Environmental Damage Rating Analysis Tool as a Policy Instrument

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Abstract

In order to compare the environmental damage of vehicles, rating systems are analyzed as to allow decision makers to dedicate their financial and non-financial policies and measures in function of the ecological damage.
Different types of pollutions (acid rain, photochemical air pollution, noise pollution and global warming, etc.) and their effect on numerous receptors such as ecosystems, buildings and human beings (e.g.: cancer, respiratory diseases, etc) are investigated.
The methodology described, know as Ecoscore, is based on a methodology similar to a Life Cycle Assessment (LCA) which considers the part played by emissions in certain types of damage (e.g. by using the Exposure-Response damage function). Total emissions involve oil extraction, transport and refinery, fuel distribution and electricity generation and distribution, (Well-to-Wheel approach). Emissions due to the production, use and dismantling of the vehicle (Cradle-to-Grave approach) should be considered too. The different types of damage are normalized to make assessment possible. Hence a reference value determined by a chosen reference vehicle, will be defined as a target value (the normalized value will thus determine a kind of Distance to Target). The contribution of the different normalized types of damage to a single value, EcoScore, is based on a panel weighting method.
This new approach differs from other methodologies in the fact that it has been especially developed for the evaluation of the environmental damage of vehicle emissions in an urban context, such as the Brussels Capital Region. Additionally this methodology not only considers conventional vehicles, but can also assess all alternative fuels and drive trains with new vehicle technologies, like electric and hybrid vehicles.
Some examples of Ecoscore calculation will illustrate the methodology.

Keywords: Emissions, pollution, environment, well-to-wheel

1 Introduction

The transport sector is a cause of non-negligible quantities of pollutant emissions that have a direct and indirect pressure on many environmental receptors (human beings, buildings, climate, etc.). The pollution caused by transport is a heavy load especially in urban areas. The reason for this is the combined presence of a large number of pollution sources (different modes of transport and heating systems) on the one hand, and a large number of receptors (people and buildings) on the other.
Studies carried out under the auspices of the European ExternE project [1,2] that looked into the assessment of the external costs of the energy and transport sectors have shown that local effects constituted the bulk of the damage caused by emissions from road transport. In recent studies by the CEESE [3], the yearly effect of transport in the Brussels Capital Region is estimated to be 774 M€.

A Brussels ordinance entitled "Air" [4] affirms that in the coming 5 years at least 20% of the vehicles belonging to institutions and administrative services from the Brussels Capital Region must be 'clean'. The question is "What are Clean Vehicles?"
In this respect the Brussels Capital Region commissioned a study entitled "Clean Vehicles" via the Brussels Institute for the Management of the Environment (BIME). The Vrije Universiteit Brussel (ETEC) and the Université Libre de Bruxelles (CEESE) have carried out a joint study programme. Some of the results of the 500-page final report [5] will be highlighted in this paper.
New research projects are commissioned by the Flemish government with the aim to compare the Ecosocre methodology with the European Cleaner Drive project [6] and to evaluate the usability of the developed Ecoscore to adapt policy instruments (taxation, incentives, consciousness-razing campaign, etc.) in favour of cleaner vehicles [7]. A new project proposal is submitted to the Belgian Federal Office for Scientific, Technical and Cultural Affairs (OSTC) with the aim to extend the environmental rating model with economical and social aspects to come up with a sustainable screening of vehicle technologies [8].

2 Methodology

A number of projects have focused on the problem of establishing an environmental indicator adapted to all the road vehicles. This is, for example, the matter of the list of "clean vehicles" developed by the "Verkehrsclub Deutschland" [9] and used in Germany, Switzerland and Austria; the "Green Book" edited in the USA by ACEEE [10] or the "Ecolabelling" carried out for the Flemish Region [11] as well as the European Cleaner Drive project [6].
The methods used differ in many respects and mainly in terms of their ranges. They are focused on human preferences as in the case of cost-benefit analysis, or more on environmental aspects as in the case of environmental impact assessments. However, this latter method does not define an approach to decision-making or to a method for the structuring and aggregation of environmental and economic effects. LCA provides an answer to these drawbacks. This approach not only enables the associated effects to be ordered at the different stages in the life of a product or a service but also provides an aggregation system in the assessment of the overall balance of the product or service.
LCA has undergone numerous developments in recent years [12]. It has the advantage of being standardized (ISO 14040 Series), and has already found applications in the case of road vehicles [13,14,15] in particular. In these applications, LCA is mostly employed as an analytical environmental tool for industry. The study presented in this paper is more consumer oriented because most of the environmental burdens take place throughout the stage of the vehicle use.
Furthermore, some studies mainly concern a generic vehicle or average production processes which don't facilitate any choice for the consumers. That is the reason why this study develops a methodology for a per-model applicability.

