International Journal of Automotive Technology, Vol. 4, No. 2, pp. 77−86 (2003)

1229−9138/2003/012−03

HOW TO DEFINE CLEAN VEHICLES? ENVIRONMENTAL IMPACT RATING OF VEHICLES

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(Received 10 October 2003; Revised 21 February 2003)

ABSTRACT−How to compare the environmental damage caused by vehicles with different fuels and drive trains? This paper describes a methodology to assess the environmental impact of vehicles, using different approaches, and evaluating their benefits and limitations. Rating systems are analysed as tools to compare the environmental impact of vehicles, allowing decision makers to dedicate their financial and non-financial policies and support measures in function of the ecological damage. The paper is based on the "Clean Vehicles" research project, commissioned by the Brussels Capital Region via the BIM-IBGE (Brussels Institute for the Conservation of the Environment) (Van Mierlo *et al.*, 2001). The Vrije Universiteit Brussel (ETEC) and the Université Libre de Bruxelles (CEESE) have jointly carried out the workprogramme. The most important results of this project are illustrated in this paper. First an overview of environmental, economical and technical characteristics of the different alternative fuels and drive trains is given. Afterward the basic principles to identify the environmental impact of cars are described. An outline of the considered emissions and their environmental impact leads to the definition of the calculation method, named Ecoscore. A rather simple and pragmatic approach would be stating that all alternative fuelled vehicles (LPG, CNG, EV, HEV, etc.) can be considered as 'clean'. Another basic approach is considering as 'clean' all vehicles satisfying a stringent emission regulation like EURO IV or EEV. Such approaches however don't tell anything about the real environmental damage of the vehicles. In the paper we describe "how should the environmental impact of vehicles be defined?", including parameters affecting the emissions of vehicles and their influence on human beings and on the environment and "how could it be defined ?", taking into account the availability of accurate and reliable data. We take into account different damages (acid rain, photochemical air pollution, global warming, noise, etc.) and their impacts on several receptors like human beings (e.g.: cancer, respiratory diseases, etc), ecosystems, or buildings. The presented methodology is based on a kind of Life Cycle Assessment (LCA) in which the contribution of all emissions to a certain damage are considered (e.g. using Exposure-Response damage function). The emissions will include oil extraction, transportation refinery, electricity production, distribution, (Well-to-Wheel approach), as well as the emission due to the production, use and dismantling of the vehicle (Cradle-to-Grave approach). The different damages will be normalized to be able to make a comparison. Hence a reference value (determined by the reference vehicle chosen) will be defined as a target value (the normalized value will thus measure a kind of Distance to Target). The contribution of the different normalized damages to a single value "EcoScore" will be based on a panel weighting method. Some examples of the calculation of the Ecoscore for different alternative fuels and drive trains will be calculated as an illustration of the methodology.

KEY WORDS : Environment, Pollution, Modelling, Alternative fuel, Primary energy, Emissions

1. INTRODUCTION

The transport sector is responsible for a great amount of pollution, which has a direct or indirect impact on different receptors (people, buildings, agriculture, ecosystems, 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 (cars) on the one hand, and a large number of receptors (people and buildings) on the other hand. Studies carried out in the frame of the European ExternE project that was dedicated to the evaluation of external costs of the energy and transport sectors, showed namely that the local impacts represented the major part of the damage induced by the emissions of road transport. In recent studies of the CEESE (Favrel *et al.*, 2001), the yearly impact of the transport in the Brussels Capital Region

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was estimated to 774 M.

The introduction of clean vehicles would be an interesting solution to contribute to a significant reduction of harmful exhaust gases in the city, in the perspective of a durable transport policy. A Brussels ordinance "Air" states that in the coming 5 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. But the question is "what are Clean Vehicles?"

2. COMPARISON OF DIFFERENT ALTERNATIVE FUELS AND TRACTION SYSTEMS

In this paragraph a short overview will be given of the different vehicle technologies (gasoline, diesel, LPG, natural gas, biodiesel, battery, fuel cell and hybrid electric vehicles) that are compared with each other in terms of state of the art, infrastructure, safety, range, energy consumption, emissions and cost price. This comparison is given in Table 1.

