car systems have implemented on the reference scenario, where only legacy technologies are used. The number of vehicles participating into the system vehicles can be further enhanced by implementing tolls to enter the city centre. Figure 7 shows the electric vehicles in the city centre with 8 rent-a-car stations and tolls applied (Colour code as in Table I). One can clearly see the concentration of electrics emanating from the station locations (e.g. North station in the upper part of the graph).

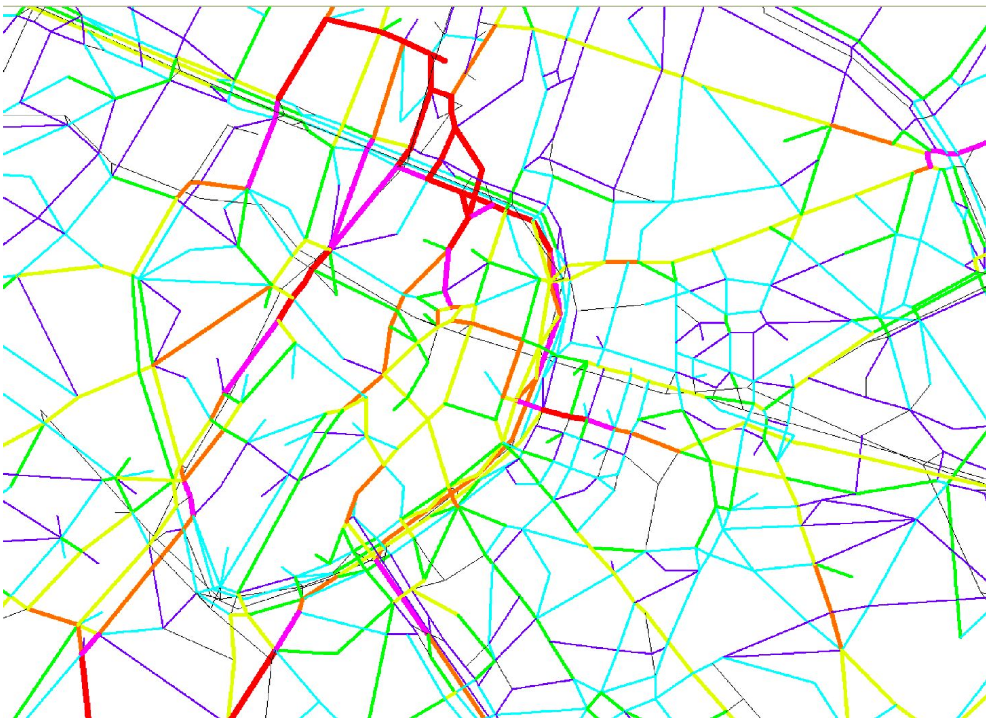

Figure 7: Electric rent-a-car vehicles in city centre – 8 stations – tolls applied

The introduction of these vehicles into the city centre will of course reduce local emissions.
The main impact of these measures will again be located in the city centres.

7 Combined measures

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.
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.
The presence of legacy vehicles will be greatly reduced particularly in the city centre, as shown in Figure 8, which should be compared with the reference scenario in Figure 3.

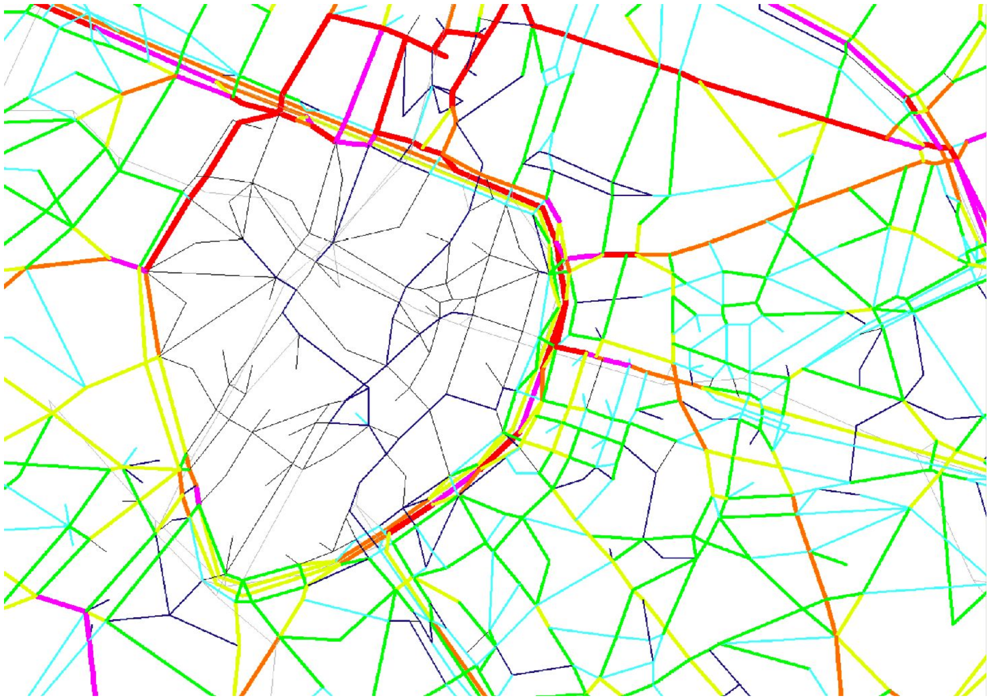

Figure 8: Combined scenario – Legacy vehicles in city centre

Emissions are also greatly reduced as shown in Table V. The mutual comparison of the emissions 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 V: Emissions – Combined measures scenario

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 decommissioning 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 on 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 VI.

(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 VI: 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.

9 Conclusions

9.1 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.

In this framework, an interesting contribution to promote the deployment of zero-emission vehicles can be offered by associations like CITELEC [5] which address local authorities in order to inform them about the opportunities of electrically propelled vehicles and to provide them with technical advice on vehicle performances and associated infrastructure, as well as assisting them with the participation in European research and demonstration programmes.

9.2 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 implementations of various policy measures.

10 Acknowledgment

The paper is based on a research project entitled “Integrated modelling of the urban development, mobility and air pollution analysis in the Brussels-Capital region: Policy measures based on environmentally friendly vehicle technologies”, financed in the framework of “Prospective Research for Brussels” and carried out by Vrije Universiteit Brussel. [6]

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