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CLEAN VEHICLE RESEARCH: LCA AND POLICY MEASURES

«CLEVER»

J. VAN MIERLO, F. BOUREIMA, M. MESSAGIE, N. SERGEANT, L. GOVAERTS, T. DENYS, H. MICHIELS, S. VERNAILLEN, L. SCHROOTEN, C. BECKX, C. MACHARIS, L. TURCKSIN, A. BERNARDINI, W. HECQ, F. KLOPFERT, M. ENGLERT, B. DE CAEVEL, M. DE VOS

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CLEAN VEHICLE RESEARCH: LCA AND POLICY MEASURES "CLEVER"

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Promotors

Joeri VAN MIERLO
(ETEC-VUB: Department of Electrotechnical Engineering and Energy Technology, Transportation Technology Research Group - Vrije Universiteit Brussel - Pleinlaan 2, Building Z, 1050 Brussels)

Leen GOVAERTS
(VITO: Vlaanse Instelling voor Technologisch Onderzoek, Boeretang 200, 2400 Mol)

Cathy MACHARIS
(MOSI-T-VUB: Mathematics, Operational Research, Statistics and Informatics- Transport and Logistics Research Group - Vrije Universiteit Brussel - Pleinlaan 2, Building M, 1050 Brussels)

Walter HECQ
(CEESE-ULB: Centre d'Etudes Economiques et Sociales de l'Environnement – Université libre de Bruxelles, Université d'Europe - av. Jeanne 44, CP 124, 1050 Brussels)

Bernard DE CAEVEL
(RDC-Environment, Avenue Gustave Demey 57, 1160 Brussels)

Authors

Fayçal BOUREIMA, Maarten MESSAGIE, Nele SERGEANT (ETEC-VUB)
Hans MICHIELS, Tobias DENYS, Stijn VERNAILLEN, Liesbeth SCHROOTEN, Carolien BECKX (VITO)
Laurence TURCKSIN, Annalia BERNARDINI (MOSI-T-VUB)
Frédéric KLOPFERT, Marion ENGLERT, Walter HECQ (CEESE-ULB)

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Vrije Universiteit Brussel
Electrical Engineering and Energy Technology

Vrije Universiteit Brussel
Department of MOSI – Transport and Logistics

vito
vision on technology

rdc
environment

ULB

CEESE

D/XXXX/XXXX/XX (to complete by Belspo)
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Avenue Louise 231
Louizalaan 231
B-1050 Brussels
Belgium
Tel: +32 (0)2 238 34 11 – Fax: +32 (0)2 230 59 12
http://www.belspo.be

Contact person: XXXXXXXX
+32 (0)2 238 3X XX

REFERENCE

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Acronyms, Abbreviations and Units

ACEA	European Automobile Manufacturers' Association
ACT	Annual Circulation Tax
Adv	Advantages
AFV	Alternatively Fueled Vehicle
AHP	Analytic Hierarchy Process
B5, B10, B30, B100	Blend of diesel with 5, 10, 30 or 100 % biodiesel
BEV	Battery Electric Vehicle
Bq	Becquerel (unit of radioactivity)
CC	Clean Car
CF	Clean Fuels
CH_4	Methane
CM	Car Manufacturers
CM	Choice Modeling
CML	Centrum voor Milieukunde Leiden
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CT	Circulation Tax
CV	Contingent Valuation
D	Diesel
DALY	Disability Adjusted Life Year
E5, E10, E20, E85	Blend of petrol with 5, 10, 20 or 85 % ethanol
EC	European Commission
Eff	Efficiency
ELV	End-of-Life Vehicle
Env	Environmental
eq.	Equivalent
EU	European Union
EuroNCAP	European New Car Assessment Program
EV	Electric Vehicle
FCAI	Federal Chamber of Automotive Industry of Australia
FCEV	Fuel Cell Electric Vehicle
FD	Fuel Distributors
Feas	Feasability
FISITA	International Federation of Automotive Engineering Societies
FPS	Federal Public Service
FU	Functional Unit
GHE	Greenhouse Effect
GHG	Greenhouse Gas
HC	Hydrocarbons
HEV	Hybrid Electric Vehicle
HP	Horsepower
ICE	Internal Combustion Engine
IIT	Information Integration Technology
ILCD	International Reference Life Cycle Data System
IPA	Impact Pathway methodology
IPCC	International Panel on Climate Change
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
KC	Kilometer Charge

LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LPG	Liquefied Petroleum Gas
MIMOSA	Type of transport emission model
mio	millions
MIRA	Milieurapport Vlaanderen (Environmental Report Flanders)
MJ	Mega Joule (unit of energy)
N_2O	Dinitrogen Oxide
NGO	Non-governmental Organisation
NH_3	Ammonia
NiMH	Nickel Metal Hydride
NOx	Nitrogen Oxides
O_3	Ozone
P	Petrol
PF	Public Fleet
$PM_{2,5}$, PM_{10}	Particulate Matter (fraction smaller than 2,5 or 10 µm)
Prio	Priority
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
PV	Present Value
RME	Rapeseed Methyl Ester
RT	Registration Tax
SO_2	Sulphur Dioxide
SUBS	Subsidies
SUV	Sports Utility Vehicle
TI	Total Impact
TIC	Techno-Institutional Complex
TTW	Tank-to-Wheel
UK	United Kingdom
v.km	Vehicle kilometre
VAT	Value Added Tax
VMM	Vlaamse Milieumaatschappy (Flemish Environmental Agency)
VRT	Vehicle Registration Tax
WTP	Willingness-to-Pay
WTT	Well-to-Tank
WTW	Well-to-Wheel
ZE	Zero Emission

Executive summary

A. Context

In a period when environmental issues on a local, regional and global scale are becoming very important, the relationship between transport and the environment needs to be clarified. The finite nature of oil resources and the associated political and economic effects presently lead to the need to assess alternative energy sources and to reduce dependency on imported oil. In addition to these energy aspects, there are important environmental, safety and economy related (e.g. congestion) reasons for changing our transport systems. In order to make transportation more sustainable, different possible options are available: controlling the need for motorised travel, land use planning, making travel safer (driving behaviour), encouraging modal shifts (walking, cycling, public transport) and technical innovation. Among these options, technical innovation of vehicles plays a key positive role.

B. Objectives

The objectives of the project can be described as follows, with a focus on the passenger car market:

- Create an objective image of the environmental impact of vehicles with conventional and alternative fuels and/or drive trains;
- Investigate which price instruments and other policy measures are possible to realize a sustainable vehicle choice;
- Examine the external costs and verify which barriers exist for the introduction of clean vehicle technologies on the Belgian market;
- Analyse the global environmental performances of the Belgian car fleet;
- Formulate recommendations for the Belgian government to stimulate the purchase and use of clean vehicles.

C. Main conclusions/recommendations

Life Cycle Assessment

To compare the environmental impacts of vehicles with different conventional (diesel, petrol) and alternative fuels (Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG), alcohols, biofuels, biogas, hydrogen) and/or drive trains (internal combustion engines and battery (BEV), hybrid and fuel cell electric vehicles (FCEV)), a Life Cycle Assessment (LCA) has been performed, within a Belgian context. An LCA not only takes into account the so-called Well-to-Wheel emissions (tailpipe exhaust and emissions due to production and distribution of the fuel/electricity), but also the pollutants which are emitted during the production, maintenance and end-of-life phase of the vehicle. Because of the large variety of environmental impact categories, it is almost impossible and sometimes misleading to claim that a vehicle is better than the others from all viewpoints. In this project, a list of relevant environmental impact categories has been made in order to have a good appreciation of the environmental score of conventional and alternative vehicles. When dealing with climate impact, conventional vehicles have the highest impact. Battery electric vehicles (BEV) powered with the Belgian electricity supply mix, have a lower greenhouse effect than all the registered family cars in Belgium, with exception of the sugar cane based bio-ethanol E85 vehicle. For the different impact categories considered in this study, the impacts of the LPG technology are comparable to diesel. FCEV are more interesting than petrol and diesel vehicles for greenhouse effect, respiratory effect and acidification. CNG vehicles appear to be an interesting alternative for conventional vehicles. They have a low climate impact (comparable to hybrid technology) and the best score for respiratory effects and acidification. However CNG is produced from a non-renewable fossil fuel.

Life Cycle Cost Assessment (LCC)

From a user perspective, the cost-efficiency is often a crucial factor. The LCC can not only be used to examine whether clean vehicles currently are a cost-efficient alternative to conventional vehicles, but it can also be applied to investigate whether pricing measures, based on the environmental performance of vehicles, can enhance their financial attractiveness.

Within each vehicle type, diesel vehicles represent the greatest cost-efficiency on a per kilometer basis as compared to the reference petrol vehicle, which is mainly the result of differences in fuel-efficiency (20 to 30% more efficient than petrol engines) and in fuel taxation (almost 40% less excises than on petrol fuel). Diesels are known to emit more PM and NOx emissions than petrol fuel, which implies that diesel vehicles should be subjected to a higher fuel tax per litre, given the differences in fuel use per kilometre. On the other hand, this would mean that diesel and petrol vehicles with approximately the same characteristics should be faced with equal fixed vehicle taxes, which would lead to a drastic revision of the current vehicle taxation system. No differentiation in fixed vehicle taxes is currently in place for diesel vehicles with externality reducing characteristics, such as PM-filters, facing a higher cost on a per kilometre basis than conventional diesel vehicles.

Within each vehicle segment, alternatively fueled vehicles (LPG, CNG) and vehicles with alternative drive trains (BEV, HEV) produce competitive costs on a per kilometre basis with respect to the reference petrol vehicle, but are often not cost-efficient with respect to the comparable diesel vehicle. Although biofuels can enjoy a small excise reduction, they are faced with higher fuel taxes on a per kilometre basis as a result of their lower energy density. LPG and CNG vehicles are exempted from paying fuel taxes, but are confronted with an additional fixed tax burden. Many of these alternative technologies also cope with additional conversion costs to make them fuel compatible or with

extremely high purchase prices (in case of BEVs), which add to long payback periods for these vehicles.
Overall, the LCC analysis demonstrates that (more) sustainable vehicles are at present not financially attractive for the Belgian end-user. A new fiscal system based on the environmental performance of cars, using the Ecoscore methodology, can therefore be useful to stimulate the use and purchase of clean vehicle technologies and eliminate existing tax distortions. The new system will then better reflect the cost that each vehicle imposes on the society. However, the steering effect of such a tax reform and other pricing measures should not be overestimated. Pricing measures (like taxation) only act on a small fraction of the overall vehicle costs and have a smaller weight in the purchase decision than e.g. purchase or fuel costs, so it will only indirectly affect the consumers' purchase decision. Moreover, other purchase factors, such as reliability, safety, etc., determine the purchase decision too.

Price elasticities

Policy measures will only be effective if they induce the right behavioural responses. A green vehicle demand model has been developed, which enables to estimate the distribution of respondents wiling to switch to a more environmentally friendlier car, based on different weighted pricing levels of combined policy measures.
Overall, it is shown that combined pricing measures will affect the adoption rate of clean vehicles, but to a certain extent. A possible reason for this outcome is that (1) other factors besides operating costs might be of particular relevance too in the purchase decision (such as purchase price, quality) and that (2) some pricing measures (such as congestion pricing, parking tariffs etc.) rather affect vehicle use than vehicle ownership. This means that a further adoption of clean vehicles will depend on additional supply-sided measures and additional governmental incentives that act on the other important aspects that determine the purchase decision and this confirms the need for an entire policy package which not only consists of pricing measures (sticks), but also of subsidies (carrots) and regulations (see further).

