Validation of the well-to-wheel approach in the Ecoscore methodology with life cycle assessment for passenger cars

N. Sergeant, M. Messagie, F.-S. Boureima, J.-M. Timmermans, L. Turcksin, C. Macharis & J. Van Mierlo
Mobility, Logistics and Automotive Technology Research Center (MOBI), Vrije Universiteit Brussel, Belgium

Abstract

Two methodologies are often used for assessing the environmental impact of a specific car, namely the Ecoscore methodology, a well-to-wheel environmental rating tool for vehicles, and Life Cycle Assessment (LCA). The environmental impact of a selection of petrol and diesel cars of different ages, as well as alternatively fuelled vehicles (LPG, CNG, HEV, BEV), has been assessed using both methodologies. The influence of neglecting the impact of the vehicle production, maintenance and end-of-life (EoL) phases has shown to be very small, especially for conventional vehicle technologies (petrol, diesel, LPG). For hybrid (HEV) and battery electric vehicles (BEV), the manufacturing and EoL of the battery also play an important role, which is mainly displayed in the impact on human health and ecosystems. However, since the impact on global warming counts for 50% in the final Ecoscore, these differences will play a smaller role and – more importantly – still lead to the same ranking of the vehicle technologies as in the LCA results for greenhouse effect. These results have shown that the Ecoscore methodology is an efficient environmental rating tool and hence that a well-to-wheel approach can be considered as a good approximation of a full LCA, in these cases where only the homologated emission and fuel consumption data are available. LCA can however provide a more profound assessment, in case sufficient data are available, since more impact categories and pollutants can be taken into account.
Keywords: environment, emissions, passenger cars, well-to-wheel, ecoscore, life cycle assessment (LCA).

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1 Introduction

The Ecoscore methodology [1] is a well-to-wheel (WtW) environmental vehicle rating tool, which has been developed to apply in different policy measures for the Flemish government to promote the purchase and use of cleaner vehicles. Since this tool had to be transparent and easily applicable on a policy level, emission and fuel consumption data had to be available for all vehicles on the Belgian market. The Life Cycle Assessment (LCA) methodology however, requires an extensive set of emission data per vehicle, which is not always easy to retrieve. The more pragmatic Ecoscore tool is therefore based on a 'simplified' LCA methodology, where only the airborne WtW emissions are taken into account, but which allows the calculation of an environmental impact for each individual vehicle.

In this paper, a comparison will be made between the Ecoscore and LCA results of different vehicle technologies and vehicles of different ages, to assess the influence of neglecting the impact of the manufacturing, maintenance and end-of-life phases of a vehicle's full life cycle and hence validate the Ecoscore approach, where only the WtW emissions are included.

2 Methods

2.1 Life cycle assessment methodology

Life Cycle Assessment (LCA) is a standardised methodology (ISO 14040 [2], ISO 14044 [3]) which studies the environmental aspects and potential impacts of a product or service from 'cradle-to-grave', i.e. from raw material acquisition through production and use until disposal.

In the 'Clean Vehicle Research: LCA and policy measures' (CLEVER) project, an extensive LCA has been performed of the complete Belgian passenger car fleet. The environmental impacts of vehicles with conventional (diesel, petrol) and alternative fuels (LPG, CNG, bio-fuels, biogas, hydrogen) and drive trains (combustion engines and battery (BEV), hybrid (HEV) and fuel cell (FCEV) electric vehicles) have been analysed in a Belgian context by Van Mierlo *et al.* [4]). All stages of the life cycle of a vehicle are included in the analyses: raw material extraction, transport, distribution, manufacturing of components, assembly, vehicle use (on a WtW basis), maintenance and end-of-life (EoL) treatment (Figure 1). A detailed description of the methodology, assumptions, inventory and LCA model can be found in [4, 5].

The different vehicles are mutually compared on the same basis, defined as the functional unit (FU), to ensure an objective comparison. The FU of this LCA has been defined as the use of a passenger car in Belgium over a lifetime driven distance of 230.500 km corresponding to a vehicle lifespan of 13,7 years [6, 7], taking the lifetime driven distance of the vehicle into account [8].