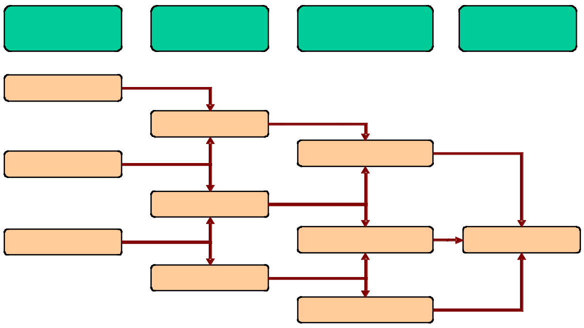

Figure 1: One single value for the environmental Impact Rating

Regarding the "ecoscore" development, the environmental assessment of a vehicle comprises a "five-step" scheme, similar to that used in LCA (Life Cycle Assessment) of products. These steps are in fact the answers given to these five following questions :

- “Which pollutant emissions are associated to the vehicle to assess?” (inventory)
- “Which types of damage are these emissions contributing to?” (classification)
- “Which values are to be attributed to this damage?” (characterisation)
- “Is this damage important in comparison with those of the vehicles of reference?” (normalisation)
- “How important is a type of damage in comparison with an other damage?” (weighting)

Figure 1 illustrates the methodology resulting in one singe end-score: starting from the inventorying, classification and characterisation of the different emissions, the effects and damage are calculated on the basis of scientific expertise and converted into one single value by the weighting system chosen.

2.1 Step 1: Emission Inventory

To be able to compare alternative vehicle technologies is not only required to compare tailpipe emissions, but also the emissions due to fuel refinery or electricity production.

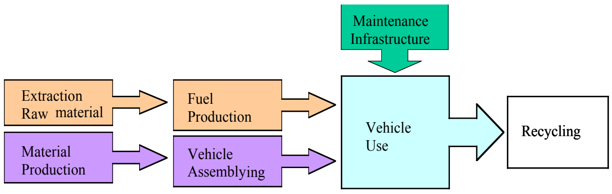

Figure 2: One ‘Cradle-to-Grave’ Overview

Total emissions involve tailpipe emissions, oil extraction, transport and refining, fuel distribution and electricity generation and distribution (Well-to-Wheel approach). Emissions due to the production, use and dismantling of the vehicle (Cradle-to-Grave approach) should be considered, but are not included in the model due to lack of data for each individual vehicle.

2.1.1 Direct Tank to wheel emissions

The purpose was to develop a transparent uniform methodology that is useful for all kind of vehicles with different types of fuels and drive trains of which all required emission data should be available for each vehicle model.

The different components of hydrocarbons, which affect respiration and cause cancer, are especially difficult to obtain for all kinds of fuel types. A first attempt was based on the calculation of the emission data from the COPERT/MEET methodology [16,17]. However this methodology was not adequate enough for all new alternative fuels.

For this reason the methodology is only based on regulated emissions (CO, HC, NO_x, PM) and emissions depending on fuel consumption (CO_2, SO_2). CH_4 is calculated out of the HC emissions and N_2O as a function of CO_2 emissions.

However in practice, vehicle emissions are mostly much higher due to the fact that the typical accelerations applied during the type approval test cycle are much lower than in reality (up to 2 times). The higher the acceleration and the driving dynamics, the higher the emissions. In fact, real-life emissions ($E_{real\ life}$) may be 2, 3 or even 30 times higher than in the emission directives (E_{reg}) [18]. Additionally, due to ageing and/or bad engine and catalyst tuning, real-life emissions will be higher than the emissions from the approved new car. Taking into considerations these factors the American reference [10] introduces correction factors (CF) into the homologation emissions.

$$E_{real\ life} = CF \cdot E_{reg} \quad (1)$$

For a robust model these correction factors must be made available for the European context (European type approval vs. real life) for different vehicle classes and age, etc. as well as for alternative fuels. Since these data is not available the Ecoscore methodology only uses the emission data from EC type approval.

2.1.2 Well to Tank emissions

Indirect emissions are related to the extraction and transportation of raw materials as well as those related to the refinery and the distribution of the fuels. This Well-to-Tank approach is particularly required when comparing different alternative fuels and drive trains (especially in the case of electric vehicles), since there can be huge differences in the emissions related to the production process of fuels and electricity.
The route from the extraction of crude oil to the use of individual refined components is long and complex [19]. Emissions do result from the extraction (gas flaring, venting and gas turbines), transport (energy used, losses) and the processing of crude oil (different refinery types) and also from the distribution of the fuel (mainly VOC evaporation in the case of petrol) [16]. The following stages are considered in the special case of bio fuels: agriculture, transport, processing, distribution and storage.
The emissions related to electricity generation are a function of the type of power station (nuclear, coal, gas, air wind, hydro, etc.) and the relative contribution of each power station to the energy consumed. It is very difficult to attribute a particular energy use of an appliance (i.e. an electric vehicle) to one particular power plant. Using an average electricity production mix as a basis seems at first sight to be a straightforward approach. However electric vehicles will be charged mostly at night, when the main sources of electricity production are the base stations, which are different from the "average" power station, the latter also including old power plants and peak units. If the introduction of electric vehicles in the next ten years is taken into account, it will be necessary to consider the investment policy of the electricity production companies. The Belgian electricity company, Electrabel, invests mainly in renewable energy or Combined Cycle Gas Turbine (CCGT) with low emissions and a high level of efficiency (55%). Additionally, from 2003 the electricity market in Europe will be liberalised and consumers will be able to buy emission-free electricity (Dutch wind, French nuclear or Swiss hydro, etc energy). Electric vehicles charged with these sources of electricity will therefore be emission-free. Nevertheless, to simplify the model the average electricity generation mix will be used and should be seen as a pessimistic case scenario for electric vehicles.