External Costs

An external cost, also known as a negative externality, arises when the social or economic activities of one group of persons provide damage to another group and when that damage is not fully accounted, or compensated for, by the first group. The environmental cost can be integrated into the LCC analysis of new vehicles. This approach allows a complete comparison with conventional vehicles, based on a full-cost approach. Diesel cars without particulate filter are associated with the highest total external cost, reaching c€ 22,6/v.km for an SUV in the most realistic scenario. Diesel vehicles equipped with particulate filters have the second highest total external cost (up to c€ 14,39/v.km for an SUV), though they are much closer to those of the petrol, LPG, CNG, flexifuel and biofuel engines (c€ 7,23/v.km to c€ 9,87/v.km). At the opposite side, electric cars generate the lowest impacts (c€ 4,75/km). Hybrid cars also prove to have lower external costs than any other technology for vehicles of the same weight. This assessment does not allow a direct comparison of flexifuel and biofuel vehicles as the emissions have been measured according to different homologation procedures. Globally, external costs are proportional to the weight of the vehicle for a given motorisation system and are thus highly correlated with the car size. The study also clearly shows the predominance of PM_{10} related impacts in the total societal costs. More specifically, non-exhaust PM appeared to be the main cost driver. At the current state of knowledge however, non-exhaust PM_{10} emissions and their specific impacts on health and building damage are surrounded by a great deal of uncertainty.

Social barriers

While economic barriers appear to be very important, results have shown that other aspects also have a significant impact on consumer behaviour about alternative cars, sometimes more important than economic aspects. Psychological barriers have a significant impact on consumer behaviour about cars. Interviews of fleet managers have highlighted that it is the combination of several barriers (supply, economic, technical and market) that make alternative vehicles particularly unattractive for introducing them in vehicle fleets (except hybrid, for which the main barrier is economic). The lack of supply of alternative vehicles in leasing companies and also the inexistence of alternatives for intervention vehicles or vans limit greatly the development of alternative vehicles in some vehicle fleets.

An important barrier which prevents car manufacturers from developing alternative vehicles is related to the fact that they expect no (or not enough) demand for those vehicles, as they are not competitive with conventional vehicles for several reasons: economic, technical and psychological. Their current strategy is rather to focus on the improvement of conventional fossil fuel cars -diesel in particular- in terms of efficiency and reduction of emissions.

Currently, the market is “stuck” because supply-side stakeholders expect no demand and demand-side stakeholders wait for supply development. This implies a need for policy intervention to release this locking mechanism. However, there is also a lack of policy measures to promote alternative vehicles.

Policy measures

A mix of policies which integrates carrots (incentives), sticks (disincentives) and regulations works best. This includes a mix of target audiences: industry and final consumers, both public and private. For private consumers, tax systems based on environmental performance are getting more and more common. No mandatory systems towards private fleet consumers exist yet today, but voluntary systems are in place and the market starts offering green products. Company car taxation seems the appropriate instrument to influence that market. For public consumers, mandatory targets for clean vehicles seem to have an effect on the overall market and are a suitable instrument to open the market. However, monitoring and impact assessment results from different implemented policy measures are still lacking most of the time. In order to get a better insight into the acceptance level of different policy measures, a series of stakeholder meetings was organized with industrial actors, NGOs, users and policy makers. On some measures (e.g. tax system based on CO_2 and Euro standard) stakeholders easily agreed; on others (e.g. environmental city zones) they did not. Four scenarios were conceived.

The **baseline scenario** only includes current and planned measures, for example (1) Euro 5 and Euro 6 emission standards, (2) CO_2 legislation for new passenger cars, (3) Low blends of biofuels, (4) EU directive on coolants in air conditioning and (5) Mandatory quota for green public fleets. The **realistic scenario** includes measures that are seen as potentially having a large impact, while they are relatively easy to implement in the short term. Extra measures in this scenario (on top of the baseline scenario) are: (1) Vehicle tax system based on the CO_2 and euro standard, (2) Advantages for early-complying-Euro 6 vehicles, (3) Standardization of clean fuels (e.g. CNG and E85), (4) Higher excises for diesel, none on clean fuels, (5) Subsidies for retrofitting old diesel cars with PM filters and (6) Subsidies for cleaner fuel systems (LPG and CNG). The **progressive scenario** includes measures that could have a high impact, but are difficult to implement. Clean vehicles are now defined based on the Ecoscore. Extra measures under the progressive scenario are: (1) Registration tax based on ecoscore combined with a time-, place- and ecoscore-dependent kilometre charge, (2) Limited access environmental city zones, (3) Mandatory green private fleet quota and (4) Scrappage scheme. Finally, a more pragmatic **visionary scenario** has been elaborated in which the vehicle ownership is expected to evolve in the direction of transport sharing.

The results of the four scenarios were clustered in three groups: fleet composition (number of vehicles), vehicle use (number of kilometers) and environmental performance (Well-to-Tank emissions and Ecoscores). The results indicate that the benefit (compared to baseline) of implementing the realistic scenario is rather confined. It seems that the share of diesel kilometers will be even higher than under the baseline. On the other hand, the progressive scenario provides a clear benefit with regard to the number of kilometers driven, emissions and the average Ecoscore. The results obtained from the visionary scenario demonstrate that there is still room for more ambitious targets in the long run.

Multi-Criteria Analysis

For policy makers, several concerns are associated with the choice of a specific policy package to stimulate clean vehicles into the market requiring the application of a multi-criteria assessment (MCA). From a governmental point of view, it is important to know how the market will react on different measures and if it will effectively steer clean vehicles into the market and hence increase the average Ecoscore and decrease the fleet emissions of the Belgian vehicle fleet ("environmental effectiveness"). Moreover, a policy package should also perform well with respect to decreasing vehicle kilometres driven and enhancing people to use other transportation modes inducing a modal shift ("impact on mobility"). Finally, a policy package should by preference be implemented relatively easily, without major obstructions from a budgetary, technical and socio-political point of view ("feasibility"). The overall ranking shows that for the reference year 2020, the progressive and baseline scenario almost have an equal absolute score, which means that they are both seen as scenarios that contribute the best to the different criteria for the reference year 2020. For the reference year 2030, the situation is slightly different. There, the progressive scenario clearly outranks the other scenarios. The overall ranking of the scenarios is noticeably influenced by the established weights attributed to the criteria groups. If, for example, feasibility becomes the major concern for policy makers (50%), then the progressive scenario will be outranked by respectively the baseline and the realistic scenario. More important than the absolute ranking is thus the insight in the strong and weak points of the considered scenarios. It is thus very important to take these sensitivities into consideration when deciding on which scenario to implement. It should also be noted that the overall assessment outcome not only depends on the type of measures introduced, but also on the specific levels of the simulated measures.

D. Contribution of the project in a context of scientific support to a sustainable development policy

New clean vehicle technologies play a key role in the sustainable development because they jointly allow, on the one hand to reduce the pressure on environment and resources and on the other hand to participate in the sustainable growth by emphasising a targeted innovation. In this framework, new clean vehicle technologies contribute to the respect of the principle of precaution because they comply with those growing objectives of environmental quality. These new techniques participate also to the prevention principle for pollution that is not backed by quantified objectives yet but the negative environmental impacts of which are denounced.

The LCA methodology is inherently based on these principles since it allows integrating several environmental quality objectives. As it considers a holistic view of production and consumption cycles, the LCA methodology partly fulfills to the integration principle of sustainability. Taking into account the overcost of new transport modes and complying with stricter standards, as well as the inclusion of external costs and new fiscal policies in the methodology are elements belonging to the polluter-pays principle. Considerations on social equity are other elements that have been analysed. It includes social components like social barriers against new techniques, overcosts and fiscal incentives scenarios for developing the purchase of clean vehicles, in the short or long term.

E. Keywords

Clean vehicles; Transport; Future mobility; Environmentally friendly vehicles; Alternative vehicle technologies; Life Cycle Assessment (LCA); Well-to-Wheel (WtW), Policy measures; Policy scenarios; Life Cycle Cost (LCC); Price elasticity; Consumer behaviour; External costs; Barriers; Emissions; Multi-Criteria Analysis (MCA)

1. Introduction

1.1 Context

A substantial increase and modifications of transport in the European Union are expected in the coming decades. In a period when environmental issues on a local, regional and global scale are becoming very important, the relationship between transport and the environment needs to be clarified. The finite nature of oil resources and the associated political and economic effects presently lead to the need to assess alternative energy sources and to reduce dependency on imported oil. In addition to these energy aspects, there are important environmental, safety and economy related (e.g. congestion) reasons for changing our transport systems. Transport is the cause of large quantities of pollutants in the atmosphere, and these have direct and indirect effects on environmental receptors (people, materials, agriculture, ecosystems and climate, etc.) (Van Mierlo and Macharis, 2005; EC, 2001; EC, 2000; EC, 1997).

In order to make transportation more sustainable, different possible options are available (Deleuze, 2000; OECD, 2002; EST, 2007; CST, 2002): controlling the need for motorised travel, land use planning, making travel safer (driving behaviour), encouraging modal shifts (walking, cycling, public transport) and technical innovation. Among these options, technical innovation of vehicles plays a key positive role, as mentioned by The Centre for Sustainable Transportation: "chiefly through widespread adaptation of vehicle types that are already marketed and through their further improvement" (STM, 2001).

New technologies are being applied to conventional petrol and diesel vehicles (improved engines, On-Board Diagnostic system, etc.) to meet more and more challenging emissions directives. Drive systems, such as fuel-cell powered and hybrid or battery-driven electric vehicles are attractive alternatives. Also, several alternative fuels (LPG, natural gas, biodiesel, bio-ethanol, biogas, hydrogen) are being considered as potential fuel choices for the future.

The environmental impact and road safety of automotive technologies over their different life cycle phases are changing. Also the End-of-Life Vehicle (ELV) treatment is expected to evolve strongly due to the related EU ELV directive entering into effect (EU, 2000).

How environmentally friendly are these conventional and new vehicle technologies? How can their environmental effects be compared? How are they accepted by the general public and other users (enterprises, public administrations)? What are the barriers to their introduction on the market? What possible incentives and policy measures could be implemented to stimulate this market?

1.2 Objectives

In this context, the CLEVER project has the intention to analyse and answer these different questions. The objectives of the project can be described as follows, with a focus on the passenger car market:

- Create an objective image of the environmental impact of vehicles with conventional and alternative fuels and/or drive trains;
- Investigate which price instruments and other policy measures are possible to realise a sustainable vehicle choice;
- Examine the external costs and verify which barriers exist for the introduction of clean vehicle technologies on the Belgian market;
- Analyse the global environmental performances of the Belgian car fleet;
- Formulate recommendations for the Belgian government to stimulate the purchase and use of clean vehicles.

1.3 Methodology

To achieve these objectives, a multidisciplinary approach has been used, in which the different tasks are performed by the different partners.

On the basis of a literature review, a preliminary **"state-of-the-art"** has been carried out on different topics, more specifically on vehicle technologies, existing environmental vehicle assessments, policy measures and consumer behaviour for the purchase of cars.

To compare the environmental impacts of vehicles with different conventional (diesel, petrol) and alternative fuels (LPG, CNG, alcohols, biofuels, biogas, hydrogen) and/or drive trains (internal combustion engines and battery, hybrid and fuel cell electric vehicles), a **Life Cycle Assessment (LCA)** is performed, within a Belgian context. LCA studies the environmental aspects and potential impacts of a product throughout its life from raw material acquisition through production, use and disposal and presents the advantage of being standardized (ISO 14040 & 14062, 2006). Next to the well-to-wheel emissions (related to fuel production, transportation and fuel use in the vehicle), which is assessed in the Ecoscore methodology, the LCA also includes cradle-to-grave emissions (related directly and indirectly to vehicle production and end-of-life processing of the vehicle). The final aim is to develop a methodology with a per-model applicability. A detailed description of the different tasks of the LCA approach (software selection, inventory and data collection, classification and characterisation, sensitivity and probability analysis, scientific validation of the Ecoscore approach) is described further in chapter 2.

To compare the cost-efficiency of different vehicle technologies, the **Life Cycle Cost** (LCC) methodology has been used. From a user perspective, the LCC is often a crucial factor. Life cycle costs are all the anticipated costs associated with a car throughout its life and include all user expenses to own and use vehicles. The LCC consists of the vehicle financial costs (purchase price, governmental support, registration tax), fuel operational costs and non fuel operational costs (yearly taxation, insurance, technical control, battery, tyres and maintenance). The used method within the LCC analysis is the net present value method as one has to accurately combine the initial expenses related to the purchase of the car with the future expenses related to the use of the car. A further description of the methodology and results of this task are described in chapter 3.