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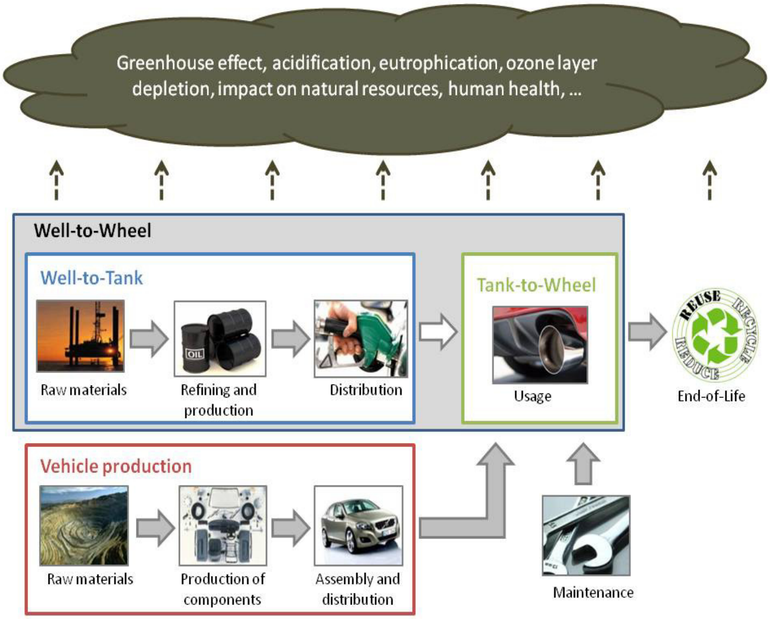

Figure 1: Schematic representation of the different life cycle phases of a vehicle and possible impacts (based on [9]).

An extensive life cycle inventory (LCI) step has been elaborated covering all the inputs and outputs (materials, chemicals, energy, emissions) from and to the environment from all the unit processes involved in the product system [10]. The vehicle specific data such as the segment, technology, fuel type, fuel consumption, Euro standard, weight and direct emissions are obtained from the Ecoscore database (www.ecoscore.be). The Ecoinvent database [11] has been used to calculate LCI data for materials, manufacturing processes, energy production, fuel production and distribution involved in the life cycles of both conventional and alternative vehicles. Detailed LCI data of different battery technologies for hybrid and battery electric vehicles have been collected from the SUBAT project [12]. The transport, shredding and further separation processes of EoL vehicles are based on the current Belgian situation [13]. Thanks to this study, all the recycling and energy recovery rates per material with respect to the real efficiency of Belgian recycling plants were collected [8]. For the manufacturing phase, complete LCI data of the Volkswagen Golf [14] have been used to model a theoretical car which is used as a baseline to model the other cars proportionately to their weight [4].

The environmental impact is calculated in the Life Cycle Impact Assessment step (LCIA). The mandatory elements of the LCIA include the selection of impact categories, the assignment of the elementary flows to the categories (classification) and the attribution of factors to each elementary flow according to its relative contribution to the category (characterisation). Optional elements

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are the calculation of the magnitude of an impact category relative to reference information (normalisation) and the grouping of the different impact indicators into a single score (weighting). However, weighting should not be used for comparative LCA studies intended to be disclosed to the public [2]. In the framework of this paper three impact categories have been assessed: greenhouse effect [15], impact on human health using the Impact 2002+ method [16] and impact on ecosystems, using the Ecoindicator99H (EI99H) method [17]. The RangeLCA 3.0 software [18] has been used to perform the modelling and the calculation.

2.2 Ecoscore methodology

The Ecoscore methodology has been developed with the aim to calculate the environmental impact for every individual vehicle and to compare different vehicle technologies in an objective way. Ecoscore is an environmental score, in which different damage effects are taken into account: climate change, air quality depletion (health impairing effects and effects on ecosystems) and noise pollution. The methodology is based on a well-to-wheel (WtW) approach, which means that besides tailpipe emissions (tank-to-wheel or TtW), also the air pollution caused by the extraction, production and distribution of the fuel or electricity (well-to-tank or WtT) is taken into account. This allows an objective and technology-neutral comparison of different vehicle fuels and technologies.

