Ecoscore, an Environmental Rating Tool for Road Vehicles

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Abstract: - This paper reports about an environmental rating tool, called Ecoscore, which was developed for the Flemish government (Belgium) for use as a policy tool and to stimulate the use of cleaner vehicles. This ranking tool integrates different aspects of the environmental impact of road vehicles into a single indicator and allows comparing vehicles with different fuel uses or with different drive trains. The Ecoscore methodology is based on the level of emissions into the air of several pollutants and integrates different damage categories like: global warming, human health impairing effects and harmful effects on ecosystems. The environmental performance is determined on a "well-to-wheel" basis and allows an objective comparison of different propulsion systems (internal combustion, battery or hybrid electric…) or of vehicles running on different fuels (petrol, diesel, LPG, CNG...). Further, this methodology is not only applicable on conventional passenger vehicles, but also on heavy duty vehicles (trucks, busses…) and alternative vehicles and even on two-wheelers. The use of the Ecoscore methodology will be illustrated in this paper by the comparison of a selection of old and new passenger cars, conventional cars and alternative cars. Also the ranking of a set of different busses has been made. Comparisons between alternative and conventional vehicles have been elaborated, and the evolution of the environmental performance of vehicles due to more and more stringent type approval classes has been analyzed. It can be concluded that the Ecoscore allows a clear assessment and an environmental rating of individual vehicles.

Key-Words: Ecoscore, Transportation, Environmental impact, Emissions, well-to-wheel, alternative vehicles, policy tool, sustainable mobility.

1 Introduction

Based on global observations of important tropospheric pollutants [1], the densely populated area covering the northern part of Belgium and the southern part of The Netherlands appear to be one of the most polluted regions of the world, after Northern Italy and the north-eastern part of China. Nowadays environmental pollution is an issue that causes great concern, not only on a local, but also on an international and even on a global level. Tackling the air pollution problems forms a unique challenge. Persons and goods transportation causes an important part of the emissions of atmospheric pollutants [2]. It is essential to understand the correlation between transport and environment to be able to tackle transportation's negative impacts [3]. To reduce harmful emissions due to the transport sector, efficient policy measures have to be implemented by the relevant authorities, especially in strongly urbanized regions. The introduction of 'clean vehicles' is one of the most promising potential measures policy makers have at their disposal for energy use reduction and for cutting down pollutant emissions [4]. In this context the question: "*Which vehicles are most environmentally friendly?*" remains a key issue [5]. A comprehensive and transparent methodology has been developed with the aim to compare the environmental burden caused by vehicles with different drive trains and using different fuels. This paper describes shortly the methodology of a pragmatic environmental rating tool. This tool is called *EcoScore* and was developed for use by the Flemish government. *Ecoscore* is going to be integrated in a consistent policy for the promotion of cleaner vehicles in Belgium. Implementation pathways for a comprehensive and goal reaching policy should be based not only on the analysis of the environmental impact but also on the barriers for purchase and use of road vehicles (technical, economical, market related, legislative and regulatory, psychological and institutional barriers). Fiscal measures for instance, should be based on the "polluter-pays" principle [6]. The Ecoscore methodology can be used as a basis for these policy tools. It is based on two other environmental rating systems: "Clean Vehicles" and "Cleaner Drive" described in previous publications [7,8,9]. The Ecoscore methodology includes knowledge of the state of the art impact factors and emission data. An important boundary condition of the methodology was that the rating method needed to be applicable to all Belgian road vehicles (passenger cars, vans, trucks and buses as well as motorised two-wheelers). Consequently three similar environmental ratings were defined, corresponding to three vehicle categories defined by the Council Directive (Directive 92/53/EEC): light duty vehicles (passenger cars and vans, M1 and N1), heavy duty vehicles (medium and heavy trucks and busses, N2, N3, M2 and M3) and two-wheelers (L1-L6).

2 Environmental assessment

Different systems exist to define the level of "environmental friendliness" of vehicles and are used for policy measures today: these systems are based on the type of fuel (e.g. CNG, bio-diesel…) or the type of propulsion (e.g. hybrid cars, electric cars…) or are based on the level of CO_2 emission or on the homologation category (e.g. Euro 4, Euro 5…). These approaches are, however not sufficient to describe the complete environmental impact of the vehicle nor to make a full comparison between different alternatives.