The proposed policy measures will only be effective if they induce the right behavioural responses. That is why in a first phase a literature review of **price elasticities** has been performed. Additionally, price sensitivities are empirically derived through the development of a "green vehicle demand model", which enables to estimate the distribution of respondents willing to switch to a more environmentally friendly car, based on different weighted pricing levels of combined policy measures (chapter 4).

The different tasks are supported with inputs of state-of-the-art **external cost** factors. The "ExternE" methodology for the calculation of external costs of transportation is updated and adapted for its use in a Belgian context. Attention has been paid to the best methods and their updating, in order to quantify the external effects associated with new vehicle technologies. Thanks to the knowledge of the externalities, the environmental cost can be integrated into the life cycle cost analysis of new vehicles. This approach allows a complete comparison with conventional vehicles, based on a full-cost approach (chapter 5).

The main barriers impeding the development of alternative vehicles (with alternative fuels and propulsion systems) in Belgium as well as their relative importance have been identified. This objective is approached through the consultation of the different groups of stakeholders. Barriers can be grouped into the following categories: economic, technical, psychological, legislative, political, institutional, environmental/societal, market, supply and demand barriers. Strong relationships exist between the different barriers; in fact, they are integrated into an aggregation of complex causal connections. The second original objective is to derive a systemic scheme representing the inter-relations between barriers. This allows for a more global view on the barriers, which is essential for drawing effective policy measures (chapter 6).

Price instruments are suitable to integrate the environmental performance of vehicles in this purchase decision. The CLEVER project allows investigating possible **policies towards a more sustainable car choice** (chapter 7). Implementation pathways for a consistent policy for the promotion of cleaner vehicles are being developed. These possible policies are price policies (road pricing, fiscal measures, modulated vehicle taxation, parking prices, subsidies...), regulatory policy, etc. The investigated policy instruments not only focus on individual vehicle-buying behaviour but also on policies towards companies and public authorities. The pathways have been developed based on the analysis of the environmental impact, the barriers for the purchase and use of cleaner vehicles. This was done in parallel with the international review of policy measures and related research and consultation of the different target groups in Belgium.

The **road emission model** from VITO has been used to assess the global environmental performance of the whole **Belgian vehicle fleet**. From this model the Ecoscore module is applied to the different vehicle categories (defined by fuel, age, engine size, etc.) of the road emission model to result in a combined Ecoscore-emissions-road model. This allows generating an indicator of the global environmental performance of the fleet and making projections on how this will evolve in time in different **scenarios**. The **projections** have been done for the years 2010 up to 2030 in steps of 5 years, with the mid-term timeframe being 2020 and the long-term timeframe being 2030. Three scenarios have been calculated within these timeframes, and one additional, more visionary, scenario has been calculated solely for 2060.

Finally, by means of a **multi-criteria analysis (MCA)**, the scenarios (baseline, realistic, progressive), elaborated in the previous chapters, have been evaluated on several criteria for which input has been gathered throughout the other tasks of the CLEVER project (chapter 8). For this purpose, a combination of the PROMETHEE methodology and the Analytic Hierarchy Process (AHP) is used. The overall aim is not to categorize the single best scenario, but to formulate suitable policy recommendations to the decision makers which take into consideration the weak and the strong points of the considered scenarios.

To finalise this project, the main conclusions of all the different tasks, gathered by the different partners, have been combined in the last section of this report (chapter 9). In this chapter, answers are formulated on the different research questions of the project, which are the basis of **recommendations for policy makers** on how to stimulate the purchase and use of clean vehicles in a Belgian context.

2. Life Cycle Assessment

2.1 Segmentation

In contrast to several other vehicle LCA studies, the CLEVER project has developed an LCA methodology with per-model applicability instead of an average vehicle LCA. This methodology allows taking into account all the segments of the Belgian car market and producing LCA results per vehicle technology and category. Thus the authorities will be able to take the right measure for the right segment and the consumer will be provided with the detailed information required for his/her vehicle choice.

Several vehicle classification systems already exist, but each of them has some insufficiencies. The main issue is the choice of the segmentation parameters. According to the systems, different parameters are used. For example, The FCAI (Federal Chamber of Automotive Industry of Australia) uses the displacement (FCAI, 2008), while the EuroNCAP (European New Car Assessment Program) uses the vehicle's length (EuroNCAP, 2007). The FISITA (International Federation of Automotive Engineering Societies) system seems to be the most exhaustive since it takes into account the displacement, the power and the weight (FISITA, 2008). The assessment of all those systems reveals that none of them exactly correspond to the Belgian market segments.

After several meetings and discussions, the CLEVER team decided to develop a new classification system based on the existing Ecoscore (Timmermans *et al*., 2006) and FEBIAC (FEBIAC, 2009) systems. The classification criteria come from the Ecoscore database[1]. The innovation of this proposal is the split-up of some vehicle categories of the Ecoscore database into two others, e.g. the 'small car' category in the Ecoscore database is split-up into 'city car' and 'supermini'. Indeed the cars of these two categories present large differences in terms of emissions. The following vehicle segments are then used: city car, supermini, small family car, family car, small monovolume, monovolume, exclusive car, sports car and Sports Utility Vehicle (SUV).

2.2 Data analysis

The modelling parameters of the life cycle of the different vehicles are extracted from the Ecoscore database. A data analysis was performed to extract these parameters from the raw data available in the Ecoscore database (Timmermans *et al*., 2006). Since the Belgian fleet includes a large variety of cars, the modelling parameters are not fixed values but ranges. In the model, all the possible variations of these

[1] The database can be consulted on www.ecoscore.be.

parameters are taken into account, resulting in a variation of the considered impacts. When including the frequencies of these values, one can match a triangular or uniform distribution with the real distribution of the values. Figure 1 and Figure 2 give an example of this approach for a Euro 4 family car using petrol.

There are strong correlations between fuel consumption and vehicle weight, carbon dioxide and sulphur dioxide. These parameters can be described as a linear function of fuel consumption, multiplied with an 'error' distribution, expressing the difference between the linear equation and the real distribution of the parameter. For the other emissions (HC, NOx, CO, PM, CH_4 and N_2O), no satisfying correlation with fuel consumption was found. These emissions are modelled as a triangular or a uniform distribution, matching the reality as closely as possible.

The chosen distributions have an important impact on the overall result, preliminary conclusions of the data analysis are therefore interesting to discuss. Fuel consumption, weight, CO_2 and SO_2 are highly dependent of the chosen segment. On the other side, the Euro standard does not influence these parameters. Impacts of manufacturing and well-to-tank (WTT) emissions do not change by introducing newer Euro standards. Tank-to-wheel (TTW) emissions of CO_2 and SO_2 will also not change by introducing newer Euro standards. On the other hand it is noticeable that the Euro standard influences highly the other regulated TTW emissions. The higher the Euro standard, the lower emissions of HC, NOx, CO, PM, CH_4 and N_2O are.

Next to the homologation emissions provided in the Ecoscore database, heavy metals and non-exhaust emissions have been included in the LCA model as well. On the one hand, the heavy metals, expressed in milligram per kg of burned fuel, are gathered from the CORINAIR project (EEA, 2006). On the other hand, the particulate matter (PM) emissions produced by the abrasion of the tires and the brakes are collected from the CORINAIR project as well and included in the LCA model. Consequently, both tailpipe and non-tailpipe emissions and their effect on the environment are taken into account in this model.

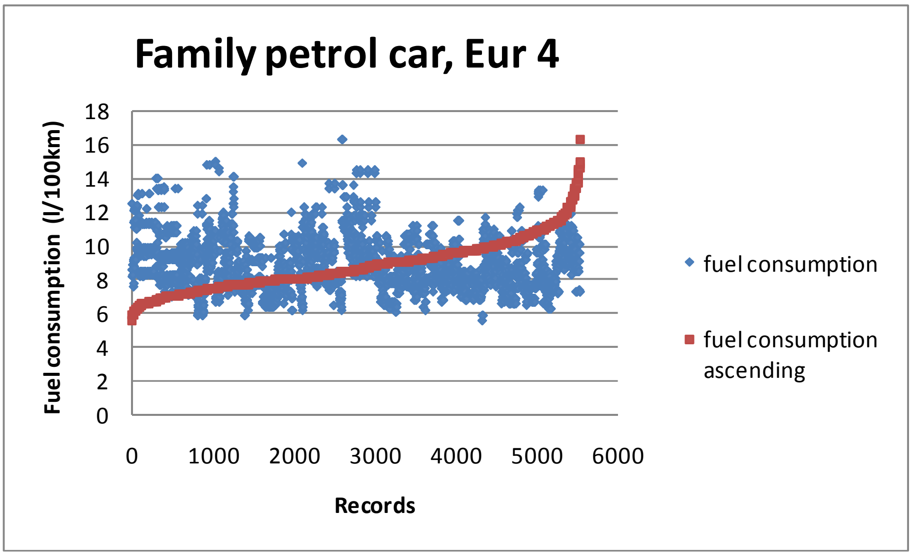


Figure 1: Range of the fuel consumption of the petrol Euro 4 family car.

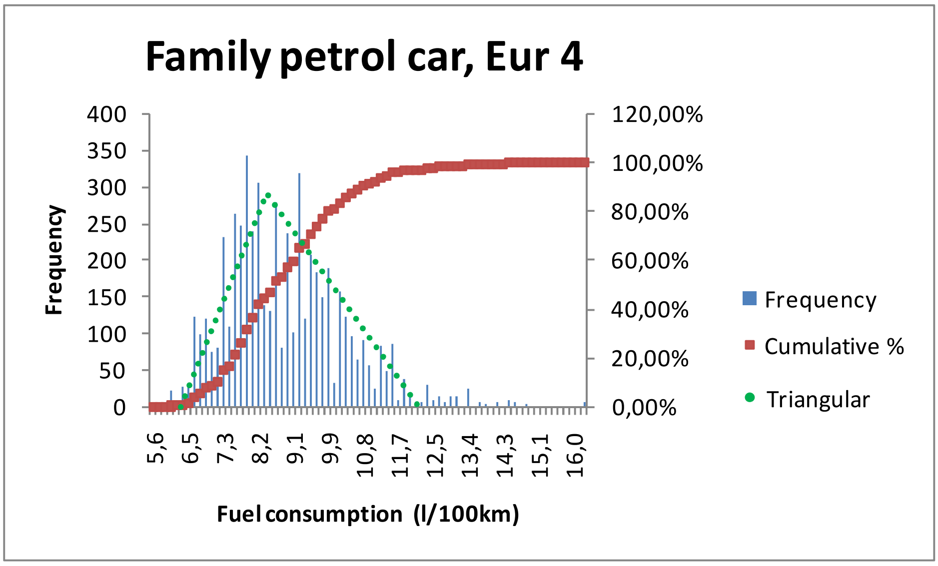


Figure 2: Distribution of the fuel consumption of the petrol Euro 4 family car.

To compare the environmental impact of the different vehicle technologies, a Functional Unit (FU) has been defined. It corresponds to the use of a passenger car in Belgium during 13,7 years and a lifetime driven distance of 230.500 km. As a car can have a lifetime driven distance shorter or longer than the FU, the actual lifetime driven distance has been modelled with a normal distribution covering about 50.000 km to more than 400.000 km with an average corresponding to the FU. The multiplication of the manufacturing step of a vehicle by the quotient of the FU over the effectively driven distance will allow taking into account the number of times a vehicle will need to be produced to correspond to the FU. When calculating the LCA results, a driven distance is chosen randomly between the minimum and the maximum of the normal distribution of the effectively driven distance.

2.3 Range-based modelling system

The different vehicle technologies are modelled in one single LCA tree (Figure 3). For each specific vehicle technology, the fuel consumption, the weight and the different emissions are written as statistical distributions. The data analysis methodology has allowed attributing to each range of data the most relevant distribution. A preliminary calculation has shown that the fuel consumption is the most important parameter of the model and it has almost a perfect correlation with the greenhouse effect which is one of the most important impact categories in an LCA of vehicles. So it has been decided to write the distribution of all the other parameters (weight and emissions) in function of the distribution of the fuel consumption. As a consequence, when running the LCA model, all the parameters will vary in function of the variation of the fuel consumption instead of varying independently. This will create a dynamic model in which every change in one part of the model will influence the other parts allowing a permanent and automatic sensitivity analysis.