The Ecoscore methodology can be considered as a ‘pragmatic’ LCA, since only the WtW environmental impact is considered, while the impacts of the production and end-of-life stages of the vehicle itself are neglected. The environmental evaluation of a vehicle through this methodology is being done according to a sequence of five steps, similar to those used in a standardised LCA: inventarisation, classification, characterisation, normalisation and weighting.

In the first step of the inventarisation, the direct (TtW) and indirect (WtT) emissions associated with the vehicle are collected. Direct emission and fuel consumption data are based on homologation data and can be consulted on www.ecoscore.be. Indirect emission data have been obtained from the MEET study [19], complemented with Electrabel data for electricity production [20].

Once the emissions have been calculated, their contribution to the different damage categories are analysed in the classification and characterisation step. The contributions of the different greenhouse gases to global warming are calculated using global warming potentials (GWP), as defined by the Intergovernmental Panel on Climate Change (IPCC). External costs, based on the European ExternE (1997) project [21], are used for the inventoried air quality depleting emissions. Noise pollution is expressed in dB(A), a decibel scale with A-weighting to take the sensitivity of human hearing into account. In these damage calculations, the exposition of the receptors to the pollutants is taken into account, but only for damage caused to human health, since it is related to the location of the emissions. Indirect emissions, which are generally emitted in a rural environment, are given a smaller weight than the direct emissions. A weighted average of urban and rural external costs is used for the direct emissions, based on the national split between urban and rural mileage. For passenger cars, 25% of the mileage is travelled in the city and 75% outside the cities.

To quantify the relative severity of the evaluated damages of each damage category, a normalisation step based on a specific reference value is performed. The reference point is the damage associated with a theoretical passenger vehicle of which the emission levels correspond with the Euro 4 emission target levels for petrol vehicles, a CO_2 emission level of 120 g/km and a noise level of 70 dB(A).

In a final step, the normalised damages are weighted before they can be added to become the "total environmental impact". These weighting factors reflect policy priorities and decision maker's opinions. An overview of the methodology is presented in Table 1. To obtain results situated between 0 (infinitely polluting) and 100 (emission-free and silent vehicle), the total environmental impact (TI or Total Impact) is rescaled to the final 'Ecoscore' indicator. The reference vehicle corresponds to an Ecoscore value of 70. The transformation, given in eqn. 1 is based on an exponential function, so it cannot yield negative scores.

$$\text{Ecoscore} = 100 * \exp(-0{,}00357 * \text{TI}) \qquad (1)$$

In this paper, the Ecoscore and LCA methodologies are compared on the level of the damage categories, since no weighting has been done in the LCA methodology. Therefore the Ecoscore results are presented as the Total Impact of each damage category separately.

Table 1: Summary of the parameters used for the Ecoscore methodology.

Classification	Weighting	Inventory	Units	Damage factors	
				rural	*urban*
1) Global Warming	50%	CO_2	GWP	1	1
		CH_4	GWP	23	23
		N_2O	GWP	296	296
2) Air quality depletion	(40%)				
2a) Human Health	20%	HC	€/kg	3	3
		CO	€/kg	0.0008	0.0032
		PM_{10}	€/kg	103.49	418.61
		NO_X	€/kg	1.152	1.483
		SO_2	€/kg	6.267	14.788
2b) Ecosystems	20%	NO_X	€/kg	0.176	0.176
		SO_2	€/kg	0.113	0.113
3) Noise	10%	Sound level	dB(A)	x-40	

2.3 Vehicle selection

Three types of comparisons were made to validate the Ecoscore WtW approach. For both petrol and diesel cars, the environmental performance was followed over the different Euro standards and hence vehicle ages. Another analysis includes the comparison of different vehicle technologies which are available on the market, all complying with the latest Euro 5 standard: petrol, diesel, LPG, CNG, petrol hybrid and BEV.

Based on the Ecoscore database of January 2010 (see www.ecoscore.be), a selection was made of vehicles from different vehicle technologies with similar size and performance (Table 2). The Volkswagen Golf was used as a reference model since it is available since Euro 2 (1996) and is still a popular car on the Belgian market. When no VW Golf model was available, similar cars have been chosen from the database. For CNG the Opel Zafira was used, for BEV the Nissan Leaf and for the petrol hybrid the Toyota Prius. For these vehicles, the LCA results were calculated, making a distinction between the different life cycle phases, as well as the Total Impact. This was done for three impact categories: greenhouse effect, impact on human health and impact on ecosystems, since these are the categories included in the Ecoscore methodology.