2.1. State of the Art

In Belgium, different car manufacturers offer natural gas cars or electric cars, but their supply is still smaller than LPG-cars supply. Biodiesel and alcohols are not available yet in Belgian filling stations. On the long term, i.e. within 5 to 10 years, the battery in electric cars will be totally or partly replaced by a fuel cell (on board electricity production from hydrogen). In the category of hybrid vehicles, the only model that is currently sold in Belgium is the Toyota Prius. The Renault Kangoo with range extender is expected to enter the market soon.

2.2. Infrastructure

Gasoline and diesel are broadly available in Belgian filling stations. Moreover, those stations are mostly equipped with a distribution system for LPG. The number of filling stations for natural gas is very limited. The big difference between natural gas on the one hand and biodiesel and alcohol on the other hand, is that a distribution network exists for the former.

The electric vehicles in Europe all have an "on-board" charger that can be coupled on a domestic socket-outlet. Besides private socket-outlets, which are broadly present in houses, there is a shortage of public charging stations. The infrastructure necessary for hybrid or fuel cell electric vehicles depends on the used fuel.

2.3. Safety

Gasoline is extremely flammable in liquid or gaseous state. Moreover it can cause serious injury to the central nervous system. The majority of the components constituting gasoline are toxic. Laboratory tests permit to conclude that diesel fumes are toxic, carcinogenic and mutagenic. Furthermore, the particulate matters that are emitted by diesel cars are very unhealthy.

Originally equipped LPG cars are much more safer than adapted ones. Crash tests demonstrated that LPG vehicles do not present more risks than gasoline vehicles. Natural gas cars need a tank to store the pressurized gas (200 bar). The current technology of such tanks is safe. The safety aspect is comparable with gasoline vehicles. The ester in biodiesel is not toxic and is degradable for 98%. Methanol is highly corrosive and toxic.

The risks associated with battery electric cars are minimal compared to vehicles with combustion engines. The battery can be recycled at the end of the lifetime.

2.4. Range

The range of gasoline vehicles is taken as reference and amounts to 500 km. Diesel vehicles have a longer range than gasoline vehicles. Monofuel LPG vehicles and natural gas vehicles have a lower range (200 to 300 km). Biodiesel and alcohol have a lower range because of the lower energetic contents of the fuels.

Battery electric vehicles have a range that is situated between 70 and 100 km. Fuel cell electric vehicles have a range of about 600 km and hybrid electric vehicles have a range that lies higher than that of gasoline and diesel, due to the high efficiency of the traction.

The filling time of gasoline-, diesel- and LPG cars last a few minutes. Biodiesel and alcohols are not available at Belgian filling stations, but the filling time would also be a few minutes. We distinguish two ways of fuelling a natural gas car; i.e. the "quick fill" and the "slow fill". The quick fill lasts a couple of minutes, while the slow fill lasts roughly 5 hours.

Three types of charging infrastructure for electric cars can be discerned: the "normal", the "semi-fast" and the "fast" infrastructure. With the normal infrastructure (using a standard 16 A socket-outlet), the charging takes 5~8 hours, with the semi-fast type (using a 32 A socket-outlet) it lasts half as long and finally with the fast type (at power levels of 20 kW or more) it takes only about 15 minutes tot reach a 80% SoC.

2.5. Cost

When taking the purchase cost of gasoline vehicles as reference, diesel-, LPG- and biodiesel cars are slightly more expensive. Natural gas cars and electric vehicles are much more expensive than gasoline vehicles. Currently the Belgian government is considering introducing a reduction of the "tax on new vehicle registration" for vehicles respecting the Euro IV directive.

Concerning subsidies, a distinction is made in Belgium

Table 1. Overview comparison of the technologies (for the Belgian situation).