Table 1: Indirect emissions for Belgium (mg/kWh)

	CO	NMHC	CH4	NOx	PM	CO2	SO2
Reference	18.4	761.4	62.6	151.9	8.6	33100	236.2
Petrol	18.4	761.4	62.6	151.9	8.6	33100	236.2
Diesel	16.6	315.4	56.5	129.6	3.6	24500	174.2
Bio-fuel	493.2	280.4		871.9	66.6	108700	245.5
CNG	5	99	805.3	38.2	2.9	14800	60.8
LPG	14.8	202.7	58	116.3	5.4	21600	114.1
Electricity Renewable	0	0	0	0	0	0	0
Electricity Belgian Mix 2001	18.4	44*	1.75	440	36	290000	420
Electricity CCGT 1995	78	129	266	495	0	447500	0
Electricity Belgian Mix 1995	60.1	44	865	1041.8	97.9	339500	1920

(*no new data available, data of MEET 1995 used).

As seen in Table 1 [17,20], the bio-fuels related emissions are high due to the agricultural processes. CNG vehicles have high CH_4 indirect emissions, which is a greenhouse gas. Although the indirect emissions related to electricity production seem to be high, there are no direct emissions as is the case for the other types of vehicles. Emissions due to electricity production decreased significantly last 10 years. Table 1 shows the emission values corresponding to the Belgian Mix in 1995 [17]. At that moment the share of electricity from Coal power plant was 23.3% of the total electricity production. However this fraction was responsible for 85% of CH_4 emissions due to coal extraction and more than 90% of SO_2 and PM emissions due to production of electricity out of coal. At the moment more and more Combined

Cycle Gas Turbines are used. Additionally, filtering of emissions at the chimneys of the power plants has been improved.
The energy used per km for non-electric vehicles can be calculated from the fuel consumption (FC) and the energy content of the fuel. The consumption of electric vehicles is mostly expressed directly in kWh/km. The indirect emission can easily be calculated on the basis of this energy consumption and Table 1.
Contrary to direct emissions, indirect emissions are not produced at the place of vehicle operation. Since refinery plants and electricity production plants are mostly situated far away from densely populated areas, their effects on human health are lower than direct tailpipe emissions, because of the dispersion of these indirect emissions. One gram of particulate matter emitted by a diesel car in a crowded city will cause much greater damage to human health than one gram of particulate matter emitted from a chimney far away from the residents. To take this into account, some references such as [10] introduce a weighting factor (e.g. 50%) in calculating the total emissions related to health effects; this is illustrated by equation (2).

$$E_{total} = E_{direct} + w_{ind.} . E_{indirect} \qquad (2)$$

Contrary to health effects, no weighting is allowed for overall damage like global warming since every gram of CO_2 makes the same contribution to this effect.

2.1.3 Noise pollution

Since the methodology was developed in the first instance for a typical urban context (Brussels Capital Region), noise pollution should also be taken into account. Noise is one of the main causes of annoyance for the inhabitants of Brussels [21]. In the Brussels Capital region 28% of the population is exposed to sound levels higher than 65dB(A). The WHO considers that a daytime sound level of 50 dB(A) $L_{Aeq,8h}$ is irritating. On the basis of an enquiry 43% of the population considers the noise caused by traffic to be too high [22].
In some references like [9] and [11], noise is compared by calculating the different intensity of sound levels expressed in dB(A). However since this is a logarithmic scale, every reduction of 3dB(A) implies halving the real noise pollution. A reduction of 10 dB(A) even represents a 90% decrease of the annoyance from noise. The noise level (L) expressed in dB(A) is therefore converted in the EcoScore methodology, as is shown in equation (3).

$$E_{noise} = 10^{\left(\frac{L(dB(A))}{10}\right)} \qquad (3)$$

2.2 Step 2: Classification

The second stage of the "ecoscore" methodology consists of classifying the different pollutant emissions assessed according the category(ies) of damage to which they contribute.