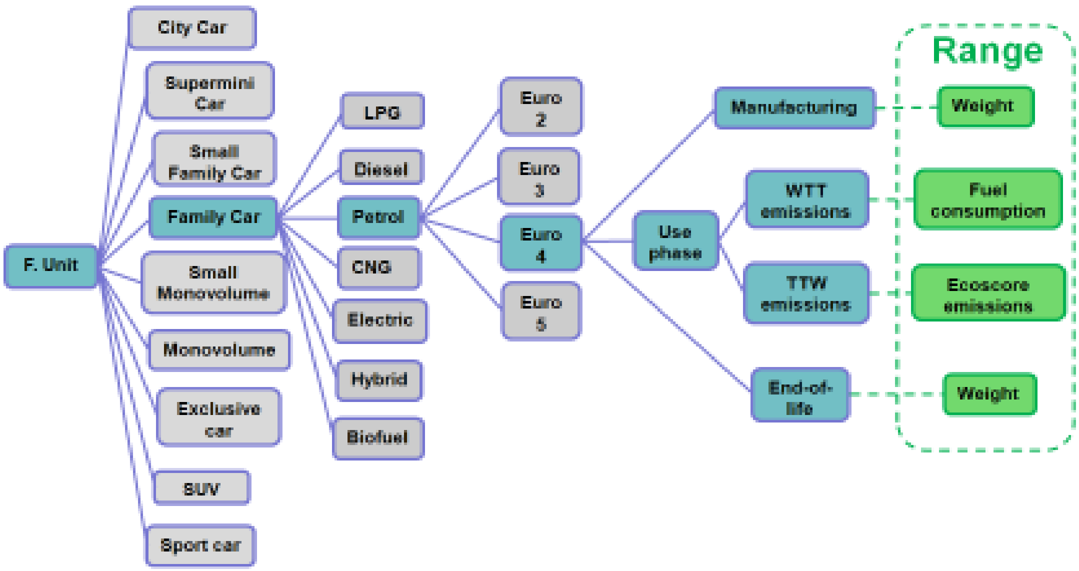


Figure 3: Range-based modelling system used in CLEVER.

2.4 Life Cycle Inventory (LCI)

The life cycle inventory has covered all the life cycle phases of conventional and alternative vehicles. It includes the production and use of fuels, the extraction of raw materials, the assembly, the use phase and the end-of-life. The LCI step of the CLEVER project has been performed thanks to a special data gathering strategy. A list of all the relevant data sources and projects has been made during a detailed literature review. Priority has been given to specific Belgian and European data. The Ecoinvent v2.0 (2007) and Ecoscore databases (Timmermans *et al.*, 2006) have been the main data sources. Raw material production, manufacturing, transport, fuel, energy, maintenance and Well-to-Wheel data are collected for conventional and alternative vehicles. However, some adaptations have been made to avoid repetition and to solve the problem with lack of data. Thus, for the manufacturing phase complete LCI data of the VW Golf (Schweimer and Levin, 2000) have been used to model a theoretical car which is used as a parameter to model the other cars proportionately to their weight. For the emission control technologies, only LCI data of a sedan catalytic converter are obtained. It is also important to note that average Tank-to-Wheel data are considered instead of urban and extra-urban data since the direct emissions come from the New European Driving Cycle (CEC, 1992). Finally, the gathering of direct emissions of biofuel cars has been completed by the emission measurement campaign which has been performed by the BIOSES project (BIOSES, 2010; Tucksin *et al*., 2010).

New materials, fuels and substances have been added to this LCI:

- The material breakdown of FCEV including the fuel cell and the hydrogen tank has been gathered from (Kudoh *et al*., 2007). The hydrogen production has been updated with the steam reforming of natural gas inventory data gathered from the European Roads2hycom project (Prieur *et al*., 2009).
- LPG and CNG production assumptions have been gathered from the CONCAWE project (EUCAR, 2007) and used in the Ecoinvent database (Jungbluth, 2007a) to calculate their LCI data.
- The LCI data of the lithium ion battery have been completed with the detailed production data of the electrolyte (lithium hexafluorophosphate)(Kudoh *et al*., 2007).
- Direct emissions and fuel consumption of flexi-fuel vehicles have been gathered from the BIOSES project (BIOSES, 2010).

Detailed LCI data of vehicles and fuels are available in the CLEVER LCA report (Boureima *et al.,* 2011).

2.5 Impact calculation methods

After the completion of the LCI, the different elementary flows that are linked to a product system need to be converted into environmental indicators. These indicators allow quantifying and comparing the potential environmental impacts of the different product systems. This step of the LCA is called Life Cycle Impact Assessment (LCIA). The LCIA has mandatory and optional elements. The mandatory elements 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). The optional elements 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)(ISO, 2006). However, weighting shall not be used for comparative LCA studies intended to be disclosed to the public (ISO, 2006).

LCIA methods can be classified into two main approaches which are the 'midpoint' approach and the 'endpoint' approach (Figure 4). The midpoint approach allows quantifying the environmental impact somewhere in the cause-effect chain between the release of the pollutants and the ultimate final damage to the environment (Bare *et al*., 2000). This approach has the advantage of being based on common impact mechanisms on which a good level of agreement exist in the scientific community (Jolliet *et al*., 2004). It uses well known physical and chemical phenomena to describe the physical change in the environment due to the release of a pollutant. As a consequence, this approach has low modelling uncertainty. However, the level of information provided by the midpoint approach is not enough for a good interpretation of the LCA results by the decision makers because their main concern is most of time the damage of this environmental alteration on 'humans, animals and plants' (Jolliet *et al*., 2004). The endpoint approach or 'damage oriented approach' conducts the cause-effect assessment untill the ultimate damage to the environment, to the human health and to the natural resources. It has the merit of being more understandable and interpretable but can lead to high uncertainties.

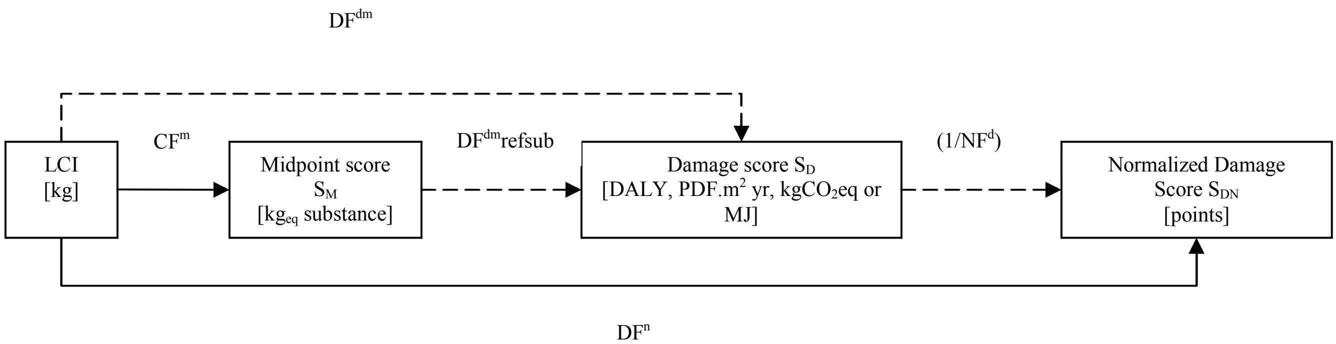


Figure 4: Basic structure of environmental impact evaluation (Humbert *et al*., 2005).

Notes: LCI = flows generally expressed in kg, but LCI can also be expressed in Bq, $m^2 \cdot yr$ or even MJ; CF^m = Midpoint Characterization Factor; DF^{dm} = Damage Factor for the considered midpoint categories; DF^{dm}refsub = Damage Factor of the considered reference substance for the considered midpoint category; DF^n = Normalized Damage Factor; NF^d = Normalization Factor for the considered damage category.

As required by ISO (2006), LCIA category indicators and characterisation models based on international agreement should be used. In this perspective, the European commission via the Joint Research Centre (JRC) has initiated the International

Reference Life Cycle Data System (ILCD) in order to ‘provide governments and businesses with a basis for assuring quality and consistency of life cycle data, methods and assessments’ (EC, 2010). In the framework of the ILCD activities, an analysis of the existing LCIA methods has been performed. In this analysis, the main existing methodologies are described regarding the documentation, the general principals, the consistency across a list of predefined impact categories and the interesting innovative aspects (EC, 2010). Finally, a list of preselected LCIA methods has been produced (Table I). These preselected LCIA methods will be assessed in detail by the ILCD team and a final list is expected for 2011.

In this study, it has been decided to use only LCIA methods preselected in the framework of the ILCD activities and which are relevant for the specific context of automotive LCA. The selected methods are:

- IPCC (2007)
- Air acidification (Guinée *et al*., 2001)
- Mineral extraction (Goedkoop and Spriensma, 1999)
- Non-renewable energy demand
- Respiratory effects (inorganics) (Jolliet *et al*., 2003)

Table I: Pre-selection of characterisation models for further analysis (EC, 2010).

	Climate change	Ozone depletion	Respiratory inorganics	Human toxicity[11]	Ionising radiation	Ecotoxicity	Ozone formation	Acidification	Terrest. Eutrophication	Aquatic Eutrophication.	Land use	Resource Consumption	Others
CML2002	o	o		M	o[12]	o	M	M	M	M	o	M	
Eco-indicator 99	E	E	E	o	o		E	E	E		E	E	
EDIP 2003/EDIP97[13]	o	M	o	M	o	M	M	M	M	M		M	Work environ. Road noise
EPS 2000	E	E	E	E	o	E	E	o	o	o	E	E	
Impact 2002+	o	o	E	M E	o	M E	E	M E		M E	o	E	
LIME	E	E	M	E		o	M E	M E	o	E	E	E	Indoor air
LUCAS	o	o		o		o	o	o	o	o	o	o	
MEEuP	o	o	M	M		M	M	M	M	M		water	
ReCiPe	M E	E	M E	M E	o	M E	M E	M E	o	M E	M E	E	
Swiss Ecoscarcity 07	o	o	o	o	M E	M	o	o	o	o	M E	water	Endocrine disruptors
TRACI	o	o	M	M		M	M	M	o	M		o	
Specific methods to be evaluated	Ecological footprint		[14]	USETox		USETox		Seppälä		Payet	Ecological footprint	deWulf et al.	Noise Müller Wenk
Specific methods of potential interest (not to be evaluated)				Watson (Bachmann)	Ecotoxicity of radiation (Laplace et al.)		EcoSense (Krewitt et al.)	EcoSense (Krewitt et al.)		Kärrman & Jönsson	[15]		Meijer indoor air UNEP Indoor air (Bruzzi et al., 2007)

o: Available in the methodology, but not further investigated

M: Midpoint model available and further analysed

E: Endpoint model available and further analysed

As it can be noticed in Table II to Table VII, the most important and relevant elementary flows are considered in the selected impact calculation methods. Endpoint methods, with the exception of respiratory inorganics, have been used for all the selected impact categories.

For the specific cases of renewable and non-renewable energy demand, the calculation method has been developed by RDC-ENVIRONMENT with inputs from themselves and from the Swiss Agency for the Environment, Forests and Landscape

(BUWAL). The energy demand (Table V) includes all types of primary energy involved in a product system. It also includes the heating value of products, resources and materials.

The respiratory inorganics impact on human health (Table VI) is particularly interesting in this study because it includes particulates, carbon monoxide and nitrogen and sulphur based emissions. These emissions are among the pollutants allowing clear differentiation between vehicle technologies and fuels.

The IPCC (2007) method has been extended to biogenic CO_2 and the CO_2 uptake from the air during the synthesis of the organic matter. A negative factor is attributed to the CO_2 uptake.

The air acidification (Table III) and eutrophication (Table IV) calculation expressed respectively in kg SO_2eq/kg and kg PO_4eq/kg are from the CML 2001 methodology (Guinée *et al*., 2001). It includes mainly nitrogen, sulphur and phosphorus based emissions. These two methods allow performing a comprehensive assessment of the effect of the fertilisers for biofuels on the one hand and assessing the impact of the use of products and resources containing sulphur (e.g. crude oil), phosphorus or nitrogen on the other hand.