With the Ecoscore methodology, different damage-categories are taken into account. The effects of Global Warming account for 50% of the end-score, effects on the human health for 20%, effects on the ecosystems for another 20% and noise pollution for the remaining 10% (see Figure 1).

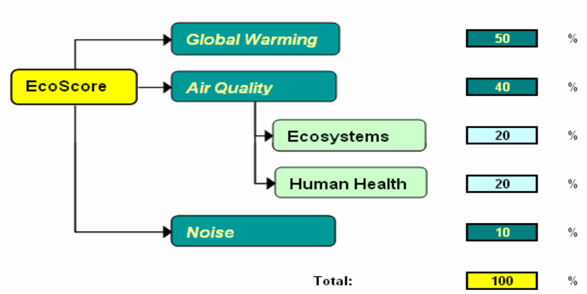

Figure 1: Damage categories weighting Ecoscore

The contributions to the separate damage-effects of the different pollutants considered are calculated based on respectively GWP's (Global Warming Potentials), external costs (for both Human Health and Ecosystems) and decibels. This environmental assessment allows combining the different effects into a single indicator. The Ecoscore is expressed by a number between 0 and 100, were 100 corresponds to the highest possible environmental friendliness. The methodology is based on a "well-to-wheel" analysis. This means that next to direct (tailpipe) emissions, which are produced during the time the vehicle is driven around, also indirect emissions (formed during the production and distribution of the fuel) are taken into account. A short overview of the Ecoscore methodology will be given in the following section of this paper.

3 The Ecoscore methodology

The assessment of the environmental rating system is based on a "five-step" scheme, similar to that used in a Life Cycle Assessment. Each of these five steps will be described shortly in this paragraph.

The first step of the five-step LCA approach is the inventory phase. As mentioned above, a well-to-wheel framework was chosen, comprising tailpipe emissions and emissions proportional to the emissions needed for the transport and production of the fuel consumed by the vehicle. A large number of factors influence the vehicle's tailpipe emissions and fuel consumption. The most important factors are the vehicle's drive train technology and the vehicle's accessories, the traffic situation and the driving behaviour [10]. Furthermore, aging effects of the motor can result in an increase of the emission levels of vehicles over time. Inclusion of 'in use compliance' to homologation directives (cfr. 98/69/EC) could ensure that emission limits are respected for a longer time of operation of the vehicle. These variations make it very difficult to compare vehicles with each other. Type approval emission values can present some differences as compared to real vehicle emissions, but provide a common evaluation basis for all vehicles to be assessed. Because this methodology will be used as a policy tool, it is important to use emission data that are available for all individual road vehicles. Direct emissions are linked to the use of the vehicle itself. Each vehicle sold on the European market has to be compliant with the type approval test. These tests give information about the so called regulated emissions: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X) and, in the specific case of diesel vehicles, particulate matter (PM).

In the case of passenger vehicles and light-duty vehicles (M1 and N1) these emissions are expressed in grams per kilometre. For heavy-duty vehicles (M2, M3, N2 an N3) emission levels are expressed in grams per delivered kilowatt-hour. The latter emissions are evaluated on the level of the motor of the vehicle. The emissions and consumption of the vehicle (per kilometre) will thus further depend on the different applications (the same motor can be used in different types of vehicles).

Besides the regulated emissions, some unregulated emissions are considered as well: carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrous oxide (N_2O) and methane (CH_4). Both carbon dioxide and sulphur dioxide can be calculated starting from the fuel consumption.

The Ecoscore methodology now encompasses three main damage categories: Global Warming, Air Quality and Noise. The damage category Air Quality is subdivided into: Human Health effects and effects on Ecosystems.

Step 2 of the assessment consists in the classification of the different pollutants in function of the damage to which they contribute. A schematic overview of step 1 and 2 is given in below.