Feature	Gasoline	Diesel	LPG	Natural gas	Bio-diesel	Alcohol	EV		FCEV	Hybrid EV
State of the art	EURO IV-norm Currently available		Broadly available	Limited availability	Not available at filling station	Not available at filling station	Limited availability of different types		Not yet available	Only 1 available model
Range	Ref.	Higher than gasoline	300 km (mono-fuel)	200 a 250 km (mono-fuel)	Mix	Mix	70 a 100 km		Comparable with gasoline	Higher than gasoline or diesel
Filling time	Some minutes			10 min./ 6~7 hour	Some minutes	/	15 minutes or 5~8 hour		In function of the fuel	
Safety	Strongly flammable	Carcinogenic, mutagenic and toxic	Original installation is comparable with gasoline	Comparable with gasoline	Biodegradable	Highly toxic and en corrosive	Safer than gasoline and diesel. Battery can be recycled		In function of the fuel	
Available infrastructure	Extended network available			Shortage of public filling stations	No public filling stations		Distribution network exists. Shortage of public filling stations. Socket.		In function of the fuel	
Cost price	○	+	+	++	+	○	+++			++
Governmental intervention	Yes, if EURO IV-norm is satisfied		Different for original and adapted systems.	No	No	No	No		No	
Direct energy consumption	100%	70–90%	85–104%	80–125%	85–90%	105–125%	25–30%		Dependent on the fuel	Dependent on the fuel
Primary energy consumption	100%	70–90%	80–100%	80–115%	63–110%	105–120%	25–80%			50–90%
Emissions:							E.P.E*	E.P.I.*		
NOx	100%	150–900%	60–160%	35–100%	190–370%	30–90%	0%	15–40%		25–40%
HC	100%	30–1000%	25–170%	10–230%	40–60%	85–230%	0%	1–23%		10–50%
CO	100%	15–60%	15–80%	25–80%	20–80%	40–125%	0%	0–1%		10%
SO_2	100%	170–900%					0%	200%		
PM	100%	1000%	10–100%	5–10%	90–1000%	40%	0%	65–75%		
CO_2	100%	75–100%	80–100%	90–100%	40–110%	100–185%	0%	15–160%		60%

*E.P.E: electricity production excluded or on the bases of renewable energy sources; *E.P.I.: electricity production included between LPG cars that have originally been equipped with a LPG-installation on the one hand and gasoline cars that have been transformed into LPG-cars on the other hand. For the first type of vehicle, a yearly reduction of the tax on new vehicle registration amounting to ±297.47 is allocated. For the second type, a subsidy of ±508.18 is allocated under certain circumstances if the transformation has taken place between 01/01/2001 and 31/12/2001. In Belgium, no governmental intervention exists for all the other vehicles (natural gas, biodiesel, alcohol, electric, fuel cell electric and hybrid electric vehicles).

2.6. Energy Consumption

To evaluate the energy consumption of vehicles, it is necessary to take not only the direct energy consumption into account, but also the indirect consumption. The direct, or Tank-to-Wheel, energy consumption is related to the use of the car (fuel consumption, electricity consumption). The indirect energy consumption is considered in this paper as the result of fuel production and distribution (Well-to-Tank) excluding manufacturing, recycling and dismantling energy consumption.

Diesel and LPG vehicles are generally consuming slightly less primary energy than gasoline vehicles. Biodiesel vehicles use less direct energy than gasoline vehicles. The agricultural process however requires a lot of energy. Alcohol vehicles consume in general more direct and primary energy then diesel vehicles. An electric motor has a much higher efficiency (80 to 90%) than a thermal engine (10 to 30%) and as a consequence it consumes much less energy, even if the energy for electricity production and battery charging is taken into account. Electric vehicles can consume up to 75% less direct and indirect energy than gasoline vehicles, depending of the way electricity is produced. The global energetic return of a fuel cell electric car depends on the way hydrogen is produced. If we use electricity that has been produced by wind- or solar energy, to produce hydrogen out of water by means of electrolyze, the global energetic return will not be very high but there wont be any emission. The energy consumption of hybrid electric vehicles depends not only on the chosen drive train topology and power control, but also on the used fuel.

2.7. Emissions

Diesel vehicles emit generally more than gasoline vehicles. If LPG cars are well tuned, the emissions will be lower than for conventional cars (This is more often the case for cars that have originally been equipped than for transformed cars). When using natural gas vehicles, the possibility exists that HC is emitted in larger quantities (2 a 3 times more) compared to gasoline vehicles, due to the CH_4 well-to-tank emissions. Most of the pollution related to the use of biodiesel occurs during the agricultural phase, the oil extraction and the estering process. For alcohol, we can conclude that ethanol and methanol provide a small gain regarding direct emissions, but this gain is mostly nullified by the emissions released during the production of alcohol.