Table 2: Classification of the studied atmospheric pollutants per category of damage

	Effects	Pollutants
Human health	Carcinogenic effects	VOC (1,3 Butadiene ; Formaldehyde ; Benzene) HAP (Benzo(a)pyrene ; Benzo(a)anthracene ; Dibenzo(a)anthracene)
	Respiratory effects (organic components)	VOC (NMVOC ; methane)
	Respiratory effects (inorganic components)	CO, Particles, TSP (Total Suspended Particles), NOx (in NO_2 equ.), SO2
Global Warming		CO_2 , CH_4, N2O
Eco-systems	Ecotoxicity	VOC (Benzene ; Toluene) ; HAP
	Acidification, eutrophication	NOx (in NO_2 equ.), SO2
Buildings		Particles (PM10), SO_2
Noise		Noise

The different effects and damage can be calculated as a function of the pollutants emitted as summarised in Table 2 which mainly based on the scientific method developed in the Eco-Indicator [23].
In function of the availability of data the methodology has been modified to a simplified but comprehensive model allowing to compare all types of vehicles. The following damage is considered: 'global warming', 'Human health - respiratory and cancer diseases', 'Eco-systems - acidification', 'damage to buildings' and 'noise pollution'.
The final classification of the different pollutant as well as their contribution to a specific damage can be found in the next step (see Table 3).

2.3 Step 3: Characterisation

He third step of the assessment consists of calculating the contribution rate of the incriminated pollutants in each category of damage.
To evaluate the damage rate in each category, the calculated level of emissions, expressed in [g/km] or in [g/kWh], is multiplied by a damage factor δ_{ij} expressed in specific units according to following formula :

$$D_{i,j} = \delta_{i,j} . E_{j,total} \qquad (4)$$

With:

- $D_{i,j}$: the partial damage of the category i, associated to the pollutant j ;
- $\_{i,j}$: the damage factor of the category i, linked to the pollutant j ;
- $E_{j,total}$: the total emissions due to pollutant j.

Table 3: Characterisation and classification of different effects and damages

Damage	*Weighting*	*Emission (Ej)*	*Unit*	*Contribution (δ_{ij})*
Global Warming	25	CO2	GWP	1
		CH4	GWP	23
		N2O	GWP	296
Human health : Respiration & Cancer	50	HC	Daly/kg	6.46E-07
		NOx	Daly/kg	8.87E-05
		CO	Daly/kg	7.31E-07
		PM	Daly/kg	9.78E-06
Eco-systems : Acidification	10	NOx	PDF.m^2.y/kg	5.713
		SO2	PDF.m^2.y/kg	1.04
Buildings	5	SO2	€/kg	8.3
		PM	€/kg	259
Noise	10			1

For each category of damage, the factors δ_{ij} (see Table 3) either come straight from the Eco-Indicator 99 methodology [23], considered as a reference for effects on health and ecosystems, or from other studies such as, for example, the CEESE-ULB specific study on damage to buildings [3]. As far as the greenhouse effects are concerned, the climate change potentials of each incriminated greenhouse gas are separately taken into consideration.
Damage is expressed in specific units that are common in each category, so that they can be added up to generate an overall damage assessment for each category. The representative units for the different damage are :

- The greenhouse gas emissions are expressed in CO_2-equivalent or Global Warming Potential (GWP).
- The deterioration cost of buildings is expressed in €/yr ;
- Damage from acidification and eutrophication are characterised by looking at observed effects on plants. From these observations the probability that a plant species still occurs in an area can be determined. This is called the Probability Of Occurrence (POO), which is translated for into Potentially Disappeared Fraction (PDF=1-POO). For a certain time period and surface it is expressd in PDF.m_.yr [23].

- Damage analysis, links health effects to DALYs, using estimates of the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL). The core of the DALY system is a disability weighting scale. The scale lists many different disabilities on a scale between 0 and 1 (0 meaning being perfectly healthy and 1 meaning death) [1]. This system allows calculating the number of Disability Adjusted Life Years if one knows how many people in Europe are exposed to a certain background concentration of toxic substances in air, drinking water and food [23].

2.4 Step4: Normalisation

In order to measure the relative extent of the different damage, the formerly evaluated damage is "normalised" according to a specific reference value for each category of damage.
This way, it becomes possible to compare damage caused by the vehicle to be assessed with a reference situation and to determine what type of important or, on the contrary, restricted effects this vehicle can have.
First of all, total damage Q_j of a given damage category j are obtained by adding partial damage $D_{i,j}$ related to every single concerned pollutant.
Mathematically, the normalised damage is calculated for every category of damage j, on the basis of equation (5):

$$q_j = \frac{Q_j}{Q_{j,ref}} \qquad (5)$$

with :

- q_j : the normalized damage ;
- Q_j : the damage associated to the vehicle to be assessed ;
- $Q_{j,réf}$: the damage associated to a vehicle of reference.