Table 2: Selected vehicles with their fuel consumption (FC), main direct emissions, Ecoscore and total impact (TI).

Fuel/ Techn.	Euro standard	Car model	FC [l/100km]	CO_2 [g/km]	CO [g/km]	HC [mg/km]	NO_x [mg/km]	SO_2 [mg/km]	PM [g/km]	Ecoscore	TI
Petrol	Euro 1 (1994)	Chrysler Stratus	8,2	196	2,720	530	440	1,24	0	48,9	200,42
	Euro 2 (1996)	VW Golf	8,9	213	2,200	275	225	1,34	0	52,4	181,39
	Euro 3 (2000)	VW Golf	9,0	215	2,300	200	150	1,36	0	54,0	172,66
	Euro 4 (2005)	VW Golf	8,1	194	1,000	100	80	1,22	0	58,9	148,34
	Euro 5 (2009)	VW Golf	6,2	144	0,286	28	45	0,94	0	67,1	112,05
Diesel	Euro 1 (1994)	Jeep Cherokee	9,5	251	2,720	100	870	1,62	0,14	21,0	438,12
	Euro 2 (1996)	VW Golf	6,2	164	1,000	70	630	1,05	0,08	36,8	280,22
	Euro 3 (2000)	VW Golf	5,4	143	0,640	60	500	0,92	0,05	46,7	213,62
	Euro 4 (2005)	VW Golf	5,2	137	0,129	13	237	0,88	0,02	60,5	140,96
	Euro 5 (2009)	VW Golf	4,9	128	0,245	40	136	0,83	0,001	70,2	99,10
LPG	Euro 5	VW Golf	7,1	169	0,330	0,032	0,012	1,17	0	71,2	95,29
CNG	Euro 5	Opel Zafira	7,8	139	0,215	0,065	0,022	0	0	73,6	86,10
HEV	Euro 5	Toyota Prius	3,9	89	0,258	0,058	0,006	0,59	0	77,4	71,81
BEV	Euro 5	Nissan Leaf	0,15 kWh/km	0	0	0	0	0	0	86,0	42,42

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3 Results and discussion

In the following figures, a comparison is made between Total Impact and LCA results for three impact categories: greenhouse effect, impact on human health and impact on ecosystems.

Figure 2 shows the results of this comparison for petrol cars of different ages according to the Euro standard. For the three assessed impact categories, the same trend is seen for TI as for LCA. The impact on human health and ecosystems decreases with the age of the petrol car, if assessed with LCA or TI. For greenhouse effect, the Euro 2 and Euro 3 petrol car have a higher impact than Euro 1, 4 and 5 due to the higher TtW emissions of these Euro 2 and 3 cars, which is directly related to the higher fuel consumption and hence CO_2 emissions of these vehicles (see Table 2). Since their regulated emissions (CO, NO_x, HC) decrease according to the emission standards, their impact on human health and ecosystems is lower than for the Euro 1 petrol car. Between these different vehicles, the impact due to manufacture, maintenance and end-of-life remains almost constant and can be seen as an additional offset. The differences are almost entirely due to the WtW emissions of the vehicle.

Figure 3 gives a similar comparison as was shown in Figure 2, but this time for diesel cars of different Euro standards. Again the LCA and TI results display the same trend between the different cars. The impact on greenhouse effect, health and ecosystems decreases towards more recent cars. This can be almost entirely assigned to the WtW emissions, since the contribution of the manufacture, maintenance and end-of-life phases remains quite stable over time.