Step 3 of the assessment consists of the characterization of the damage. Depending on the considered damage category, different impact factors were used for the characterization of the damage due to both the indirect and direct emissions. The contributions of the different green house gasses to global warming are calculated using global warming potentials (GWP), as defined by the IPCC. External Costs were used to allocate a weighting to the different inventoried air quality depleting emissions affecting human health and ecosystems. These external costs are based on the EU ExternE project [11] with updated values, baseline 2000 [12]. These external costs are values expressed in monetary terms per kilogram of emission of a certain pollutant, and reflect the overall damage cost to human health.

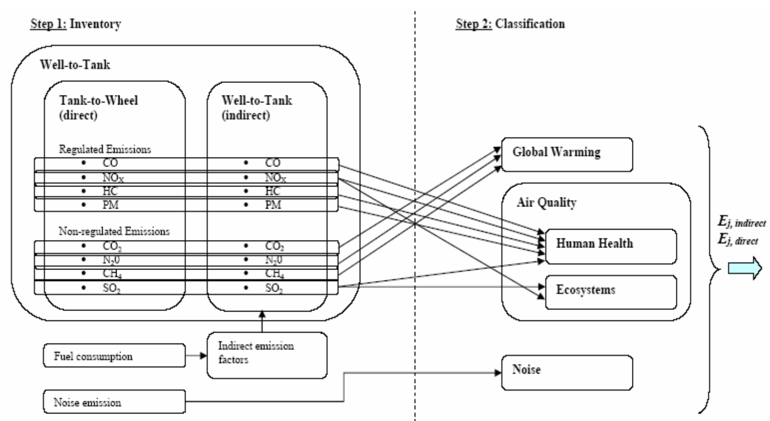

Figure 2: schematic overview of step 1 and step 2 [14]

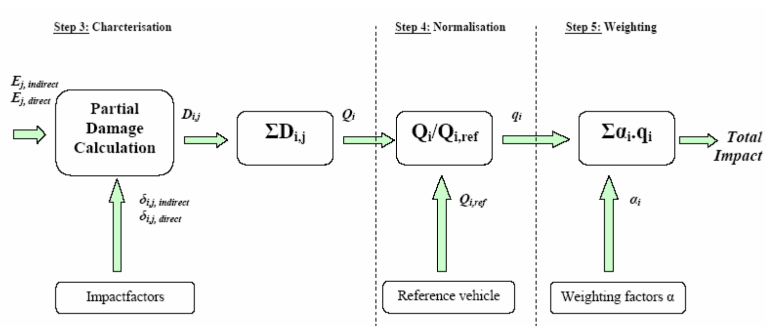

Figure 3: schematic overview step 3, 4 and 5 [14]

In order to measure the relative extent of the different damages, the formerly evaluated damage is being normalized according to a specific reference value for each category of damage. This is step 4 of the assessment. In this way, it becomes possible to compare the damage caused by the vehicle to be assessed, with a reference situation.

The final stage, step 5, of the assessment consists of weighting the normalized damages before adding them in order to have a final environmental score.

This result is called the 'Total Impact'. Steps 3 up to 5 are shown schematically in .

For communication purposes, the result, namely the total impact, is further converted to a rating between 0 and 100. 0 is representing an infinitely polluting vehicle and 100 indicating an emission free and silent vehicle. The reference vehicle corresponds to an Ecoscore of 70. The transformation is based on an exponential function and it can not deliver negative scores. More details on the Ecoscore methodology can be found in references [15,16].

4 Ecoscore of passenger cars

In this paragraph, the Ecoscore methodology is illustrated by the assessment of a set of passenger cars. Vehicles with different fuel uses and drive trains were selected.