The mineral extraction damage (Table VII) expressed in MJ surplus/kg allows assessing the additional energy requirement for further mining of the mineral resources in the future due to the lower resource concentration. This method is particularly interesting for the manufacturing phase of vehicles in general and the manufacturing of specific components (battery, fuel cell, hydrogen tank, etc.) in particular.

Table II: IPCC (2007) method including biogenic CO_2 and CO_2 uptake from the air.

Elementary flows	**Characterisation factor (kg CO_2eq/kg)**
CFC 12 (CCl_2F_2)	10900
CFC 113 ($CFCl_2CFCl_2$)	6130
HFC 23 (CHF_3)	14800
HCFC 21 ($CHCl_2F$)	210
CFC 11 ($CFCl_3$)	4750
Chloroform ($CHCl_3$)	756
HFC 134a (CF_3CH_2F)	4470
Hexafluoroethane (C_2F_6, FC116)	12200

Halon 1211 (CF_2ClBr)	1890
CFC 114 (CF_2ClCF_2Cl)	10000
Sulphur Hexafluoride (SF_6)	22800
Halon 1301 (CF_3Br)	7140
HCFC 22 (CHF_2Cl)	1810
Methan (biomass)	25
Nitrous Oxide (N_2O)	298
Methane (CH_4)	25
Carbon Dioxide (CO_2, biomass)	1
Carbon Dioxide (CO_2, in air)	-1
Carbon Dioxide (CO_2, fossil)	1
CFC 13 (CF_3Cl)	14400
HCFC 124 ($CHClFCF_3$)	609

Table III: CML 2001 Air acidification (Guinée *et al*., 2001).

Elementary flows	**Characterisation factor (kg SO_2eq/kg)**
Sulphuric Acid (H_2SO_4)	0.65
Hydrogen Sulphide (H_2S)	1.88
Hydrogen Fluoride (HF)	1.60
Ammonia (NH_3)	1.60
Hydrogen Chloride (HCl)	0.88
Nitrogen Oxides (NOx as NO_2)	0.50
Sulphur Oxides (SOx as SO_2)	1.20
Nitrogen Dioxide (NO_2)	0.50
Sulphur Dioxide (SO_2)	1.20
Hydrogen Sulphide (H_2S)	1.88

Table IV: CML 2001 eutrophication (Guinée *et al*., 2001).

Elementary flows	Characterisation factor (kg PO_4eq/kg)
ammonia	0.350
chemical oxygen demand	0.022
nitrogenous matter	0.420
nitrous oxide	0.270
phosphates	1.000
phosphorus, total	3.060
phosphorus pentoxide	1.340
nitrate	0.100
nitrite	0.100
nitrogen	0.420
nitrogen dioxide	0.130
nitrogen monoxide	0.200
nitrogen oxides	0.130

Table V: Non-renewable energy (BUWAL/RDC)

Elementary flows	Characterisation factor	Unit
Peat	25.0	MJeq/kg
Coal (in ground)	19.0	MJeq/kg
Oil (in ground)	45.6	MJeq/kg
Lignite (in ground)	9.5	MJeq/kg
Natural Gas (in ground)	48.1	MJeq/kg
Uranium (U, ore)	451000.0	MJeq/kg
Unspecified Fuel Energy	1.0	MJeq/MJ

Table VI: Impact 2002+ respiratory inorganics (endpoints) (Jolliet *et al.*, 2003).

Elementary flows	Normalised damage factors (Impact 2002+ points)
Ammonia (NH_3)	1.20E-02
Carbon Monoxide (CO)	1.03E-04
Nitrogen Dioxide (NO_2)	1.25E-02
Nitrogen Oxides (NOx as NO_2)	1.25E-02
Sulphur Oxides (SOx as SO_2)	7.69E-03
Sulphur Dioxide (SO_2)	7.69E-03
Particulates ($PM_{2.5}$)	9.86E-02
Carbon monoxide (biomass)	1.03E-04

Table VII: Eco-indicator 99 Hierarchist, Resources, Mineral extraction damage (midpoints) (Goedkoop and Spriensma, 1999).

Elementary flows	MJ surplus/kg
Aluminum in bauxite	2.38
Chromium (Cr, ore)	0.9165
Copper (Cu, ore)	36.7
Iron (Fe, ore)	0.051
Lead (Pb, ore)	7.35
Manganese (Mn, ore)	0.313
Mercury (Hg, ore)	165.5
Molybdenum (Mo, ore)	41
Nickel (Ni, ore)	23.75
Tin (Sn, ore)	600
Zinc (Zn, ore)	4.09

2.6 Results

2.6.1 Greenhouse effect

The LCA results of this study should be interpreted with caution. The objective of this study is not to compare different technological options (hybrid, FCEV, BEV, ICE…) of one single vehicle but to compare different existing vehicle technologies of the Belgian fleet. More specifically, the compared vehicles do not have the same size or the same energy consumption but they are from the same market segment and are being used for the same purpose by the end-user. The comparison of different family car technologies shows that the climate impact is highly influenced by the vehicle technology, the type of fuel and the type of feedstock used to produce the fuel (Figure 5). One can notice in this figure that the sugar cane based bio-ethanol E85 vehicle has the lowest greenhouse effect. This is essentially due to the benefit of the CO_2 uptake from the air during the production of the sugar cane. Additionally, the electricity used in the sugar cane fermentation plant is produced with the bagasse obtained after the crushing of the sugar cane. However this good score of the E85 fuel highly depends on the feedstock type and e.g shifting from sugar cane to sugar beets will increase the impact of the E85 vehicle more than three times (Figure 5). After the sugar cane based E85 vehicle, the BEV using the Belgian supply mix electricity has the lowest greenhouse effect. This good score of the BEV can be explained by the fact that 55% of the Belgian production electricity mix is nuclear and the fact that BEV is an exhaust emission free vehicle. Despite the low greenhouse effect of the BEV, the contribution of the lithium ion battery to the overall impact is still higher. However, a large share of the impact of the lithium battery is balanced by the benefit of the recycling. Like the BEV, the FCEV is also an exhaust emission free vehicle but it has a greenhouse effect which is higher than the BEV and comparable to the biodiesel B100 (RME) (Figure 5). The difference between the FCEV and the BEV is essentially due to the fact that the hydrogen is produced with natural gas while more than half of the Belgian electricity is nuclear. Contrarily to the sugar cane based E85, the B100 (RME) production is almost greenhouse gas neutral. Indeed, the benefit of the CO_2 uptake from the air during the rape production is balanced by the effect of the intensive agricultural practices such as the fertilizing and the machinery.

Another interesting finding of this study is the good climate impact score of CNG vehicles in comparison to alternative vehicles such as hybrid and LPG. In fact, the natural gas production is less energy intensive and pollutes less than the production of petrol and propane/butane based LPG. Additionally, natural gas also has a good combustion efficiency. However, the benefit of fuel saving of hybrid cars (lower TTW impact) compared to ICE vehicles is clearly identified in Figure 5. The relatively higher greenhouse effect of the LPG car can be explained by the fact that the LPG is modeled with propane/butane combined with a liquefaction process. The use of flare gas to produce LPG would reduce this impact. In general, for alternative vehicles such as FCEV and BEV the recycling of specific components such as the fuel cell or the lithium battery has a big environmental benefit. Furthermore the type of feedstock and the conversion technology for alternative fuels (biofuels, hydrogen…) have a strong influence on the GHE of the vehicles.

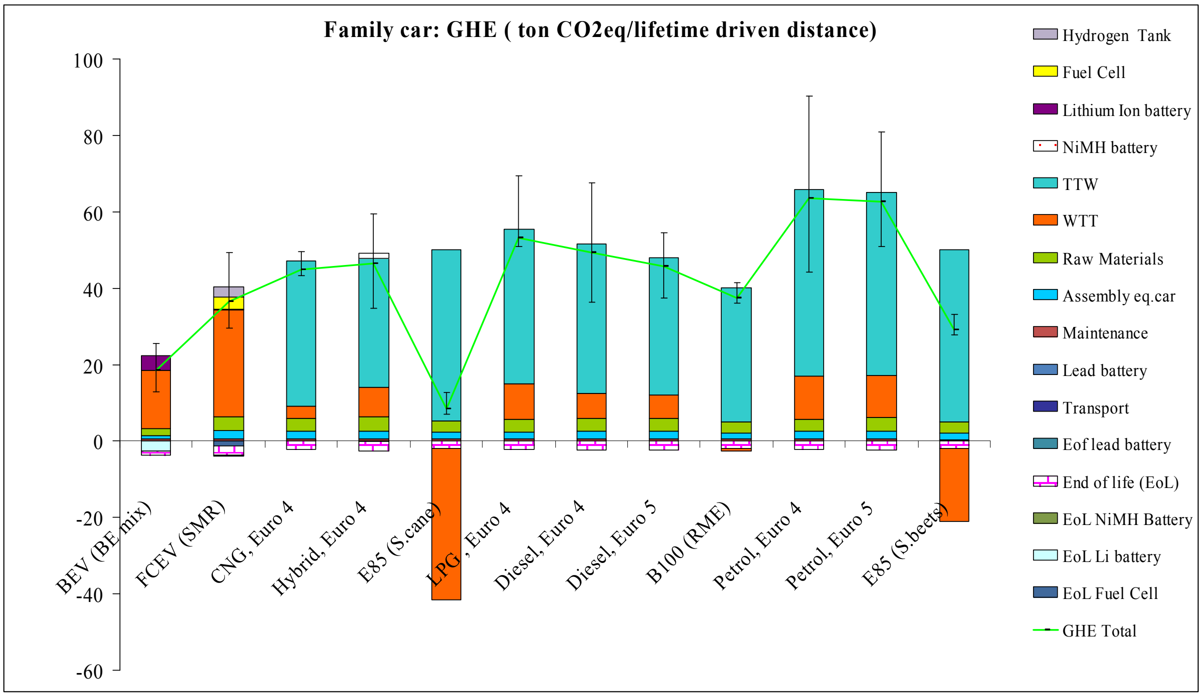


Figure 5: Comparative Greenhouse Effect (GHE) assessment of family car technologies.

In order to have a deeper understanding of the results of this study, the LCA model has been run 1000 times with different values chosen randomly between the minimum and the maximum of all parameters modeled as a range. However extreme values corresponding to 2% of the iterations have been excluded. Thanks to this approach, the effect of the simultaneous variation of the vehicle weight, the energy consumption and the emissions has been assessed. No weight variation has been considered for specific cases (FCEV, BEV, E85, CNG and B100) where only one vehicle is available. However, the errors on the measurements of the fuel consumption and the direct emissions have been included for these vehicles. As a consequence, vehicle technologies with large variety of brands and models (Petrol, Diesel, LPG and Hybrid) will have a wide spread of LCA results. With such an approach, stronger conclusions are drawn because the worst case of a given technology can be compared to the most favourable case of another one. For example, one can notice in Figure 5 that the considered BEV powered with the Belgian electricity is not only better than the other fossil fuel vehicles in average but also better than the smallest fossil fuel vehicles of its segment. Thanks to this iterative approach, the overlaps between the different technologies are identified. On a policy perspective, the decision makers can use these kinds of results to determine for which groups of vehicles they can take the same policy measures or on the contrary to identify for which groups specific measures are necessary.

On Figure 6, different scenarios of BEV using different types of electricity have been compared to assess the influence of the electricity production technology on the LCA results of BEVs. The BEVs powered with windpower, hydropower or nuclear power appear to have a very low greenhouse effect. They are followed by the scenarios of the Belgian electricity mix and the natural gas electricity which also have very low greenhouse effect in comparison to diesel and petrol vehicles. However, extreme scenarios in which BEVs are powered with oil or coal electricity appears to have climate impacts which are comparable to the ones of diesel cars. In average, the greenhouse effect of petrol cars is still higher than the one of BEVs powered with oil or coal electricity. Nevertheless, The error bars (Figure 6) show that small petrol cars within the family car segment can have a greenhouse effect which is comparable to a BEV powered with coal or oil electricity.