The last set of graphs (Figure 4) gives a comparison between different vehicle technologies and fuel types, all complying with the Euro 5 emission standard. The impact on greenhouse effect is the lowest for the BEV, followed by the hybrid vehicle. The same ranking of vehicle technologies results from the LCA and TI analysis. The WtT and TtW phases are the largest contributors for this impact category. For the impact on human health and ecosystems, the other life cycle phases play a more important role, especially for the alternative vehicle technologies. The larger impact of the manufacturing phase for the CNG car is due to the higher weight of this car compared to the VW Golf (1623 kg versus ±1250 kg for the Golf). The larger impact on health and ecosystems of the manufacturing and end-of-life of the hybrid and BEV are due to the impact of the battery of these cars. This change in the contribution of the different life cycle phases has created some changes in the relative position of the vehicles, especially for human health. The CNG car has the lowest impact (TI and LCA) on human health due to the very low WtW emissions. Also for the impact on ecosystems, the CNG car has the lowest impact, together with the BEV.

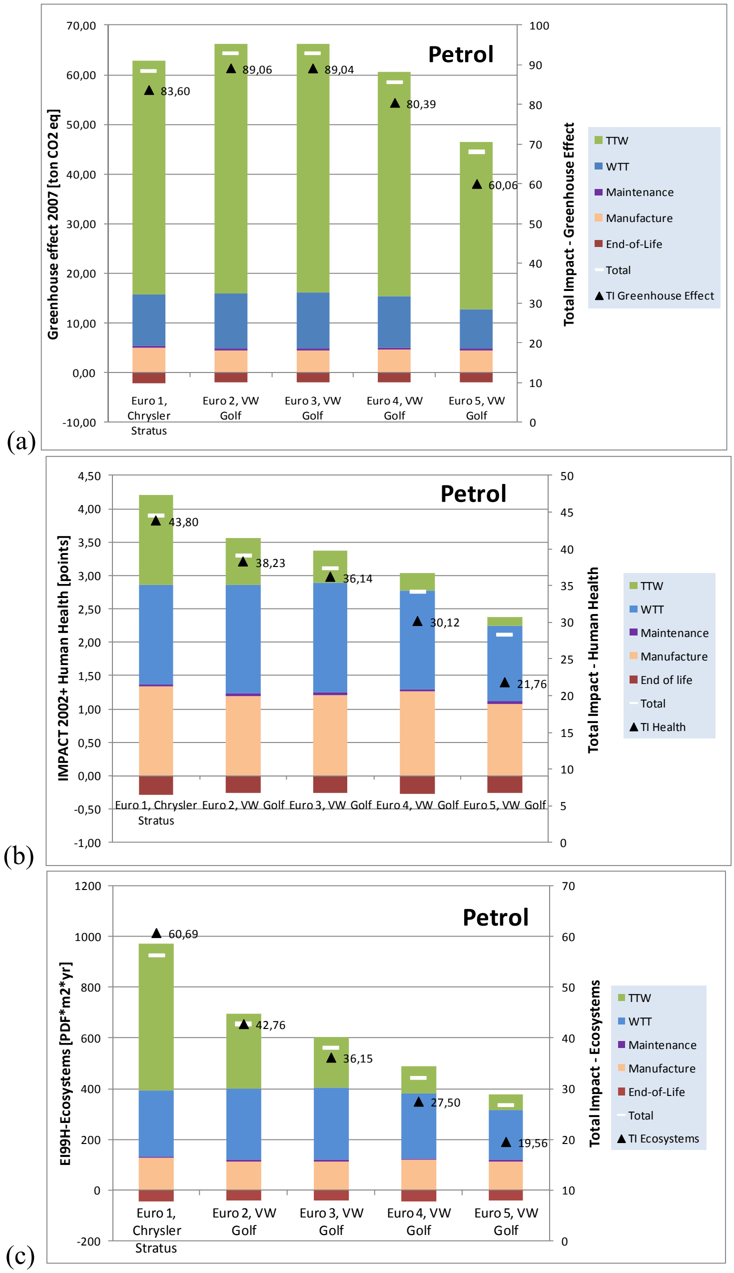
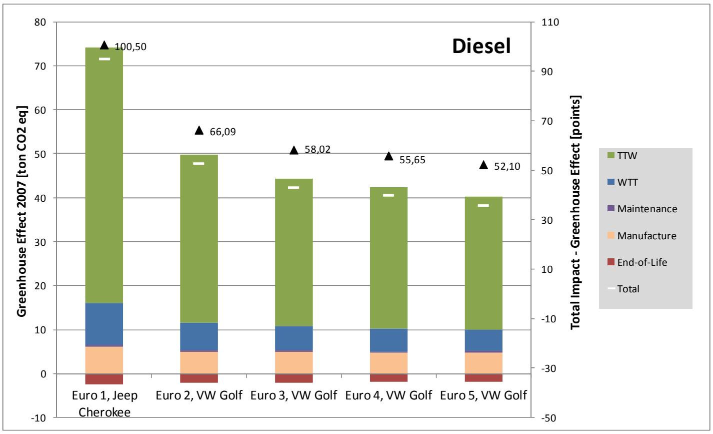