For the Ecoscore, it was decided to take as reference the damage associated with a fictive vehicle of which the different emission levels would correspond to so-called reference levels. As for any other vehicle to be assessed, the emissions of the reference vehicle include direct as well as indirect emissions.
For passenger cars the values imposed by the Standard Euro IV for petrol vehicles are taken as a reference. For light duty vehicles the reference values correspond to the Standard Euro IV required for medium-sized diesel cars (1305-1760 kg).
As far as CO_2 emissions are concerned, the value of 120g/km is taken as reference, as this value is the objective the automobile industry has accepted to aim at in the European Union. The indirect emissions can also be calculated from these target values since they are proportional to the fuel consumption and CO_2 emissions.
For SO_2 emissions, the reference level is based on the content of 50 ppm of sulphur in the petrol or diesel forecasted from 2005 on.
The currently permitted regulated sound level for passenger cars is 74dB (directives 70/157/EC and 92/97/EC). A reduction of 4dB is technically feasible. Hence the level of 70 dB(A) has been chosen as a reference.

2.5 Step 5: Weighting

The final stage of the assessment consists of weighting the normalised damage before adding them to have a final environmental score.

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[1] Example: Carcinogenic substances cause a number of deaths each year. In the DALY health scale, death has a disability rating of 1. If a type of cancer is (on average) fatal ten years prior to the normal life expectancy, we would count 10 lost life years for each case. This means that each case has a value of 10 DALYs.
During a summer smog period, many people have to be treated in hospital for a number of days. This type of treatment in a hospital has a rating of 0.392 on the DALY scale. If the hospital treatment lasts 0.01 years on average (3.65 days), each case would be weighted 0.004 DALYs.

The weighting factor applied to each effect taken into consideration is not only based on a scientific point of view. Policy priorities and decision-makers opinion are also very important. This is an aspect of the methodology that allows to weight the damage categories and to give more weight to issues that decision-makers decide to be more essential than others.
A specific weighting system for the Brussels-Capital Region seems to be necessary, given the specificity of this largely urbanised region where environmental priorities can differ very much from those of a country or a continent.
In terms of weighting, the "ecoscore" is very much concerned with the effects on health: they account for some 50% of the total (see Table 3). The effects linked to the climate change are granted with as much as 25%. The remaining 25% are distributed among the effects on ecosystems (10%), the noise pollution (10%) and damage to buildings (5%).

$$\text{Ecoscore} = 25\% \cdot Q_{\text{greenhouse}} + 50\% \cdot Q_{\text{respiration \& cancer}} + 10 \cdot Q_{\text{acidification}} + 5\% \cdot Q_{\text{buildings}} + 10\% \cdot Q_{\text{noise}} \quad (6)$$

3 Results

The methodology has been developed for some examples [24]. These examples are only indicative and serve to evaluate the applicability of the methodology. Different fuel types and drive trains were selected. Various engine capacities and vehicle sizes were taken to have an idea of the best and worst vehicles.
The total Ecoscore is given in Table 4. In a Belgian (even a Brussels) context, a good environmental impact rating (Ecoscore) can be seen for the electric car (Peugeot 106 electric) in comparison with other technologies. Also petrol hybrid, CNG and LPG vehicles score well and are mostly lower than the reference vehicle (EURO IV). Most petrol and diesel vehicles examined can not be considered as clean (in comparison with the reference) since they have higher Ecosocres than the reference vehicle. Due to their low fuel consumption small and light petrol vehicles score good. The Ecoscore of "conventional" EURO IV vehicles is much lower than EURO III vehicles. Diesel vehicles have bad Ecoscores. This is due to the fact that the NO_x emissions (and PM emissions) from diesel vehicles are much higher than for petrol vehicles. These NO_x emissions contribute heavily to damage to health. In the future new NO_x clean-up devices and PM filters may bring the damage to health down. The highest scores (out of 2000 evaluated vehicles) correspond to heavy vehicles with large engine capacities.

Table 4: Some examples of the Ecoscore (Belgium – Brussels situation)

		Tot. Ecoscore	Global Warming	Respiration & Cancer	Acid Rain	Buildings	Noise
Elecrenew	106	6	0	0	0	0	6
ElecCCGT95	106	57	16	28	6	0	6
ElecBelg01	106	60	10	32	7	5	6
HybridPetrol	Insight (2001 YM)	62	17	28	6	4	8
CNG	Brava	69	34	16	3	2	13
Petrol	Smart City Coupe Hatchback	73	25	32	6	6	5
LPG	Vectra, Model Year 2002	86	31	30	6	4	16
CNG	S60 Model Year 2002	87	31	24	5	3	25
CNG	S80 Model Year 2002	90	36	22	4	3	25
LPG	Astra	93	29	37	8	3	16
HybridPetrol	Prius	95	25	43	8	6	13
Petrol	Polo (from February 2002)	99	30	39	7	7	16
Petrol	Golf Hatchback (3 Door)	116	34	49	10	8	16
LPG	S60 Model Year 2002	122	40	43	9	5	25
LPG	V70 Model Year 2002	128	42	46	10	5	25
Petrol	Avensis	146	37	67	13	8	20
Petrol	S60	154	44	62	12	10	25
Diesel	607	204	29	116	25	10	25
Diesel	Golf Estate	290	26	143	25	72	25
Diesel	S60	340	28	156	24	112	20
Petrol	All Models	385	120	177	35	28	25
Petrol	Blazer	455	70	283	61	16	25
Diesel	TAXI TTT	680	51	328	51	225	25
Diesel	Window Van	704	44	344	53	247	16

