Establishment of an environmental indicator adapted to all existing or future road vehicles

Vincent FAVREL *, Sandrine MEYER *, Walter HECQ *
Joeri VAN MIERLO **, Laetitia VEREECKEN **, Gaston MAGGETTO **

* Univ. Libre de Bruxelles, CEESE-ULB, av. Jeanne 44 CP 124, 1050 Brussels, Belgium
fax : + 32 2 650 46 91 - email : sameyer@ulb.ac.be

** Vrije Univ. Brussel, ETEC-tw-VUB, Pleinlaan 2, 1050 Brussels, Belgium

Résumé : Etablissement d’un indicateur environnemental adapté à tous les véhicules routiers existants ou futurs

Pour permettre aux décideurs politiques et gestionnaires de flotte de sélectionner les véhicules sur base de leurs performances environnementales, un indicateur appelé écoscore a été développé. Cette méthodologie compare des véhicules routiers actuels (essence, diesel, etc.) et à venir (ex: pile à combustible), quels que soient la catégorie envisagée (voitures, utilitaires légers ou lourds, etc.), le carburant utilisé (ex: carburants fossiles, biofuels, etc.) ou le mode de propulsion (moteur thermique, moteurs électrique ou hybride, pile à combustible). Elle consiste en une approche du type « cycle de vie » et se base sur l’importance des impacts environnementaux du véhicule analysé par rapport à un véhicule de référence. Les dommages étudiés correspondent à l’utilisation de ces véhicules (émissions directes de polluants atmosphériques, bruit) et à leur approvisionnement énergétique (émissions indirectes), et concernent diverses catégories de récepteurs : climat (réchauffement global), population (maladies respiratoires, etc.), écosystèmes et bâtiments. Ils sont mesurés à l’aide, notamment, de fonctions dose-réponse spécifiques aux récepteurs étudiés, normalisés en faisant appel à un véhicule de référence, puis pondérés selon leur contribution aux dommages totaux et finalement additionnés dans un score global, l’écoscore.

Mots-clés : Indicateur environnemental ; véhicules propres ; véhicules routiers ; écoscore ; LCA ; outil d’aide à la décision ; émissions ; énergie ; externalités.

Abstract

This paper aims to clarify the choices between vehicle technologies by developing a decision support tool. The methodology developed enables the comparison, from an environmental point of view of current (petrol, diesel, etc.) and future (e.g.: fuel cell) road vehicles, whatever the category of vehicles (cars, light and heavy duty vehicles, etc.), the type of fuel (fossil fuels, biofuels, etc.) or the propulsion mode (IC, electric or hybrid engines, etc.) to be considered. It consists of an LCA (life-cycle analysis) approach and is based on the importance of the environmental effects of the vehicle studied in comparison with a vehicle of reference. The damage analysed is a result of the use of vehicles and their energy supply, and concerns different categories of environmental receptors : the climate, the general public, ecosystems and buildings.

Key-words : Environmental indicator ; clean vehicles ; road vehicles ; ecoscore ; LCA ; decision support tool ; emissions ; energy ; externalities.

Introduction

The transport sector is a source of non-negligible quantities of pollutant emissions that have a direct and indirect influence on many environmental receptors (human beings, buildings, climate, etc.). The pollution caused by transport is a heavy burden especially in urban areas. The reason for this is
the joint 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 in the European ExternE project (ExternE, 1998), that was dedicated to the evaluation of external costs of the energy and transport sectors, showed in particular that local impacts caused by the use of vehicles represented a major part of the damage induced by the emissions of road transport. In recent studies carried out by the CEESE (Favrel, 2001), the yearly impact of road transport in the Brussels-Capital Region was estimated at 774 M€.

One of the measures envisaged to improve the air quality - whether on the local, regional or global level - , to diminish noise exposure and to reduce energy consumption, involves the possibility of introducing new technologies into fleets of road vehicles. New technologies are being introduced in the case of conventional petrol and diesel vehicles (advanced engines, management systems, etc.) to meet more and more challenging emission directives. Driving systems like fuel-cell powered and hybrid- or battery-driven electric vehicles are attractive alternatives. Also, several alternative fuels (LPG, CNG, alcohol’s, biodiesel, hydrogen, etc.) are being considered as potential fuel choices for the future.

Both the decision-makers and consumers have a difficult choice when confronted with vehicles that are not yet widely available, because of a lack of information on the techniques available, their costs, and their effects on the environment.

This paper aims to clarify the choices between vehicle technologies by developing an assessment instrument that provides a comparison between different existing and future types of vehicle technologies.