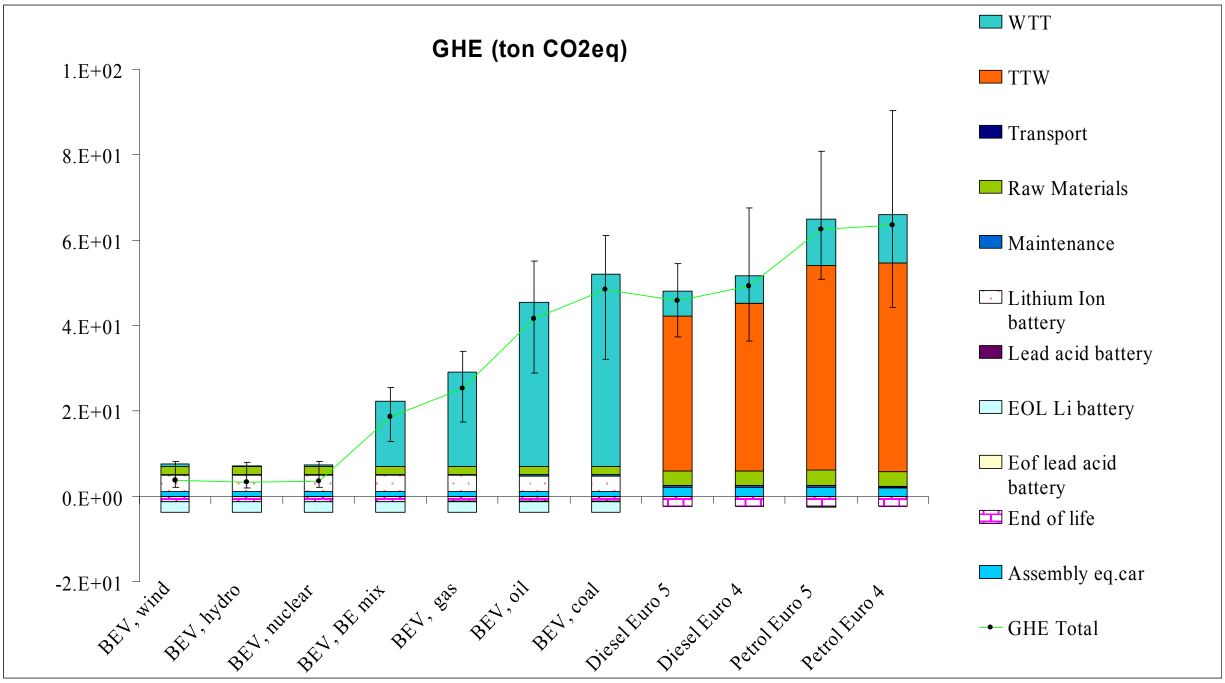


Figure 6: Sensitivity of the GHE impact of BEV to the type of electricity production

Additionally, the different electricity production scenarios have been investigated in detail in order to assess the contribution in terms of GHE of the different unit processes involved in the electricity production chain. For renewable electricities such as windpower and hydropower, the construction of the power plant is the main contributor and represents 95% of the overall GHE of the electricity production. Contrarily to renewable electricities, the power plant construction is responsible for less than 1% of the overall GHE for electricty of fossil (coal, oil, gas) origins where the combustion of fossil feedstock is responsible for 85 to 90% of the greenhouse gas emissions. In the specific case of nuclear electricity, the power plant construction is responsible for about 14% of the greenhouse gas emissions.

2.6.2 Respiratory effect

Close to the GHE, the respiratory effects of the different family car technologies have been compared (Figure 7). Contrarily to the GHE, the E85 sugar cane technology has the worst score for the respiratory effects (inorganics). This is mainly due to the burning of the sugar cane field before the harvest. The main pollutants emitted during the field burning are Carbone monoxide, methane and particles (Moreira *et al.*, 2000). However, a regulation allowing a progressive shift from manual harvesting (with field burning) to automatic harvesting (without field burning) is being implemented in Sao Paolo by 2021 (Sao Paolo, 2002). It is then followed by the RME vehicle. This high respiratory effect of the RME car is mainly due to the emission of ammonia and nitrogen oxides which are directly linked to the use of nitrogen based mineral fertilisers. Additionally, the biodiesel vehicle emits more nitrogen oxides than the corresponding diesel vehicle.

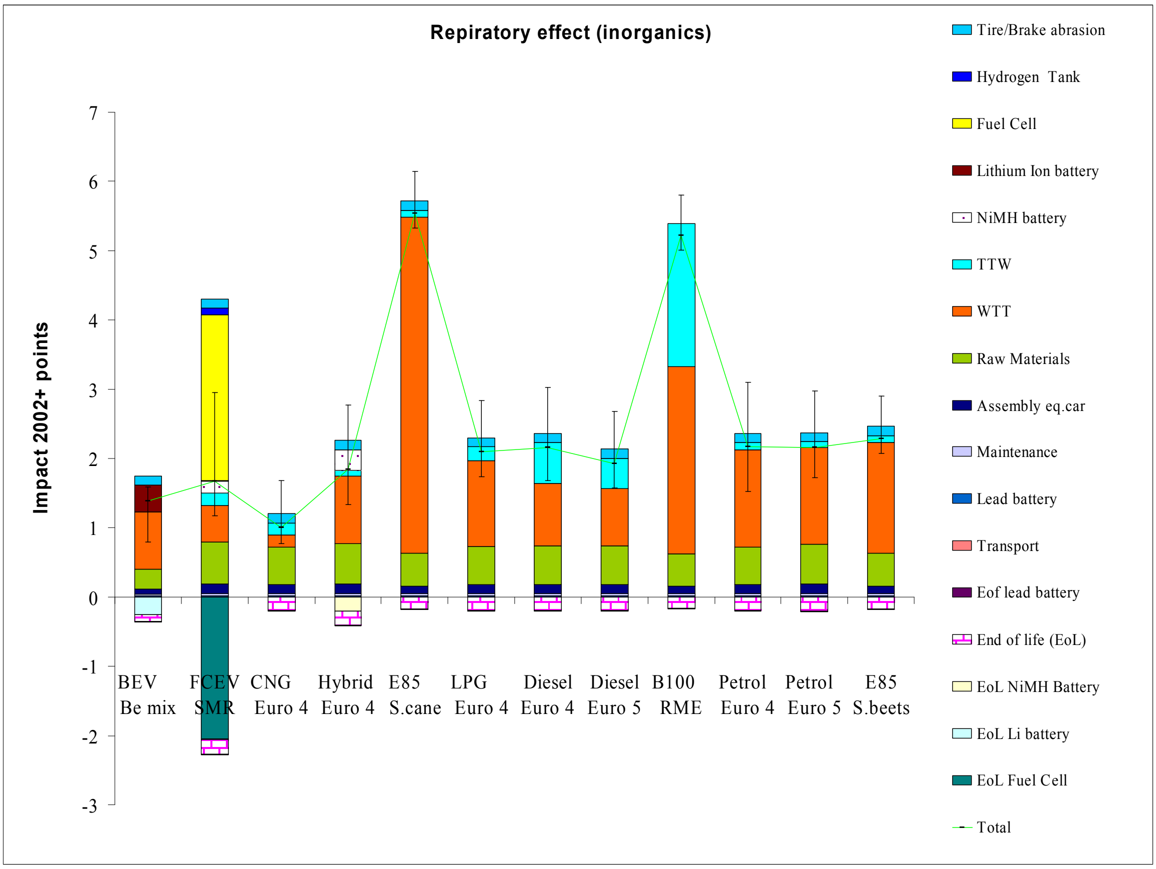


Figure 7: Respiratory effects of different family car technologies.

The best score in this impact category goes to the CNG vehicle. The production of the natural gas has relatively low emissions for all the considered pollutants in this category. This is also true for the direct emissions of the CNG vehicle. The CNG technology is followed by the BEV. The FCEV has a respiratory effect lower than the ICE vehicles but slightly higher than the BEV. Without recycling of the fuel cell, the FCEV would have the worst score for this impact after the E85 and the RME vehicles.

2.6.3 Acidification

Unlike the case of climate impact, petrol and diesel vehicles appear to be more interesting than biofuel vehicles when dealing with the acidification impact (Figure 8). In the case of conventional and biofuel vehicles, it appears that the fuel production step is the main contributor. The considered pollutants are nitrogen based emissions, sulphur based emissions and fluoride and chloride acids. They are derived either from the ingredients used to produce the fuel or from the feedsock itself, e.g. sulphur content of crude oil. The RME vehicle has the worst score in this category and pollutes two times more than diesel vehicles. This is mainly due to the high emissions of nitrogen based pollutants during the feedstock production and the higher NOx emission during the use phase of RME vehicles. Sugar cane and beet E85 vehicles have comparable acidification impacts and score a bit lower than petrol vehicles. This is due to the feedstock production as well as the use of sulphuric acid before the fermentation of the cane or beet juice. On average 29g and 11g (Jungbluth *et al.*, 2007b) of sulphuric acid are needed to respectively produce a kg of beet ethanol and a kg of sugar cane ethanol. Another interesting finding for this impact category is the result of the FCEV. In fact, the production of platinum contained in the fuel cell has a very strong acidification impact but this impact is balanced by the recycling of the fuel cell. As a consequence, the FCEV will have for this impact the third best score after CNG and BEV.

The benefit of switching from petrol to hybrid can also be seen in Figure 8. In fact, the low contribution of the WTT phase of the hybrid vehicle in comparison to the petrol one is due to the lower petrol consumption of a hybrid car compared to a conventional petrol car. However the higher contribution of the NiMH battery due to the nickel can be seen in this figure. Finally, it can be noticed that the acidification impact of diesel vehicles is lower than the impact of petrol. This is due to the fact that the production of petrol emits more NOx than the production of diesel. Diesel vehicles emit more NOx during the TTW phase but not enough more to balance the benefit of the lower NOx emission during the WTT.

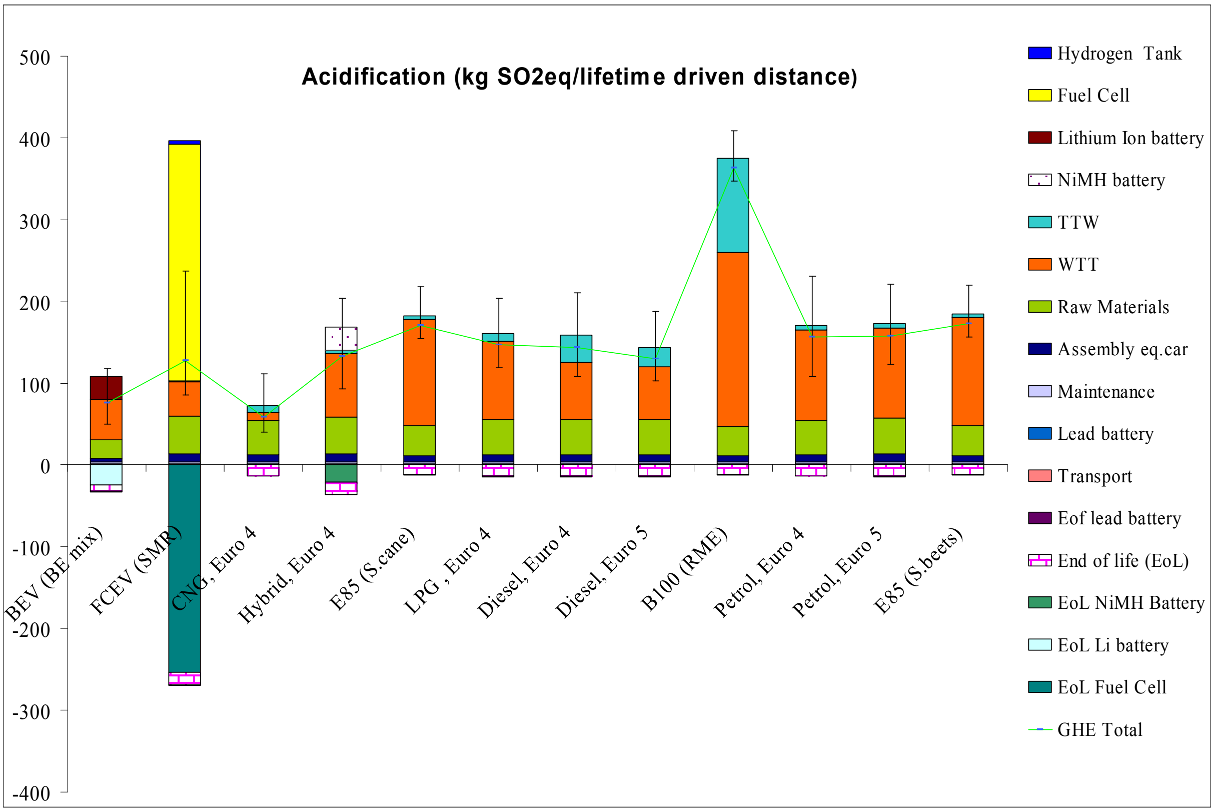


Figure 8: Acidification impact of diffrent family car technologies.