Table 4 also shows the results of the different considered effects on global warming, health, acidification, buildings and noise pollution of the vehicles evaluated. Generally, due to their highly efficient drive train, electric, hybrid and diesel powered vehicles contribute less to global warming than CNG, LPG and petrol driven vehicles. Regarding health damage, the diesel vehicles have a very bad effect (due to high NO_x and PM emissions), and CNG vehicles score best. Electric, hybrid and LPG vehicles have also a very good health score. In the case of acidification, NOx emissions bring the diesel vehicle into very bad position and their PM emissions contribute greatly to the damage to buildings. Noise pollution is very low in the case of electric and hybrid vehicles.

4 Discussion

4.1 Communication to general public

For communication use to the general public the results of the above described scientific model should be converted to an easy to understand number. The EcoScore equals zero when there are no emissions and turns out to be very high, up to 700 and more, the higher the emissions of the considered vehicle are. For communication purposes the EcoScore is transformed to a rating between 0 and 100, where zero means an infinitely polluting vehicle (worst) and 100 indicates an emission free vehicle (best). This approach yields no negative scores since these would be quite confusing for the general public. This conversion can be done with equation (7). Figure 3 illustrates the results of the conversion.

- EcoScore = 0 ❹ 100
- EcoScore = 100 ❹ 50
- EcoScore = infinitive ❹ 0

$$\text{Rating} = 100\, e^{-0{,}0069.\text{EcoScore}} \qquad (7)$$

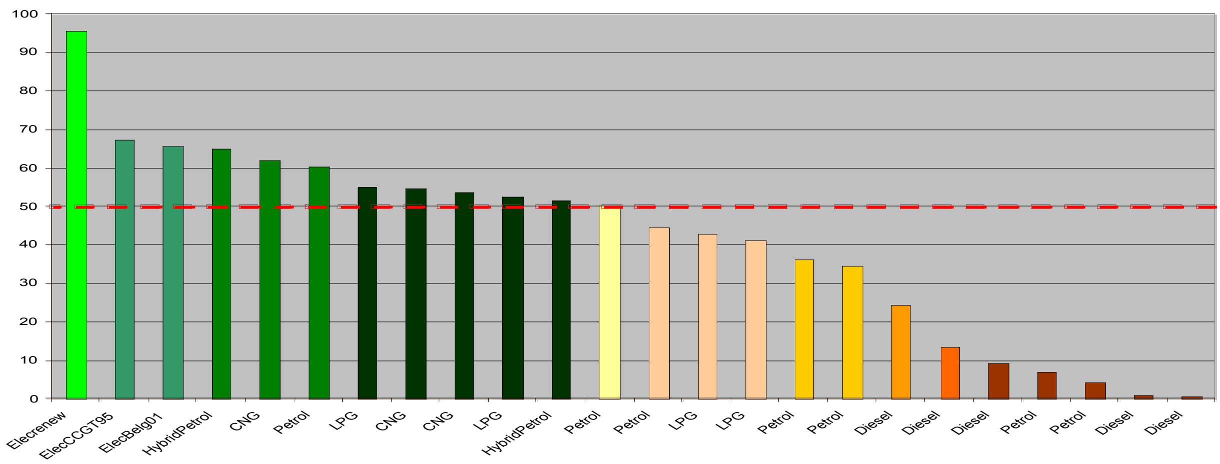

Figure 3: Some examples of the converted Ecoscore screening (Belgium – Brussels situation)

4.2 Adaptation of the methodology to heavy vehicles

The application of the "ecoscore" methodology to heavy duty vehicles and buses required some adaptations because of the coexistence of emission data that differ by their nature and by their units. Within some damage categories emission data of engines are expressed in g/kWh out of the type approval data, whereas emissions linked to vehicles are expressed in g/km. Type approval tests for heavy vehicles are in fact based on consumption and emission tests of the engine and not of the whole vehicle.

For this reason the model was transformed: tank-to-wheel and well-t-tank emissions of heavy vehicles were evaluated separately following the "ecoscore" methodology. However in this case it is not possible to take into account the tank-to-wheel SO_2 emissions (expressed in g/km), since they contribute to damage to human health of which the other emissions are expressed in g/kWh. Also the tank-to-wheel CH_4 emissions, contributing to global warming, could not be taken into account for the same reason. For the well-to-tank emissions at the contrary SO_2 and CH_4 can be taken into account since they are all expressed in g/km (proportional to fuel consumption).