Table 1: Well-to-wheel emissions, energy efficiency and Ecoscore of passenger cars

	CO_2	SO_2	NO_x	HC	PM10	Energy consumption	Ecoscore
	(%)	(%)	(%)	(%)	(%)	(%)	
Petrol Euro 4	100	100	100	100	100	100	**64,5**
diesel Euro 4	78	56	171	26	421	72	**63,2**
LPG Euro 4	93	54	90	41	68	105	**69.5**
CNG Euro 4	77	25	28	24	34	110	**75,8**
Hybrid Euro 4	67	61	39	54	61	61	**75,8**
Battery Electric	27	43	38	1	132	67	**85,3**

gives the comparison between a petrol vehicle (set as reference) and other types of vehicles who all comply to the most recent emission regulation, Euro 4 (in application since January 1st, 2005) and having a comparable engine capacity (1600cc). Emissions, energy consumption and the Ecoscore have been analyzed for these vehicles. Diesel vehicles seem to score well on CO_2 emissions, but are much less favourable at the level of emissions of PM_{10} and NO_X in comparison to petrol vehicles. The selected LPG and CNG vehicles, as well as the hybrid vehicle, have lower emission levels than the petrol vehicle. Electric vehicles can result in a very large reduction of emission levels, except for PM_{10} emissions. Well-to-wheel PM_{10} emissions are even slightly higher than for the petrol vehicle, but still a lot lower than for the diesel vehicle.

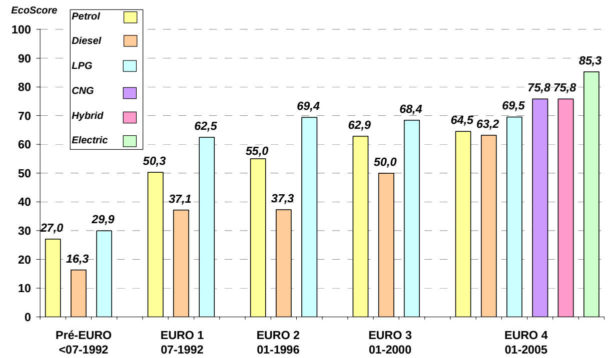

Figure 4: Ecoscore of old and new passenger cars

In Figure 4 one can see the Ecoscore of a set of vehicles with different ages and fuels or drive trains. Next to the emissions from , the pollutants CH_4, N_2O and CO, as well as noise pollution are also taken into account for the calculation of the Ecoscore. The better the environmental performance of a vehicle, the higher the Ecoscore.

From and Figure 4, a very favourable Ecoscore can be observed for the battery electric vehicle (Peugeot 106 electric). This result has been confirmed by other international studies [17]. For the calculations, indirect emission data related to the average electricity production mix for Belgium have been used. When only electricity originating from combined cycle gas turbine (CCGT) plants would be considered, the Ecoscore would even increase up to 85,7 points. If only renewable energy sources would be used to recharge the electric vehicle, the Ecoscore reaches 96,7 points. The electrical vehicle keeps its advantage in the three cases. Also the hybrid vehicle (Toyota Prius) and vehicles on natural gas (Opel Astra) have a high score. The LPG vehicle (Opel Vectra) has the best score among the vehicles with conventional fuels. The petrol vehicles and diesel vehicles have a comparable Ecoscore. One can also observe the positive evolution through time, due to the implementation of the successive emission regulations. Also the noise emissions were lowered because of the more and more severe regulations. The average emissions of CO_2 of vehicles is related to the fuel consumption and is not necessarily improving with time. The positive effect of improved motor technology is often cancelled by an increase in vehicle mass or an increased energy consumption of on-board accessories, such as airco-systems [18]. The new generation of diesel vehicles seems to have caught up with the petrol vehicle, as far as its environmental performances are concerned. Also the difference between these latter vehicles and LPG vehicles became smaller over time.

Further, Figure 4 clearly shows the positive evolution of the environmental performance of vehicles over time. However, within a certain class of vehicles, in other words for a specific year of manufacturing, large differences in the Ecoscore are possible. Vehicles with larger energy consumption (e.g. sports utility vehicles) have a much lower score compared to vehicles with an average or a low energy consumption. Consequently a Euro 4 vehicle doesn't necessarily have a better score than a Euro 3 vehicle.

5 Ecoscore of urban buses

Public transportation can largely contribute to the improvement of transportation's sustainability, in particular in an urban context. Recently, a study has been performed for the Brussels' Public Transportation Company (MIVB-STIB) to assess the environmental performance of conventional and alternative propulsions for urban buses. Based on available data from conventional and alternative propulsions, an assessment of the environmental performance has been made [19,20].