An application of this methodology has been carried out for the Brussels Capital Region in the context of the ordinance air, (Moniteur belge, 1999), which states that in the coming 3 years at least 20% of the vehicles of the public fleets of the institutes and administrations of the Brussels Capital Region must be “clean vehicles”.

1 - Methodology

Numerous attempts have been made for assessing products or activities that may have a damaging effect on the environment. For that purpose a lot of instruments have been developed : impact pathway methods including externalities assessment, cost-benefit analysis, environmental impact studies, life cycle analysis, etc.

The methods used differ in many respects and particularly 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 for decision-making or for a procedure in order to structure and aggregate environmental and economic effects. LCA provides an answer to these drawbacks. This approach not only enables the associated effects to be structured at the different stages in the life of a product or a service but also provides an aggregation procedure in the assessment of the overall balance of the product or service.

LCA has undergone numerous developments in recent years (Consoli, 1993). It has the advantage of being normalised (ISO 14040 Series), and has already found applications in the case of road vehicles (Lewis, Gover, 1995 ; Davison, 1999 ; Nicolay, 2000) in particular. In these applications, LCA is mainly employed as an analytical environmental tool for industry. The study presented in this paper is more consumer orientated because most of the environmental burdens take place during the stage of the vehicle use.

Furthermore, the current available 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.
Ecoscore methodology

A number of projects have focused on the problem of establishing an environmental indicator adapted to all road vehicles. This is, for example, the matter of the list of “clean vehicles” developed by the “Verkehrscrub Deutschland” (VCD, 1999) and used in Germany, Switzerland and Austria; the “Green Book” edited in the USA by ACEEE (DeCicco, 2000) or the “Ecolabelling” carried out for the Flemish Region (Govaert, 2001).

These lists are still based on partial elements because an environmental assessment is very difficult to make, essentially because of the large diversity of the types of damage to integrate and also because of the different characteristics of this damage. This is why it is not possible to combine different environmental effects in one single indicator by means of such lists. The “ecoscore” methodology tries to overcome this fact.

Regarding the “ecoscore” development, the environmental assessment of a vehicle follows 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 with 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 another damage?” (weighting).

Inventory

The inventory calculates the pollutant emissions associated with the different life stages of a product, including its production, its use and its final storage.

The Ecoscore methodology limits the environmental assessment to the use of this vehicle (Tank-to-wheel, i.e. direct emissions), to noise pollution and emissions of atmospheric pollutants associated with the production of fuel or electricity used to run the vehicle studied (Well-to-tank, i.e. indirect emissions).

Whatever the category of vehicles taken into consideration, the total emissions \( E_{\text{total}} \) are equal to the direct \( E_{\text{direct}} \) plus the indirect \( E_{\text{indirect}} \) contributions. At this stage, the Ecoscore methodology multiplies the indirect reference emissions by a factor \( W_{\text{ind.}} \) inferior to 1 for the emissions that have a local impact on health and buildings and equal to 1 for the other impacts (De Cicco, 2000).

\[
E_{\text{total}} = E_{\text{direct}} + w_{\text{ind.}} E_{\text{indirect}}
\]

where \( w_{\text{ind.}} \) is the weighting coefficient, varying between 0 and 1, and imputed to indirect emissions (it is equal to 1 for HCs and NOx; to 0.4 for SO2; to 0.1 for CO and particles).

Direct emissions are divided into regulated emissions, for which the results of the vehicle approval tests are used, and non-regulated emissions (CO2, SO2, some VOC that have an impact on health). As far as the last ones are concerned, the emission levels are assessed on the basis of fuel consumption, i.e. the percentage of each type of pollutant in the overall amount of volatile organic compounds (VOC) emitted, according to the hypotheses of the European COPERT methodology (Ntziachristos L. et alii, 1999).

Classification

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

The “ecoscore” methodology distinguishes between five different categories of damage: health (cancer, respiratory diseases), greenhouse effect, impact on ecosystems (ecotoxicity, acidification and eutrophication), effects on buildings and noise pollution.
### Effects