2.6.4 Non-renewable energy consumption

The manufacturing and the use of vehicles require large amounts of non-renewable energy (fossil and nuclear). Reducing the dependency on non-renewable energy is one of the big challenges of the automotive sector. As it can be seen in Figure 9, the use of biofuel vehicles can be one of the answers to this issue. The E85 sugar cane vehicle, the RME vehicle and the E85 sugar beet vehicle have the lowest non-renewable energy consumption. This is mainly due to the use of high shares of biomass energy during the production of biofuels. In the specific case of the E85 sugar cane technology, the production and the use of electricity from bagasse (crashed cane) is the main reason. The production of RME is more intensive than the production of sugar beet ethanol. However the fact that the heating value of the RME is higher and the good efficiency of the diesel engine are favouring the RME technology. The biofuel vehicles are then followed by the BEV. The best efficiency of the electric engine compared to the internal combustion ones is the main reason. The BEV is followed by hybrid and diesel vehicles which have a comparable non-renewable energy consumption. It is interesting to notice for this indicator, that the Euro 5 diesel car has a slightly lower impact than the Euro 4 hybrid vehicle while the impact of the Euro 4 diesel is a bit higher. It shows the influence of the Euro standard on the vehicle LCA results. This is also true for petrol and diesel vehicles (Figure 9).

FCEV, Petrol, LPG and CNG vehicles have comparable non-renewable energy consumption and consume more than the other technologies. Petrol, LPG and CNG vehicles consume more fuels and are less efficient than diesel vehicles. The benefit of the good efficiency of the FCEV is balanced by the hydrogen production process which is highly energy intensive.

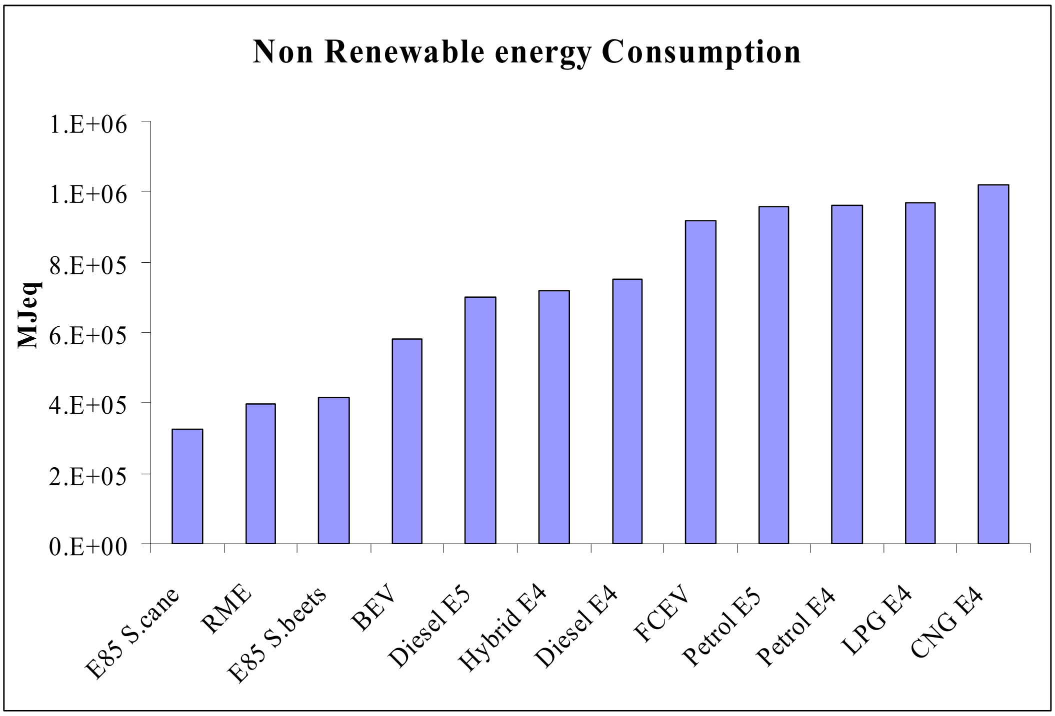


Figure 9: Non-renewable energy consumption of different family car technologies.

2.6.5 Mineral extraction

The use of mineral resources is also a key issue in the manufacturing, the use and the maintenance of vehicles. For this impact category, the size of a vehicle and the use of specific components requiring specific materials are the influencing parameters. Hybrid vehicles and FCEV have a higher impact for this indicator because of the use of specific and rare materials to produce components like the NiMH battery, fuel cell and hydrogen tank. The BEV has slightly lower mineral resource damage but the contribution of the battery is still high. Another finding for this indicator is the high contribution of the transport and distribution of the electricity used to power the BEV. This is essentially due to the use of copper in the electric cables. It is important to mention that an increase of the size of a BEV will quickly increase its mineral extraction damage. The RME vehicle has an impact higher than petrol and diesel and is comparable to hybrid and FCEV. This is mainly caused by the use of mineral fertilisers during the rape production. Petrol, diesel and ethanol vehicles have comparable results and have the best scores after BEV and CNG. This study has also revealed how important recycling is especially for heavy and precious metals contained in specific components such as batteries and fuel cells (FCEV, hybrid, BEV…).

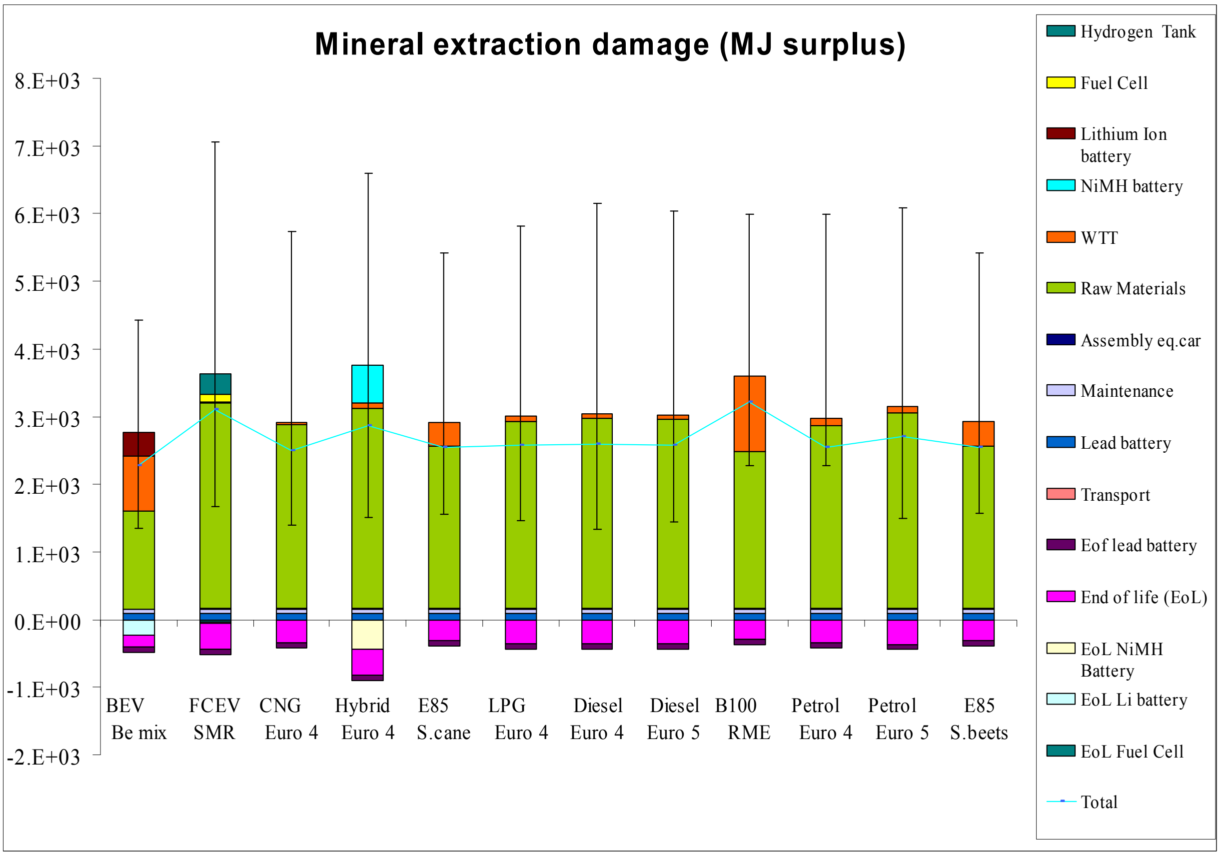


Figure 10: Mineral extraction damage of different family car technologies.

2.6.6 Comparison of reference vehicles

After the overall vehicle technology comparison within the family car segment, a list of reference vehicles which are considered to be more representative of their respective segment has been made. The aim is to perform a fair comparison between comparable vehicles since a limited number of vehicles with high weight or high fuel consumption can influence the average result of a full segment for a given technology. The individual comparison of the reference vehicles for GHE (Figure 11) gives the same ranking trend as in the Figure 5 for the different vehicle technologies. However, Figure 11 shows that the differences between the different technologies, especially the difference between petrol and diesel cars, are smaller than in the overall comparison. Finally, it appears in this study that the vehicle segment has a strong influence on the LCA results. In general, the bigger the segment (e.g. from supermini to large family car), the worse the environmental score. Additionally, the result trend when comparing different technologies within one segment remains the same.

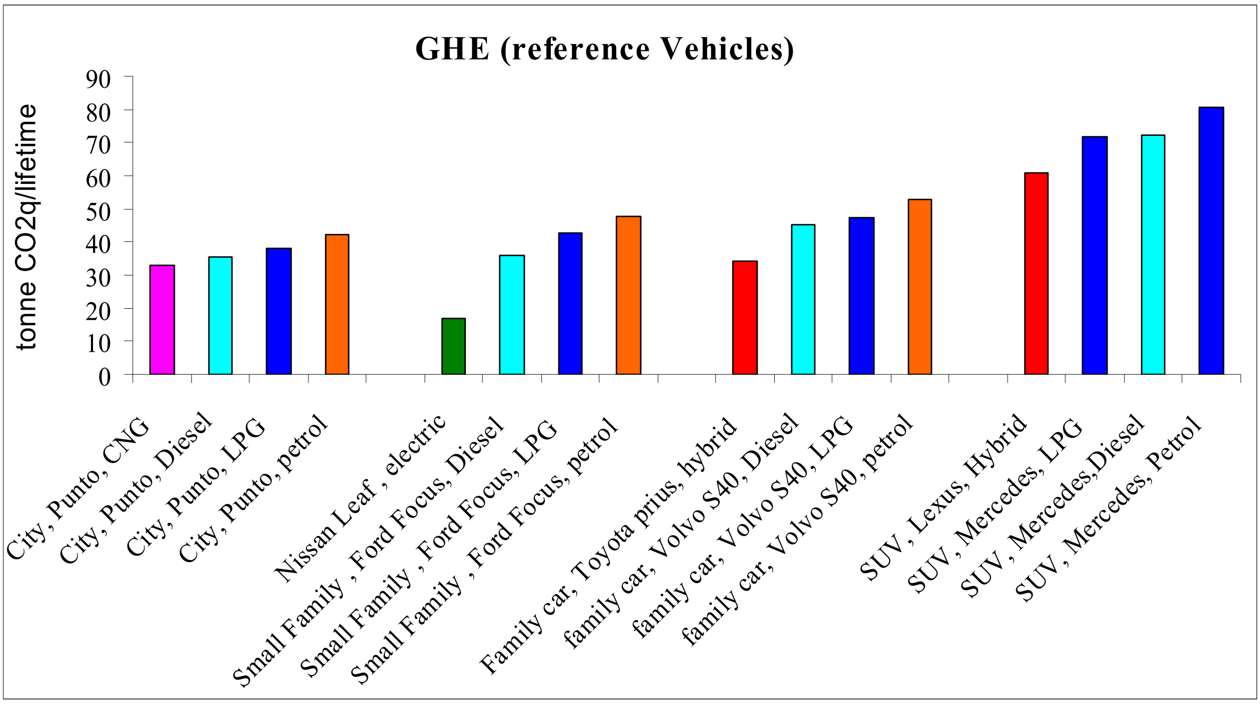


Figure 11: Greenhouse Effect of different comparable individual vehicle technologies and segments.