As mentioned before, the basic Ecoscore methodology for heavy-duty vehicles is assessing the engines of the vehicles. When one wants to assess complete buses, this method needs to be extended. The adaptations made to achieve this goal, mainly concern the direct emissions of the buses. The fuel consumption of the buses is known (expressed per 100km) and indirect emissions can be obtained by simply multiplying the fuel consumption by the indirect emission factors, just like in the passenger cars methodology. However, we still need to convert the direct emission data expressed in grams per kilowatt-hour into values expressed in grams per 100 kilometer. This is achieved by calculation, using an average efficiency of the motor and the energy content of the fuel used [19]. In the optimal area of the efficiency map, the efficiency of a diesel engine is around 40%. At partial load, the efficiency is lower. After a discussion with the Brussels Public Transportation Company (STIB-MIVB) and VITO, it has been decided to define engine efficiency at 35% for diesel buses and 30% for CNG buses. This seems realistic when taking the increase in efficiency obtained by the automatic gearbox into account as well as given the fact that in urban areas the engine often runs at full load.

To include wear out of the engines and the reduction of their emissions performances, a yearly 3% wearing factor has been introduced for some pollutants (CO, HC and PM). Regarding NO_X on the other hand, wearing out didn't seem to influence the emissions [21].

A number of diesel, compressed natural gas (CNG) and diesel-electric buses have been selected from the fleet of the Brussels public transport company. An overview of some important characteristics of these buses is shown in Table 2. Please note the capacity is based on a theoretical number of 4 places per m^2.

Table 2: Characteristics of analyzed buses

Code	Production Year	Emission Standard	Capacity	Propulsion system	Urban use consumption
A	1991	Euro 0	69	Diesel	49,91 L/100km
B	1993	Euro I	67	Diesel	46,39 L/100km
C	1994	Euro I	67	CNG	86,43 Nm^3/100km
D	1996	Euro II	65	Diesel	47,46 L/100km
E	1999	Euro II	44	Diesel	38,55 L/100km
F	2000	Euro II	36	Diesel-Electric	38,01 L/100km
G	2001	Euro III	98	Diesel	69,16 L/100km
H	2006	Euro IV	65	Diesel	48,51 L/100km
I	2006	Euro IV	98	Diesel	68,20 L/100km

As an illustration of the adapted methodology, calculations are described in detail for bus A.

Bus A was built in 1991. If the fleet of 2004 is to be analyzed, the type approval data of CO, HC and PM are thus to be increased by 39% (13 years old bus x 3% / year). The average consumption of this bus in duty is 49,91 L/100km. As the efficiency of a diesel engine has been set to 35% and the energy content of diesel is 9,80 kWh/L, the emissions in g/100km from the emissions in g/kWh are obtained through multiplication with a factor 171,154kWh/100km (= 49,91 L/100km x 9,80 kWh/L x 0,35).

The Ecoscore of different types of diesel, CNG and diesel-electric buses, ranging from Euro 0 to Euro 4 emission standards and from 36 to 98 passengers, have been calculated. The construction years of these buses range from 1991 to 2006. The emission data used for assessment were based on type approval data, except for the Euro IV for which the data where based on the emission limits. This is due to the fact that these buses were not delivered yet, when performing this study (so no type approval data were available yet), but have to be compliant with the Euro IV emission standard.

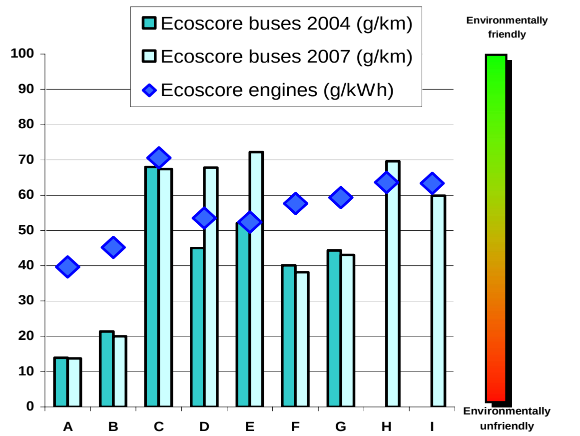

Figure 5: Overview of the buses Ecoscores (for 2004 and 2007) and of the engines Ecoscores [20]