<table>
<thead>
<tr>
<th>Human health</th>
<th>Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcinogenic effects</td>
<td>VOC (1,3-Butadiene ; Formaldehyde ; Benzene) HAP (Benzo(a)pyrene ; Benzo(a)anthracene ; Dibenzo(a)anthracene)</td>
</tr>
<tr>
<td>Respiratory effects (organic components)</td>
<td>VOC (NMVOC ; methane)</td>
</tr>
<tr>
<td>Respiratory effects (inorganic components)</td>
<td>CO, Particulates, TSP (Total Suspended Particulates), NOx (in NO2 equ.) , SO2</td>
</tr>
<tr>
<td>Greenhouse effect</td>
<td>CO2 , CH4 , N2O</td>
</tr>
<tr>
<td>Eco-systems</td>
<td>VOC (Benzene ; Toluene) ; HAP</td>
</tr>
<tr>
<td>Acidification, eutrophication</td>
<td>NOx (in NO2 equ.) , SO2</td>
</tr>
<tr>
<td>Buildings</td>
<td>Particulates (PM10) , SO2</td>
</tr>
<tr>
<td>Noise</td>
<td>Noise [in dB(A)]</td>
</tr>
</tbody>
</table>

*Table 1: Classification of the studied atmospheric pollutants per category of damage*

Tableau 1 : Classification des polluants atmosphériques étudiés par catégorie de dommages

### Caractérisation

This stage 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 $\delta_{ij}$ expressed in specific units according to following formula:

$$D_{i,j} = \delta_{i,j} \cdot E_{j,\text{total}}$$

with

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

For each category of damage, the factors $\delta_{ij}$ either come straight from the Eco-Indicator 99 methodology (Goedkoop, 1999), 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 (Favrel, 2001). As far as the greenhouse effects are concerned, the climate change potentials of each incriminated greenhouse gas are separately taken into consideration. On the contrary, the noise pollution does not need any reference to a damage factor, as noise is the one and only incriminated “pollutant”; as a consequence, there is no distinction to make in this specific case.

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 DALY (Disabled Adjusted Life Years) or the number of years of living with a disability; the greenhouse gas emissions expressed in CO2-equivalent; concerning damage to ecosystems, it is the annual surface of areas where species probably will not appear because of unfavourable conditions resulting from pollutant deposits, expressed in [PDF.m².yr]; the deterioration cost of buildings expressed in €/yr; the noise pollution expressed in dB(A).

### 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 associated with every single concerned pollutant. Mathematically, the normalised damage is calculated for every category of effects $j$, on the basis of the following relation:

$$ q_j = \frac{Q_j}{Q_{j,\text{ref}}} $$

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

For the Ecoscore, it was decided to take as a reference the damage associated with a so-called “reference vehicle”, i.e. a fictive vehicle by which the different emission levels would correspond to so-called reference levels. These reference levels are much lower than emission levels of current vehicles but they can be reached thanks to new technologies that either are already, (or will be very soon), available on the market.

As for any other vehicle to be assessed, the emissions of the reference vehicle include direct (regulated and non-regulated) as well as indirect components.

Regulated emissions of the reference vehicle:
As far as the “cars” category is concerned, for example, the values imposed by the Standard Euro IV are taken as a reference. As there are different standards for fuel and diesel engines, the strictest standard was adopted as reference value for private cars. As for the light duty vehicles, the reference values correspond to the Standard Euro IV imposed on medium-sized diesel cars (1305-1760 kg).

Non-regulated emissions of the reference vehicle:
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 for in the European Union. 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. To split the overall VOC according to the different species, it is carried out the same way as for the assessment of direct emissions, on the basis of specific emission levels determined for the overall VOC. In this case also, the lowest emission level (petrol compared to diesel) is adopted.

Indirect emissions of the reference vehicle:
The assessment of the indirect emissions is based on the fuel consumption while complying with the levels adopted for the CO$_2$ emissions (Joumard, 1999).

Noise emitted by the reference vehicle:
For the noise generated by the vehicles, we have decided to choose the following values: 74 bB(A) for cars and light duty vehicles. This value coincides with the standards currently adopted in the Brussels Region.

Weighting

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

The weighting factor applied to each effect taken into consideration is not only based on scientific arguments. Policy priorities and decision-makers sensitivity 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 important 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. The existing weighting systems (e.g. : De Cicco, 2000 ; IFEU, 1997 ; Govaerts, 2001) have been revised according to the urban specific characteristics.
In terms of weighting, the “ecoscore” is very much concerned with the effects on health: they account for some 50% of the total which is comparable to the other weighting systems, except for the IFEU model (IFEU, 1997). Regarding the effects on public health, the greatest importance is given to carcinogenic effects linked to VOC (a weight of more than 20%). The remaining 30% are equally distributed among the two categories related to the respiratory system.