The big attractiveness of electric vehicles is the fact that they dont emit exhaust gases while driving them. If the electricity that is used by those vehicles would originate from renewable energy sources such as wind energy, solar energy or hydro power, the vehicle would practically not pollute at all. The way electricity is produced, i.e. the composition of the electricity production park, is determinative for the emissions associated to these vehicles. The emissions of hybrid electric vehicles depend mainly on the used fuel. However, due to the concept of hybrid cars, their emissions will be much lower than conventional vehicles.

In order to draw some conclusions when comparing different vehicle technologies and fuels, it is useful to have a statistical representative sample of vehicles, based on the same technology. However for some innovative vehicles only a few models of specific types are commercialised. Their representativeness for the technology is not always certain. The other problem is that when (abundant) data exist for specific types of vehicles (fuel and drive train), it occurs that they are sometimes contradictory.

A large number of factors influences the vehicle emissions. The most important factors are the driving behaviour, the characteristics of the vehicle technology and the accessories in the vehicle. All those factors influencing the emissions of vehicles make it very difficult to compare vehicles with each other. In order to compare vehicles in an objective manner in function of the environmental burden, a uniform methodology has to be drawn up, that uses comparable and available data to calculate the environmental damage.

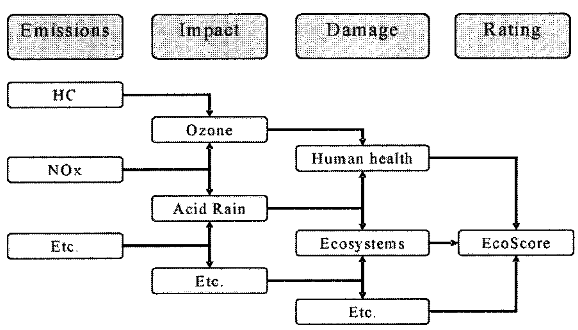

Figure 1. One single value for the environmental impact rating.

Table 2. Overview of the characterisation of the different possible to be considered impacts i.f.o. the emissions.

	Unit	Source	CO_2	HC	NOx	CO	CH_4	N_2O	SO_2	PM	PM10	PM2.5	TSP	NO	NO_2	1.3 Butadiene	Benzene	NMHC	Formaldehyde	Methane	Toluene	Xylene	HAP	Benzo(a)pyrene	Benzo(a)anthracène	Dibenzo(a)anthracène	Lead
Global warming	DALY/kg	Ecolabel 99	2.10E-07				4.40E-06	6.90E-05																			
	GWP	IPCC	1.00E+00				2.30E+01	2.96E+02																			
Respiration - organic components (summer smog)	DALY/kg	Ecolabel 99		6.46E-07			1.28E-08									1.87E-06	4.68E-07	1.28E-06	1.11E-06	1.28E-08	1.36E-06	2.21E-06					
Respiration - non-organic components (winter smog)	DALY/kg	Ecolabel 99			8.87E-05	7.31E-07			5.46E-05		3.75E-04	7.00E-04	1.10E-04	1.37E-04	8.87E-05												
Cancer	DALY/kg	Ecolabel 99								9.78E-06						1.58E-05	2.50E-06		9.91E-07				1.70E-04	3.98E-03	5.86E-02	3.10E+01	
Human health	Damage Cost (per/kg)	Green Book		3.70E-01	4.94E+00	3.00E-02			2.34E+01	3.97E+01																	
Air quality	per/Ton	Cleaner Drive		1.20E+00	3.00E+00	1.03E+00			6.76E+00		9.25E+01																
Ecosystems - ecotoical emissions	PDF,M2,year/kg	Ecolabel 99															2.75E-03				2.40E-04		7.80E-04	1.42E+02			2.54E+03
Ecosystems - acidification & eutrophisation	PDF,M2,year/kg	Ecolabel 99			5.71E+00				1.04E+00					8.79E+00	5.71E+00												
Photochemical air pollution	ppb/O3/Mt/an			3.10E-01	3.70E-01																						
Acid rain	%	VITO			9.00E+01				1.00E+01																		
Buildings	[Euro/kg]	ULB-CEESE							8.26E+00		2.59E+02																

(DALY = Disability Adjusted Life Years, GWP = Global Warming Potential, PDF = Potential Disappearance Factor).