Figure 2: LCA and Total Impact results of a selection of petrol cars of different ages (Euro standards) for greenhouse effect (a), impact on human health (b) and impact on ecosystems (c). Total Impact results are indicated with a black triangle, total LCA results with a white horizontal line.

(a)



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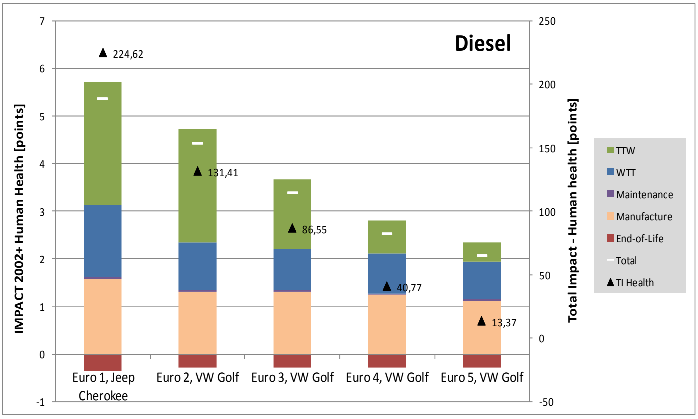

(c)

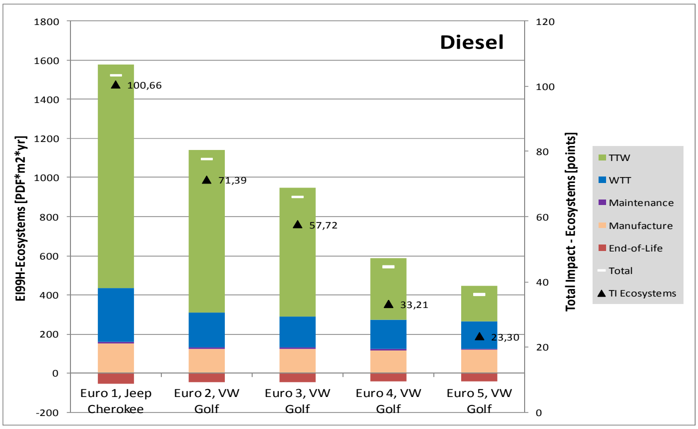

Figure 3: LCA and Total Impact results of a selection of diesel cars of different ages (Euro standards) for greenhouse effect (a), impact on human health (b) and impact on ecosystems (c). Total Impact results are indicated with a black triangle, total LCA results with a white horizontal line.