There are then the effects linked to the climate change: they are granted with as much as 25%. This weight seems lower than in other models such as the Green Car (De Cicco, 2000), the IFEU (IFEU, 1997) or the study made in Flanders (Govaerts, 2001) that gave a weight of more than 40% to this item. This difference results in fact from the specificity of the “Clean vehicle” study that is made in an urban context.

The remaining 25% are distributed among the effects on ecosystems (10%), the noise pollution (10%) and damage to buildings (5%).

The aggregated score: the “ecoscore”

The damage from the direct and indirect emissions, as well as noise pollution, has been assessed for vehicles and normalised according to the reference vehicle. The normalised damage has been weighted and added up to obtain one single score called “ecoscore”.

\[
\text{Ecoscore} = 25\% \cdot q_{\text{greenhouse}_\text{effect}} + 50\% \cdot q_{\text{respiratory}_\text{diseases}_\text{&}_\text{cancer}} + 10\% \cdot q_{\text{acidification}_\text{&}_\text{eutrophication}} \\
+ 5\% \cdot q_{\text{buildings}} + 10\% \cdot q_{\text{noise}}
\]

2 - Application

This methodology was applied to a series of currently available vehicles in each category and for each existing type of vehicle (e.g.: types of fuel and propulsion system). They are only supposed to be a series of examples aiming to control and assess the application of the “ecoscore” methodology.

Figure 1: Comparison of different cars on the basis of the “ecoscore” methodology (Favrel, Van Mierlo, 2001)

Graphique 1 : Comparaison de différentes voitures sur base de la méthodologie “écoscore” (Favrel, Van Mierlo, 2001)

The previous graph gives the results of the comparative “ecoscore” study on the environmental damage resulting from the use and the energy supply of cars available on the Belgian market. The
results take into account the fact that this evaluation was undertaken in the urban context of the Brussels-Capital Region.

The reference vehicle always reaches a 100 score.

The vehicles on the left of the reference vehicle are considered as more environment-friendly in the context of the Brussels-Capital Region. In this particular example, it concerns mainly electricity, gas and LPG driven cars.

On the contrary, the vehicles on the right of the reference vehicle produce more pollution. They are essentially “conventional” (diesel and petrol) cars.

3 - Discussion

Adaptation of the methodology to heavy vehicles

The application of the “ecoscore” methodology to heavy vehicles – 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 (e.g. : effects due to CO₂ and SO₂ emissions), emission data of engines are expressed in g/kWh (cf. vehicle approval tests essentially concern engines and not vehicles as such), whereas emissions linked to vehicles are expressed in g/km (cf. databases on vehicles).

This is why we had to proceed differently for the calculation of the aggregated score : direct and indirect emissions of heavy vehicles were evaluated separately following the “ecoscore” methodology. The two different scores were then integrated into one single score by weighting the score related to indirect emissions with the \( w_{\text{ind}} \) factor.

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 important aspects such as refuelling, autonomy, 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 adequate clean vehicle.

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 regional measures such as “speed-breakers” and ageing of the vehicles. Results could be adapted by using appropriate data-bases. However, this aspect is not really focused on here as the objective is to compare the available vehicles and to choose, from an environmental point of view, the most adequate alternative technologies for the public authorities and public transport company in Brussels.

Concerning the methodology, the study might, in the future, extend the LCA to production and recycling of vehicles.

From a practical point of view, the “ecoscore” methodology applied to “conventional” vehicles is based on emission levels identified in approval tests, while it is sometimes based on real data resulting from practical tests for vehicles “newly developed” (e.g. : some vehicles running on GNV, electric and hybrid vehicles, and vehicles with fuel cell). That means that the methodology could currently favour technologies already available on the market.

Conclusions

The methodology proposed can help developing an indicator fit to assess, on a scientific and
adjustable basis, environmental damage caused by vehicles, whatsoever the category they belong to, 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 identified, this approach quite focuses on problems occurring in urban areas by allocating greater weight factors to health effects.

Concerning research on the assessment of “clean vehicle”, 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.

From a practical viewpoint, the indicator calculated makes it possible to compare the different available vehicles on the Belgian market and to build an adequate policy for the future vehicle fleets, starting with the public vehicle fleets (Moniteur belge, 1999) before going eventually over to private fleets.

Acknowledgements
This article is based on the “Clean vehicles” research project (Favrel, Van Mierlo, 2001) jointly developed by the “Université Libre de Bruxelles (CEESE)” and the “Vrije Universiteit Brussel (ETEC)” on behalf of the Brussels-Capital Region via the “Institut Bruxellois pour la Gestion de l’Environnement (IBGE)”.

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