3. ENVIRONMENTAL IMPACT RATING

The basic idea for comparing the environmental impact of vehicles is comparing them on the basis of one single value, representative for the ecological damage the vehicle is responsible for.

A lot of methodologies already exist in different countries like the list of environmental vehicles developed by the "Verkehrsclub Deutschland" and used in Germany, Switzerland and Austria (Auto-Umweltlist, 2000); the Green Book in USA established by ACEEE (DeCicco *et al.*, 2000); the Ecolabelling in the Flemish Region (Belgium) (Govaerts, 2001), the Eco-indicator 95 and 99 in the Netherlands (Goedkoop, 1996) (Goedkoop, 2000), etc. In almost all these methodologies, the ecological damage (greenhouse, acid rain, etc.), the human health effects (cancer, respiratory diseases, etc.), noise, etc. are converted to one single value. Figure 1 illustrates this approach: starting from the characterisation of the different emissions (see further) the impacts and damages are calculated on the basis of scientific expertise and converted into one single value according to the chosen weighting system.

Based on the above quoted references, the different impacts and damages can be calculated in function of the emitted pollutants. The relative contribution of the different pollutants to a certain damage is summarised in Table 2. Next to these emission related damages, one can also consider to take into account other effects like noise, light pollution, stress and time wasting due to congestion, safety aspects, consumption of resources, etc.

In the methodology used at the moment, namely Ecoscore, we have chosen to take into account the following damages and impacts: global warming, respiratory diseases, cancer, impacts on ecosystems, buildings damage and noise perturbations.

4. EMISSIONS INVENTORYING AND CONTRIBUTION

What are the emission sources to be considered? Should we only take into account tailpipe emissions? What is the damage of emissions out of the chimney of a power station?

Some methodologies are based on a **Well-to-Wheel (WtW), Cradle-to-Grave (CtG) or Life Cycle Assessment (LCA)**, which takes into account the different steps into the life and use of the vehicle, starting from the production of the vehicle as well as the production of the fuels, over the use and required infrastructure to end up at the recycling of the vehicle. Figure 2 illustrates this approach.

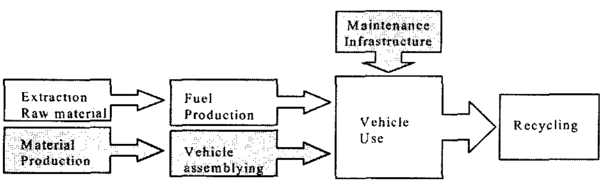

Figure 2. Overview cradle-to-grave.

Table 3. European emission directives for passenger cars (in g/km).

	Year	CO	HC	HC+NOx	NOx	PM
			Diesel			
Euro I	1992	2.72	-	0.97	-	0.14
Euro II-IDI	1996	1.0	-	0.7	-	0.08
Euro II-DI	1999	1.0	-	0.9	-	0.10
Euro III	2000.01	0.64	-	0.56	0.50	0.05
Euro IV	2005.01	0.50	-	0.30	0.25	0.025
			Gasoline			
Euro I	1993	2.72	-	0.97	-	-
Euro II	1997	2.2	-	0.5	-	-
Euro III	2000.01	2.30	0.20	-	0.15	-
Euro IV	2005.01	1.0	0.10	-	0.08	-

4.1. Direct Emissions (Tank-to-Wheel)

Considering the use of the vehicle itself, one can think about using the emissions defined by the emission regulations (EURO I, II, III or IV). Each vehicle brought on the market had to undergo a test that exists of driving a speed cycle (e.g. EDC) on a roll bench while measuring its emissions. These emissions must be lower than defined limits as can be observed in Table 3. Over the years these directives are becoming more and more stringent.

However in real traffic, vehicle emissions are mostly much higher due to the fact that the accelerations of the homologation 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 reality, they can be 2, 3 or even 30 times higher than the emission directives. Additionally, due to ageing and/or bad tuning of the engine and catalyst, real emissions will be higher than emissions of the tested new car. To take these considerations into account, the Green Book (USA) introduces correction factors on the homologation emissions (DeCicco, 2000). Other references (Auto-Umweltlist, 2000) take into account the maximum possible speed of the car to compensate the optimistic emission regulations. This maximum speed can also be used to indicate the environmental impact due to the production of the car (higher speed → stronger and heavier car → more material and energy consumption).