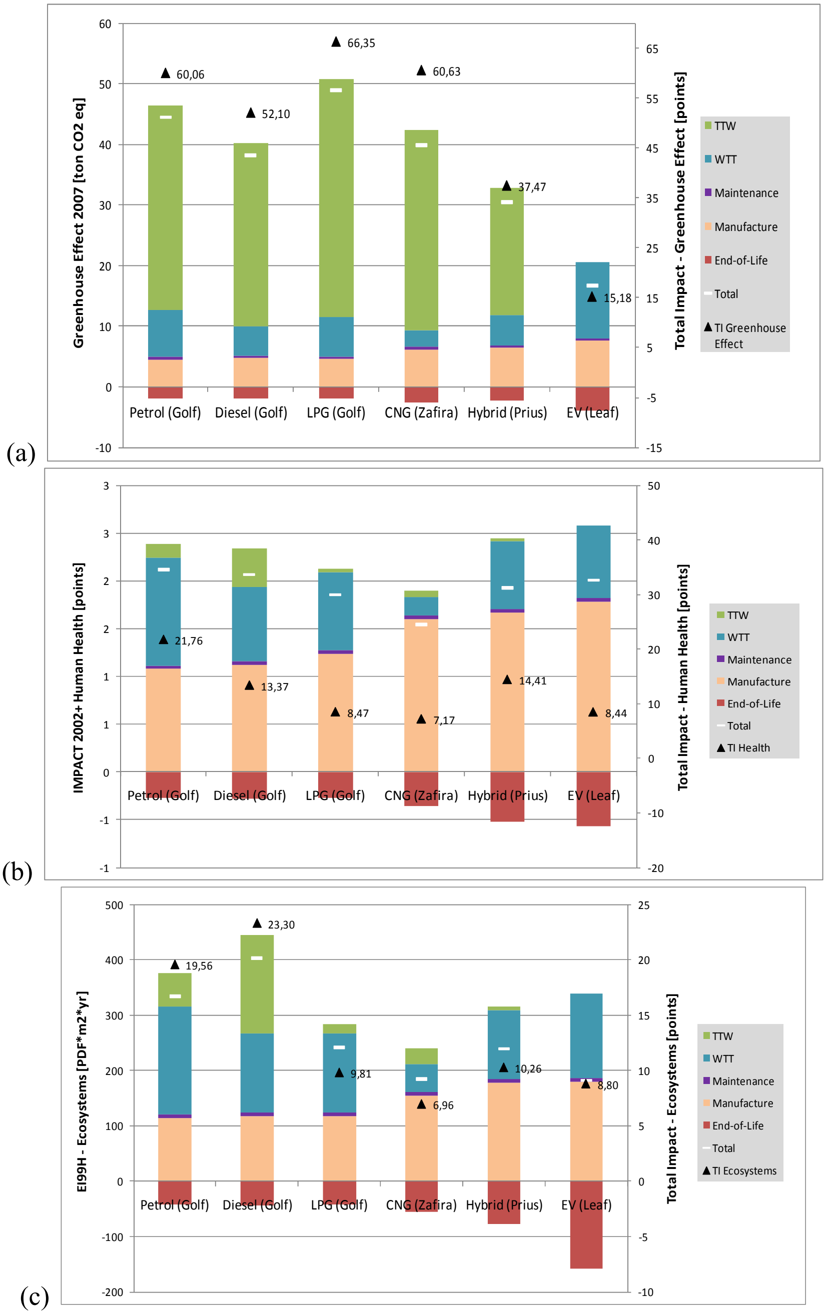

Figure 4: LCA and Total Impact results of a selection of different vehicle technologies for greenhouse effect (a), impact on human health (b) and impact on ecosystems (c). Total Impact results are indicated with a black triangle, total LCA results with a white horizontal line.

4 Conclusions

The Ecoscore methodology is built on a 'pragmatic' LCA structure, since only the phases covering the WtT and TtW part of the life cycle are considered. Within the WtW structure, some differences exist between both approaches. For the direct TtW emissions, the same pollutants from the same source (European homologation data) are used. The indirect or WtT emissions are based on different data sources.

Taking into account these considerations, the Ecoscore methodology has proven to be a good approach to estimate a vehicle's environmental impact, since the ranking of vehicles regarding their environmental performance will not be altered between both assessment methodologies. The influence of neglecting the impact of the manufacturing, maintenance and end-of-life phases has shown to be very small, especially for the conventional vehicle technologies (petrol, diesel, LPG). For hybrid and battery electric vehicles, the manufacturing and end-of-life of the battery also play an important role, which is mainly displayed in the impact on human health and ecosystems. However, since the impact on global warming counts for 50 % in the final Ecoscore, these differences will play a smaller role and still lead to the same ranking of the vehicle technologies as in the LCA results for greenhouse effect.

This proves that the well-to-wheel approach used in the Ecoscore methodology is a solid basis for the environmental assessment and ranking of different vehicle technologies. The LCA methodology is an ideal tool to provide more detailed results and this for a large range of impact categories and pollutants. Hence, the LCA methodology can give a more profound view of the actual environmental impact of a vehicle. It is however not an ideal tool to be used on a policy level due to the large amount of necessary data. This is where the Ecoscore methodology can present an interesting and more practical alternative to analyse the environmental impact of a vehicle.

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