As reference values are chosen:

- Noise : 78 dB(A)
- Tank-to-Wheel:
    - EURO IV type approval emissions for engine evaluated on the ETR cycle for CO (4 g/kWh), NOx (3,5 g/kWh), PM (0,03 g/kWh) and HC (0,55 g/kWh)
    - CO_2 (840 g/km) emissions
- Well-to-Tank (in function of fuel consumption):
    - CO_2 (77,0703 g/km), CO (0,0522 g/km), NOx (0,4077 g/km), NMHC (0,9922 g/km), CH4 (0,1777 g/km), SO_2 (0,548 g/km) and PM (0,0113 g/km)

The adapted methodology for heavy duty vehicles can be summarised as follows:

- The damages related to well-to-tank and tank-to-wheel emissions are calculated independently.
- Next they are normalised by comparing with the reference values
- Then this normalised well-to-tank and tank to-wheel damages are weighted with the help of Table 3 to end up with an well-to-tank and a tank-to-wheel Ecoscore
- And at last the different damages are weighted (w_{ind}) with the help of equation (8).

$$\text{Ecoscore global} = \frac{\text{Ecoscore}_{\text{Tank-to-Wheel}} + w_{\text{ind.}} .\text{Ecoscore}_{\text{Well-to-Tank}}}{100 + w_{\text{ind.}} \cdot 100} \qquad (8)$$

4.3 Adaptation of the methodology to other transport modes

Currently the methodology is developed in such a way that each vehicle can be compared towards another vehicle of the same category. Hence a comparison of the environmental damage between passenger cars is possible, but no comparison is possible of a passenger car with a heavy duty vehicle for instance. This is due to the fact that within each vehicle category a reference vehicle is chosen.
When one wants to compares the environmental damage different vehicles of different categories or when one wants to compare different modes of transport a same reference emissions has to applied.
Such a reference can be selected in function of some imposed targets developed by governmental bodies, e.g. to reach the Kyoto objectives or urban emission levels for the transport sector.

4.4 Potential improvements

The "ecoscore" methodology could be improved regarding the following matters.
At its current stage of development, it ignores the real traffic conditions (driver behaviour, impact of traffic circulation measures (e.g. roundabouts)).
Concerning the methodology, the study might, in the future, extend the LCA to production and recycling of vehicles.
On a practical point of view, the "ecoscore" methodology applied to "conventional" vehicles is based on emission levels identified in approval tests, while for vehicles "newly developed" (e.g. : some vehicles running on GNV, electric and hybrid vehicles, and vehicles with fuel cell) it is sometimes based on real data resulting from practical tests. It is clear that data collected from standardized tests should not be compared to data from real traffic, otherwise the methodology could become biased in favour of the technologies already available on the market.

4.5 Context of the analysis

To meet administrative requirements, the "ecoscore" has been completed by a technical and economic analysis of the vehicles, in order to include into the study significant aspects such as refuelling, range, or eventual surplus expenses linked to the choice of a clean vehicle.
Thanks to this complementary analysis, the "ecoscore" could be resituated in a more practical context in order to help the consumer in choosing an satisfactory clean vehicle.
A new analytical instrument will be developed in forthcoming projects [7,8]. This instrument will integrate the following interdisciplinary aspects:

- an analytical approach of the environmental Life Cycle Assessment (LCA), with a particular attention devoted to improving the assessment of the environmental impact of road transport on ecosystems and biodiversity,
- a conventional economic assessment (costs, public economic incentives or taxes, externalities, etc.),
- market research methodologies (interviews, focus groups, survey, conjoint analysis and stakeholders panels).

The economic and socio-economic aspects will be incorporated with the environmental LCA in order to have a set of three complementary scores at the end of the project (a socioscore, an ecoscore and an econoscore), these scores will then be expressed in a "sustainable transport" score, complemented by a qualitative assessment taking into account factors that cannot be expressed through quantitative figures only.
A screening of the availability, reliability and accuracy of the required data will be carried out together with a sensitivity analysis of the model parameters up to the end result; their relevancy on the different impacts will also be assessed.
To assist decision-makers (the general public, enterprises and public authorities) in their choice of vehicle, all the knowledge acquired during this project will be integrated into an analytical software package linked to an online database containing all the project's data collections. This will enable users to have direct access to all the information available on the different technologies and to assess the consequences of their choices concerning the make-up of their vehicle fleet (awareness building).
At the moment of writing this paper the project is in its startup phase and hence no results can be covered yet.

5 Conclusions

The methodology proposed can help developing an indicator fit to assess, on a scientific and adjustable basis, the environmental damage caused by vehicles, whatever their type, their mode of propulsion or their energy use.
This first approach is still simplified in comparison with what might be done theoretically but it meets different imperatives such as, for example, working with currently available data or having comparable results for different vehicles from a same category.
As for the weighting of the different damage factors considered, this approach is focused in particular on problems occurring in urban areas by allocating greater weight factors to health effects.
Concerning research on the assessment of "clean vehicles", the "ecoscore" methodology proposes an adjustable solution that applies to all vehicle categories but also a system that is able to be adapted to new standards of reference

References

[1] European Commission, Directorate-General XII, Science, Research and Development, JOULE (1995), 'Externalities of Fuel Cycles 'ExternE' Project. Report number 2, Methodology', EUR16521, Luxembourg

[2] European Commission, Directorate-General XII, Science, Research and Development, JOULE (1998), 'Externalities of Fuel Cycles 'ExternE' Project. Report number 7, Methodology, 1998 update', EUR16521, Luxembourg, 518 p.