4.2. Indirect Emissions (Well-to-Tank)

The background or indirect emissions are the emissions related to the extraction and transportation of the raw material as well as those related to the refinery and distribution of the fuels. In the case of bio fuels, the following steps are considered: agriculture, transport, processing, distribution and storage. This Well-to-Tank approach is especially required when one wants to compare different alternative fuels and drive trains, since there can be high differences in the emissions related to this production process.

The route from the extraction of crude oil to the use of individual refined components is long and complex. Emissions result from the extraction (gas flaring, venting, gas turbines), transportation (energy used, losses), processing of crude oil (different refinery types) and distribution of the fuel (mainly VOC evaporation for gasoline) (Keller, 1998). In reference (Weber, 2001), 75 fuel paths for 15 different vehicle technologies were considered and evaluated.

The emissions related to electricity production are function of the type of power plant (nuclear, coal, gas, wind, water, etc) and the relative contribution of each power plant to the consumed energy. To know the amount of emissions generated by the production of one unit (1 kWh) of electricity, one must know the exact production mix (i.e. the division of electricity production over the different power plants) in the area considered, according to the time of the day and the season. However, since the electricity grids in Europe are connected in an international mesh network, it is very difficult to attribute a particular energy use of an appliance (i.e. an electric vehicle) to one particular power plant. Mostly, all consumers of electrical energy are treated equally. Using an average electricity production mix as a basis, seems at first sight a straightforward approach, but it is not completely correct. This is a medium worst case for electric vehicles. Electric vehicles will be charged mostly during the night, with a total different composition of electricity production then the average, taking into account that night time electricity production mainly relies on the so-called "base" power stations, which have generally a better efficiency and lower relative emissions. The average contains also old power plants. If one wants to take into account the introduction of electric vehicles in the next ten years, then one needs to consider the investment policy of the electricity production companies. In Belgium, most new power plants are of the Steam and Gas Combined Cycle (SGC) type (with an efficiency of 53%). Furthermore, there is a moratorium on nuclear energy. From 2025, the energy will have to be produced by other then nuclear power plants. It has to be noticed that the introduction of electric vehicles is wrongly associated with the promotion of nuclear power plants. This point of view can be compared with discouraging the use of trains and trams for public transportation because they use electricity that can possibly be delivered by nuclear power plants. An additional consideration is related to individual electricity production. Companies, institutes (like universities, governments administrations, etc), can combine their central heating system with a high efficient electricity generator. This is called the Combined Heat Power (CHP) system. The system produces electricity (with an efficiency up to 50%) as well as heat for the heating of buildings (the overall efficiency of this system can be higher than 80%). In this case, one can consider that the fleet of electric vehicles of that company is charged by their own power plant. The same can be said for a private person who installs solar cells or other renewable energy sources like windmills or water turbines using an individual power production with no emissions. Finally, from 2003 the electricity market in Europe will be liberalised. Consumers can then choose to buy emission

Table 4. Background emissions (Joumard, 1999).

	CO_2	CO	NOx	NMHC	CH_4	SO_2	PM
	g/kWh	mg/kWh	mg/kWh	mg/kWh	mg/kWh	mg/kWh	mg/kWh
Petrol	33.1	18.4	151.9	761.4	62.6	236.2	8.6
Diesel	24.5	16.6	129.6	315.4	56.5	174.2	3.6
LPG	21.6	14.8	116.3	202.7	58.0	114.1	5.4
Kerosene	23.0	16.2	130.7	298.4	57.6	192.6	4.3
CNG	14.8	5.0	38.2	99.0	805.3	60.8	2.9
Bio fuel-RME	108.7	493.2	871.9	280.4		245.5	66.6
Electricity (Elektrabel 2000)	280		510		1.2	450	51

free electricity (Dutch wind energy, Swiss hydro energy, etc.). EV charged with this electricity are ALWAYS emission free.