The results of the assessment are shown in Figure 5. The Ecoscores for both the years 2004 and 2007 are represented. As an illustration, the Ecoscores of the engine (independent on the type of bus) are shown as well. The Ecoscores of buses A, B and C just evolve due to the wear out of the vehicles. It is noticeable that a relatively old CNG bus (C) performs quite similarly to a recent diesel bus (H). Apart from these conclusions, it can be stated that there is a general positive evolution of the environmental performances while the type approval emission limits are getting more stringent. As far as buses D and E are concerned, the improvement of their environmental performance from 2004 to 2007 is due to the application of catalytic particle filters.

$$Ecoscore\_incl.\_capacity = \frac{Ecoscore\ of\ Bus\ X}{Capacity\ of\ Bus\ X} \qquad (1)$$

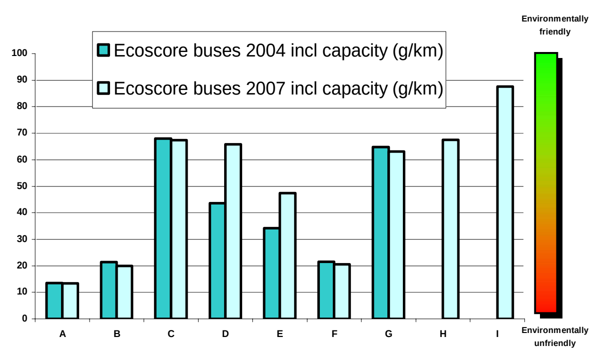

Figure 6 : Ecoscore of the buses for 2004 and 2007 including capacity [20]

When including the capacity of the buses in the analysis using equation 1 (see Figure 6), buses presenting a higher capacity (articulated buses, G and I) have a lower impact per passenger than the other ones. On the other hand, the environmental performance of buses presenting a lower capacity (buses E and F) drops when compared to the other, bigger buses.

The newly developed methodology has also been used to assess the environmental performances of different alternative bus technologies (diesel, diesel-electric, natural gas, hybrid, battery and fuel cell electric). This analysis allows concluding that the electric traction shows great potential for reducing the environmental burden of public transport. The most environmentally friendly technologies are the battery and trolley electric buses, especially when electricity is produced using renewable energy sources. Further, this analysis showed that modern and well tuned CNG buses are performing nearly as well as a hybrid diesel bus, and so scores very well in the category of buses with thermal engines. These CNG busses could score even better when used with a hybrid electric drive train. These buses could also use biogas (for example biogas produced in a municipal water treatment installation), and this could even increase the environmental score. Finally, the average yearly mileage of the different buses should be taken into account as well to allow optimal fleet management [19].

6 Conclusions

When comparing the Ecoscores from the different assessed Euro 4 passenger cars, the electric drive-train seems to have an important advantage on the level of environmental impact. The latter is true, in particular for the battery-electric car, but also for the hybrid vehicle, where the electric motor is combined with a thermal engine. Further, the energy efficiency of these drive trains is high compared to the other (conventional) technologies. CNG and LPG vehicles have a significant better environmental score compared to the petrol and diesel vehicles, despite of a lower energy efficiency compared to the petrol engine. The biggest advantage of diesel vehicles consists of their relative high energy efficiency. However, this advantage is cancelled due to the exhaust of a significant amount of harmful pollutants with detrimental effects on human health (PM and NO_X).

Due to increasing oil prices, resulting in high variable costs (per kilometre), cars with unconventional drive trains or alternative fuels become competitive with classical vehicle technologies. Fiscal measures at the disposal of the policy makers can create favorable conditions for vehicles with low CO_2 emissions per km (e.g. hybrid vehicles) and low taxes for bio-fuels, LPG, CNG and electricity. A fiscal system based on the Ecoscore of the vehicle could support in a more optimal way the use of more environmental friendly vehicles. Currently, the Flemish Administration (LNE) is working out propositions in this context.