[3] V. Favrel, T. Pons, K. Maréchal, P. Claeys, C. Ferdinand et W. Hecq (2001). "Mobilité durable en Région bruxelloise : Analyse des impacts sur l'environnement – Evaluation des externalités physiques et monétaires", final report, SSTC MDDD012, Centre d'Etudes Economiques et Sociales de l'Environnement, Université Libre de Bruxelles, Aug. 2001, 68 p. + Annexes

[4] Ch. Picque, Minister-President, Article 22 of the Ordinance of March 25 1999 of the Brussels Capital Region concerning the evaluation and improvement of the quality of the air (published in the Official Journal 24.06.1999) pp. 23861-23868.

[5] Van Mierlo J., Favrel V., Meyer S., Vereecken L., et al. (2001) Schone Voertuigen (Clean Vehicles). Final report, VUB-ETEC, ULB-CEESE, 500 p

[6] N. Hill, H. Haydock, B. Saynor, "Cleaner Drive – Development of an EU environmental rating methodology", AEA Technology, UK, http://www.cleaner-drive.com/ , july 2002

[7] Van Mierlo J. et al. "Bepalen van een EcoScore voor voertuigen en toepassing van deze EcoScore ter bevordering van het gebruik van milieuvriendelijke voertuigen", AMINAL project

[8] Van Mierlo J. et al. "Innovative Vehicle Technologies : – Environmental Damage Rating Analysis Tool – Market Barriers and User Acceptance", OSTC project

[9] Auto-Umweltliste 1999/2000, VCD, Bonn, 1999

[10] DeCicco J., Thomas M., Kliesch J. (2000), "ACEEE's Green Book", Washington, 2000, 61 p

[11] Govaert L. (2001), "Emissielabelling nieuwe personenwagens", Final report, VITO, AMINAL project, 2001/ETE/R/056, juli 2001, 23 p

[12] Consoli F. et al. (1993), "Guidelines for Life-Cycle Assessment : a 'Code of Practice' ", SETAC, pp. 51-54.

[13] Lewis C.A., Gover M.P. (1995), "Life Cycle Analysis of motor fuel emissions", European Commission, Proceedings of the workshop on 27-28 November 1995 at ULB-Brussels, 14 p.

[14] Davison P. (1999), "Life-Cycle emission analysis of fuel use", European Commission, Transport Research COST 319

[15] Nicolay S. et al. (2000), "A simplified LCA for automotive sector : comparison of ICE (diesel and petrol), electric and hybrid vehicles", SETAC, 8th LCA Symposium for Case Studies, Brussels, pp. 97-105

[16] M. Keller, P. de Haan; "Intermodal Comparisons Of Atmospheric Pollutant Emissions"; MEET project, deliverable no24, EC Contract No. ST-96-SC.204, INFRAS, Berne, Switzerland, October 1998

[17] R. Joumard (1999); "Methods Of Estimation Of Atmospheric Emissions From Transport: European Scientist Network And Scientific State-Of-The-Art"; Final report, LTE 9901 report, action COST 319, Institut National de Recherche sur les Transports et leur Sécurité (INRETS), France, March 1999, 83pg

[18] J. Van Mierlo, E. Van de Burgwal, et al. (2002); "Invloed van het rijgedrag op de verkeersemissies : kwantificatie en maatregelen.", Vrije Universiteit Brussel, TNO, AMINAL project

[19] Choudhury R., 2002, "GM Well-to-Wheel Analysus of Energy Use and Greenhouse Gas Emissions o Advanced Fuel/Vehicle Systems – A European Study"

[20] A. Becquaert, "Productie Milieurapport 2001", Electrabel, mei 2002

[21] B. Deraedt, E. van Walsum, (2001) "MIRA (2001) - Milieu- en natuurrapport Vlaanderen", Background document 2.24 "Stedelijk milieu", Vlaamse Milieumaatschappij, www.vmm.be

[22] BIM, (1998), "De strijd tegen geluidshinder in een stedelijke omgeving voor het Brussels Hoofdstedelijk Gewest"

[23] M. Goedkoop, R. Spriensma (2000), "The Eco-Indicator 99, A damage oriented method for Life Cycle Impact Assessment, Methodology report", PRé Consultants, Second Edition, 103 p. + Annexes; April 2000, 103 p. + appendices.

[24] Van Mierlo J., Maggetto G., Vereecken L., Favrel V., Meyer S., Hecq W. (2003), "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*, I MECH E, SAE and IEE, isnn 0954-4070

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