The comparison by taking the average electricity production for electric vehicles in fleet or individual use is similar as taking all types of thermal vehicle old and new, diesel and petrol together to describe one specific case of the use of an internal combustion vehicle. Nevertheless, these average electricity production mix will be used and should be seen as a pessimist case scenario.

As can be observed in the table, the emissions related to bio fuels are high due to the agriculture process. CNG vehicles have high CH_4 background emissions, which is a greenhouse gas. The background emissions related to electricity production seem to be high, however one must not forget that there are no direct emissions as this is the case for the other types of vehicles.

Contrarily to direct emissions, background emissions are not produced at the place of vehicle operation. Since refinery stations and electricity production plants are mostly installed far away from densely populated areas, their impacts on human health will be lower than direct tailpipe emissions, due to the dispersion of these indirect emissions. One gram of particle matter emitted by a diesel car in a crowded city will cause much higher health damage than one gram of particle matter emitted out of a chimney far away from the population. To take into account some references, like (DeCicco, 2000), a weighting factor is introduced to calculate the total emissions related to health effects, as illustrated with the next equation.

$$E_{total} = E_{direct} + w_{ind.}.E_{indirect} \qquad (1)$$

However for global damage, like greenhouse effect, no weighting is allowed since every gram CO_2 will have the same contribution to this impact.

5. THE REFERENCE VEHICLE–NORMALISATION–WEIGHTING

Once the different impacts on human health, ecosystems, etc. are calculated on the basis of the different identified emissions, the next step is to compare these impacts to the impacts of a chosen reference vehicle. It is not possible to compare directly the impact of Greenhouse gas with those related to respiratory diseases for example. However, dividing these impacts by the impact of a reference vehicle (normalisation) results in a relative value without unit. Hence it is possible to weight the different impact and come up with one final endscore.

In our methodology we have decided to use the most stringent values of the EURO-IV emissions directive for petrol and diesel vehicles. This is what we call the maximum value required to be possibly considered as a 'clean vehicle'. (e.g. for passenger cars: CO = 0.5000 g/km, NO_x = 0.0800 g/km, HC = 0.0500 g/km, PM = 0.0000 g/km). For the non-regulated, but fuel consumption depending emissions, we have chosen to use the following values as reference: CO_2 = 120 g/km, SO_2 = 0.0038 g/km. Also the background emissions can be calculated out of these target values since they are proportional to the fuel consumption.

Reference vehicles are selected for the different vehicle categories (passenger cars, light duty vehicles, heavy duty vehicles, buses and two-wheelers). The methodology is somewhat adapted for heavy duty vehicles and buses since the emission regulations for

Table 5. Weighting of the damages.

Damage		IFEU	Green Book	Aminal	Ecolabel 99	BIM
Health		10%	50%	20%	40%	
	Cancer	15%				20%
	Respiration-Organic Components					15%
	Respiration-Non-Organic Components					15%
Global warming		40%	50%	40%		25%
Environment		10%			40%	10%
	Acid Rain				10%	
	Photochemical			20%		
Resouces					20%	
Speed		5%				
Noise		20%		10%		10%
Buildings						5%