The developed methodology for heavy duty vehicles can be used to analyze different types of urban buses currently in use by the Brussels public transportation company as well as to assess the environmental performances of different alternative bus technologies (diesel, diesel-electric, natural gas, hybrid, battery and fuel cell electric). This analysis allows concluding that the electric traction shows great potential for reducing the environmental burden of public transport.

References:

[1] Beirle, S. et al. (2003). Weekly cycle of NO2 by GOME measurements: a signature of anthropogenic sources, Atmospheric Chemistry and Physics, Vol. 3, 2225-2232, 2003.

[2] MIRA (2005). Milieurapport Vlaanderen, Achtergronddocument 2005, Transport, Vlaamse Milieumaatschappij, www.milieurapport.be

[3] European Commission. (2001). White Paper: European transport policy for 2010: time to decide, COM, 2001. p. 370.

[4] Van Mierlo J., et al. (2006). Which energy source for road transport in the future? A comparison of battery, hybrid and fuel cell vehicles. Journal of Energy conversion and Management, 2006 (article in press).

[5] Van Mierlo J. & Macharis C. (2005). Goederen- en Personenvervoer: vooruitzichten en breekpunten. Antwerpen – Apeldoorn, Garant 2005, 579p., ISBN 90-441-1908-7.

[6] De Borger B. and Proost S. (1997). *Mobiliteit: De juiste prijs*, Garant, Leuven/Apeldoorn, 1997, ISBN 90-5350-611-X.

[7] Van Mierlo, J. et al. (2003a). Comparison of the environmental damage caused by vehicles with different alternative fuels and drive trains in a Brussels context. Proceedings of the Institution of Mechanical Engineers Part D—Journal of Automobile Engineering 217, pp. 583–593.

[8] Van Mierlo, J., et al. (2003b). How to define clean vehicles? Environmental Impact Rating of Vehicles. International Journal of Automotive Technology. Vol. 4. No 2., 77–86.

[9] Pohl H., (2003). Vehicle Environmental Rating, Proceedings of the Fuel Cell, Hybrid and Battery Electric Vehicle Symposium EVS20, Long Beach, CA.

[10] Van Mierlo, J., et al. (2004). Driving style and traffic measures – influence on vehicle emissions and fuel consumption. Proceedings of the I MECH E Part D Journal of Automobile Engineering, Vol 218 (1), pp. 43-50.

[11] ExternE project. (1997). Externalities of Energy, Vol 2 – methodology. A report produced for the European Commision, DG XII, Luxembourg.

[12] Friedrich R. and Bickel P. (2001). Environmental External Costs of Transport. University of Stuttgart – Institute of Energy Economics and the Rational Use of Energy. Springer Verlag

[15] Timmermans J.-M., et al. (2005). The Development of an Environmental Rating Tool for Application in Policy measures", 21st Worldwide Battery, Hybrid and Fuel Cell Electric Vehicle Symposium (EVS-21), Monaco, 2-6 April, 2005.

[16] Timmermans J.-M., et al. (2006) Environmental rating of vehicles with different fuels and drive trains: a univocal and applicable methodology, European Journal of Transportation and Infrastructure Research, 2006 (article in press).

[17] Hill N., et al. (2002) Cleaner Drive – Development of an EU environmental rating methodology. Report, AEA Technology, UK.

[18] Guignard A., et al. (2005) Coûts financiers directs et indirects engendrés par l'installation de systèmes d'air climatisé dans les voitures particulières, final report VUB-ETEC & CEESE-ULB, in assignement of IBGE-BIM.

[19] Matheys J., et al. (2006) MIVB Vlootanalyse – Propere Bussen eindverslag iov MIVB

[20] Matheys J., et al. (2006) Environmental assessment of the past, present and future urban bus fleets, the advantages of battery, trolley and hybrid electric buses, 22nd International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, 23rd-28th October, Yokohama, Japan.

[21] Riemersma I. (2004). Effects of engine deterioration and maintenance on emissions. COST 346 Workshop, Antwerp, 24th May 2004.