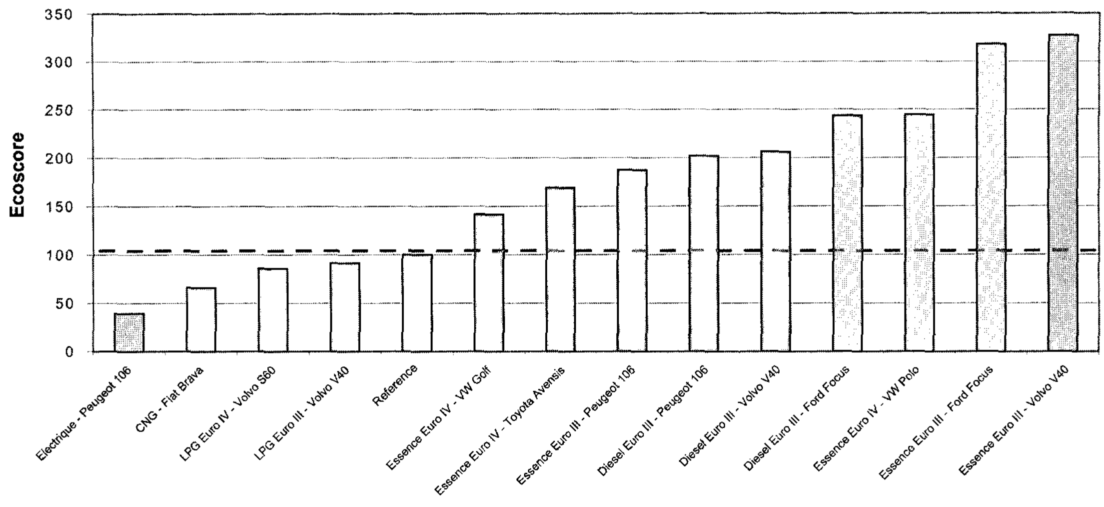

Figure 3. some examples of the Ecoscore.

these categories are based on engine tests (in g/kWh) and not on vehicle tests (in g/km).

In Table 5 different weighting systems are compared. The last column is the relative contribution of the different damages we have selected in our methodology. As can be observed, the contribution of human health is considered more important in comparison to the other methodologies while the contribution for Global Warming is considered less important. This option was based on the fact that the methodology is worked out for the Brussels Capital Region which judges health effects more important since the Brussels Region is a very crowded urban area. However, our methodology can easily be adapted for larger regions or political choices that find e.g. the greenhouse effect more important.

6. RESULTS

The methodology is worked out for some examples in function of the availability of data. These examples are only indicative to evaluate the applicability of the methodology. Different data sources were used (Belgian vehicle registration service, Vehicle Certification Agency of the UK and the European project UTOPIA, 2001). However, when a complete list of clean vehicles would be established, the same data source should be used.

It should be stated that the results of the methodology will be rather optimistic for conventional vehicles since up-to-now the input data is based on the homologation test cycle. Real tailpipe emissions will be higher due to driving behaviour, bad maintenance, bad engine tuning, aging, etc. It is much easier to control some chimneys of the electricity production plants than millions of tailpipes. Hence the methodology gives rather pessimistic results for electric vehicles, since the emission values are based on real life measured emissions and thus do not take into account the investment policies of the electricity production companies.

Despite these considerations, one can observe in Figure 3 the good environmental impact rating (Ecoscore) for the electric vehicle in comparison with other technologies.

CNG vehicles cause twice as much damage as electric vehicles, while LPG vehicles cause a damage that is three times higher than electric vehicles. However CNG and LPG vehicles are still better than the reference vehicle (stringent EURO IV). Note that the LPG installation and CNG engine have an important impact on the real life emissions. The examined petrol and diesel vehicles can not be considered as clean since they have higher values than the reference vehicle (due to COV emissions - cancer & ozone - for petrol and PM ;- health & buildings - for diesel vehicles). However this should not be generalised. Each vehicle should be individually evaluated on the basis of this methodology to see if it can be considered as clean.

7. CONCLUSIONS

A methodology is established allowing to compare the environmental impact of different vehicles of different vehicle categories (passenger cars, LDV, HDV, etc) and using different fuels and drivetrains.

The methodology is based on a comprehensive approach classifying different environmental damages. These damages are calculated on a scientific basis (Exposure-Response damage functions, etc), normalised with the help of the definition of a reference target vehicle (Distance to target) and weighted (Panel Method) by defining the contribution of the different damages to the final endscore (EcoScore).

An inventarisation of all required emissions is worked out. Hence we have described "How should one calculate the environmental damage?" However, to be able to use this methodology a large number of accurate and reliable emissions data is required. These values are not always available especially for several alternative fuelled vehicles. To establish accurate and comparable results, the methodology should be simplified to the calculation of damages for which sufficient data are available.

A definition of "Clean Vehicle" is proposed on the basis of this methodology and the Ecoscore has been calculated for some examples. Electric vehicle have the lowest environmental damage. Also the examined LPG and CNG vehicles could also be considered as clean.

ACKNOWLEDGEMENT–The paper is based on the "Clean Vehicles" research project, commissioned by the Brussels Capital Region via the BIME (Brussels Institute for the Management of the Environment, BIM-IBGE). The Vrije Universiteit Brussel (ETEC) and the Université Libre de Bruxelles (CEESE) jointly carried out the joint study programme.

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