3. Life Cycle Cost Assessment

3.1 Introduction from literature review

The state-of-the-art literature review and the survey on the Autosalon on car purchase behaviour disclosed that many attributes determine the car purchase decision, especially reliability, security, fuel consumption, purchase price and comfort. Moreover, it has been found that although positive attitudes towards environmental aspects exist, this is rarely translated into the purchase of an environmentally friendlier vehicle. Previous research examined this so-called «attitude-action» gap and showed that environmental performance (15%) is outweighed mostly by vehicle quality (reliability, safety, comfort, design: 39%), purchase costs (purchase price, registration tax: 24%) and operating costs (fuel costs, maintenance costs: 22%) in the car purchase decision. This phenomenon of other attributes outweighing the environmental ones has been repeatedly reported in the literature (Lane and Potter, 2007 ; Kolmuss and Agyeman, 2002 ; Blake, 1999). Consequently, in order to increase sales volumes of environmentally friendlier vehicles, environmental attributes should be associated with attributes that carry a greater weight in the purchase decision like quality, purchase costs and operating costs. In this respect, it is interesting to work with the concept of Life Cycle Costs (LCC) as it combines the most important financial aspects that determine the car purchase decision (purchase costs, operating costs). The LCC can not only be used to examine whether environmentally friendlier vehicles currently are a cost-efficient alternative to conventionally fueled vehicles, but it can also be applied to investigate whether pricing measures, based on the environmental performance of vehicles, can enhance their financial attractiveness. Section 3.2 explains the LCC methodology, section 3.3 presents the results and section 3.4 investigates the effect of a reformed taxation system, based on the Ecoscore, on the LCC.

3.2 Methodology

An LCC spreadsheet model has been developed to analyze the costs of different vehicles on alternative fuels and drive trains. This model integrates all anticipated costs associated with the car throughout its life and includes all user expenses to own and use vehicles. A vehicle useful lifetime of 7 years has been assumed, with an annual vehicle mileage of 15.000 kilometers (NIS, 2008). Only the first owner is considered, and not the total vehicle lifespan which is on average 13,5 years (NIS, 2008). The used method within the LCC analysis is the net present value method as one has to accurately combine the initial expenses related to the purchase of the car with future expenses related to the use of the car. A discount rate of 4% has been applied. This interest rate is the average rate of return for investments and represents the consumer opportunity cost of purchasing a vehicle relative to alternative uses of the same money (EPA, 2000; Pearce *et al.*, 2006; EC, 2005; LNE, 2008).

The LCC of each vehicle is calculated in three steps. First every stream of costs is analyzed. Then, the discounted present value of future costs is calculated and finally, an annuity factor is applied to convert total costs to annual costs, with a commercial lifespan of 7 years (Van Hulle *et al.*, 2006; LNE, 2008). As such, the cost-efficiency of several vehicle types (supermini, small city car, small family car, big family car, exclusive car, SUV) and vehicle technologies (internal combustion engine (ICE), EV, HEV) can be compared. The chosen vehicle technologies are so-called “near-term” technologies as they are (or will be soon) available on the market. That is why fuel cell and hydrogen vehicles are not considered. Within each vehicle type, the analyzed vehicles are compared to a reference diesel or petrol vehicle as they are very similar in terms of performance (displacement, power and acceleration time from 0 till 100 km/h) and standard equipment. The LCC is based on several cost parameters: depreciation, insurance, maintenance, vehicle taxation (current Belgian taxation system), governmental support (for low CO_2 emitting vehicles, for diesel vehicles equipped with PM-filter), battery costs (in case of an EV) and fuel costs.

3.3 Results

Figure 12 displays the LCCs for the alternative fuel and drive train vehicles and the comparison baseline vehicles. At first sight, it seems that there is a large dispersal of the results over different vehicle types. Vehicles can have a yearly cost of 3.000 (supermini) to more than 17.000 € (exclusive car), with a cost per passenger kilometres travelled that varies from 0,18 € (supermini) up to 1,16 € (exclusive car).

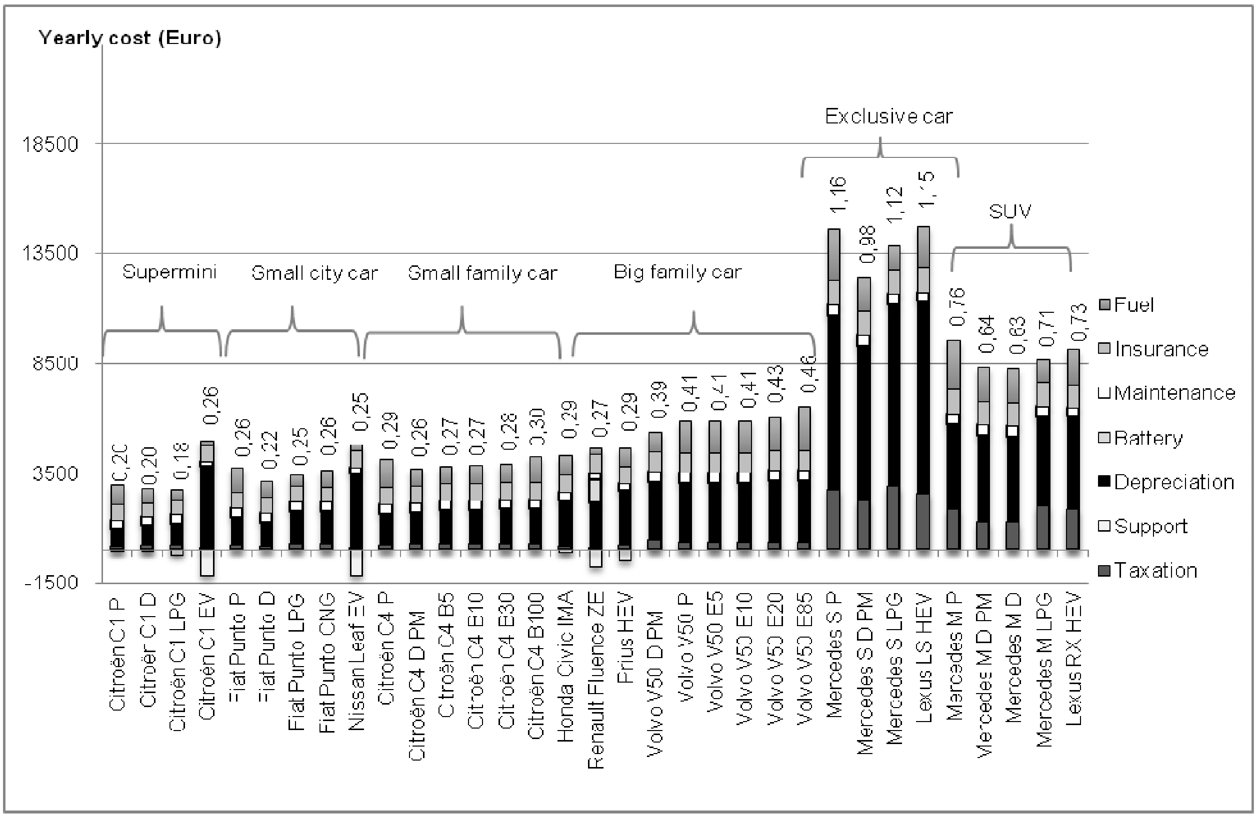


Figure 12: Life cycle costs of conventional and alternative vehicles (vertically displayed values are the yearly cost in Euro/km). Notes: P = Petrol, D = Diesel; EV = Electric Vehicle; ZE = Zero-Emission Electric Vehicle; PM = Particulate Matter filter; B5, B10, B30, B100 = Biodiesel blends; E5, E10, E20, E85 = Bio-Ethanol blends; HEV = Hybrid Electric Vehicle

A closer look at Figure 12 discloses that the diesel vehicle is more cost-efficient than its petroleum equivalent. Although these vehicles often face a higher purchase price and as a result a higher VAT on the purchase price, they benefit from better resale values (less depreciation over time) and lower taxation rates. Because of the higher excise duties on petrol (more than twice as high) and their lower fuel efficiency (20 to 30% less efficient), fuel taxes will always be higher for petrol than for diesel vehicles. Apart from the Citroën C1 LPG which gets a 15% purchase reduction because of low CO_2 emissions, LPG and CNG vehicles are currently not financially attractive for consumers as compared to vehicles with diesel engines. Despite their lower fuel costs (low production costs combined with exemption of excise duties), these vehicles encounter additional conversion costs, a higher depreciation rate, higher annual inspection costs and even an additional ACT. Only with respect to the heavily taxed petrol vehicles, they can provide competitive private consumer costs. The existing generation of HEVs cannot compete on cost-efficiency with conventional (diesel) vehicles without additional support. They still face higher purchase prices, lower resale values and encounter more fuel taxes than diesel vehicles, despite their greater fuel efficiency. The Belgian support for vehicles with low CO_2-emissions makes the Toyota Prius very cost-efficient for the end-user. Real sales data show indeed that this subsidy is vital for its encouragement. With more than 6.500 units sold in 2008, the Toyota Prius is ranked at the 22nd position of best selling cars in Belgium (Autoworld, 2009). However, other HEVs (such as Honda Civic IMA, Lexus LS and Lexus RX) with higher CO_2 levels cannot profit from this support, which makes them less attractive for the average consumer. Moreover, in some cases (Lexus LS and Lexus RX), the ACT is higher than for comparable diesel engines, whereas they release less polluting emissions. Most EVs (like C1 EV) are at present more expensive than the baseline vehicles (C1 Petrol, Diesel). This high cost is particularly the result of its high purchase price (small-scale production) which includes an expensive lithium-ion battery, combined with a higher depreciation rate. The lower maintenance costs and fuel costs (low untaxed electricity prices) and the minimum vehicle taxation tariffs cannot compensate the vehicle purchase price premium. Without the 30 % governmental support, the amortized cost per kilometer would be even higher (+ 0,08 €/km). The financial attractiveness of EVs can nevertheless increase with battery leasing. For the Renault Fluence, this leasing cost ranges from 100 €/month for low mileage users to more than 100 €/month for higher mileage users. Vehicles with blends of biofuels are also confronted with higher LCC than the reference vehicles. This is caused by several factors, namely the higher initial conversion costs, higher fuel production costs, additional fuel consumption and as a consequence higher fuel taxes (excises and VAT). The higher the percentage in the blend, the higher total fuel costs will be. Unless the imposed excises would be adapted proportional to the amount of biofuels in the blend, biofuel vehicles will not become financially attractive for end-users.

Overall, the LCC analysis demonstrates that (more) sustainable vehicles are at present not financially attractive for the Belgian end-user. The fiscal system discourages them (by an additional ACT for LPG and CNG vehicles; by high excise duties for biofuel vehicles), whilst favouring polluting vehicles (e.g. diesel cars). The existing incentives (exemption of excises for LPG, CNG, EVs; governmental support for vehicles with low CO_2 emissions and PM-filters), should be complemented with other policy measures to enhance their attractiveness. That is why next section 3.4 investigates whether a tax reform, based on the individual Ecoscore of the vehcle, will bring the LCC more in line with the environmental performance of vehicles.

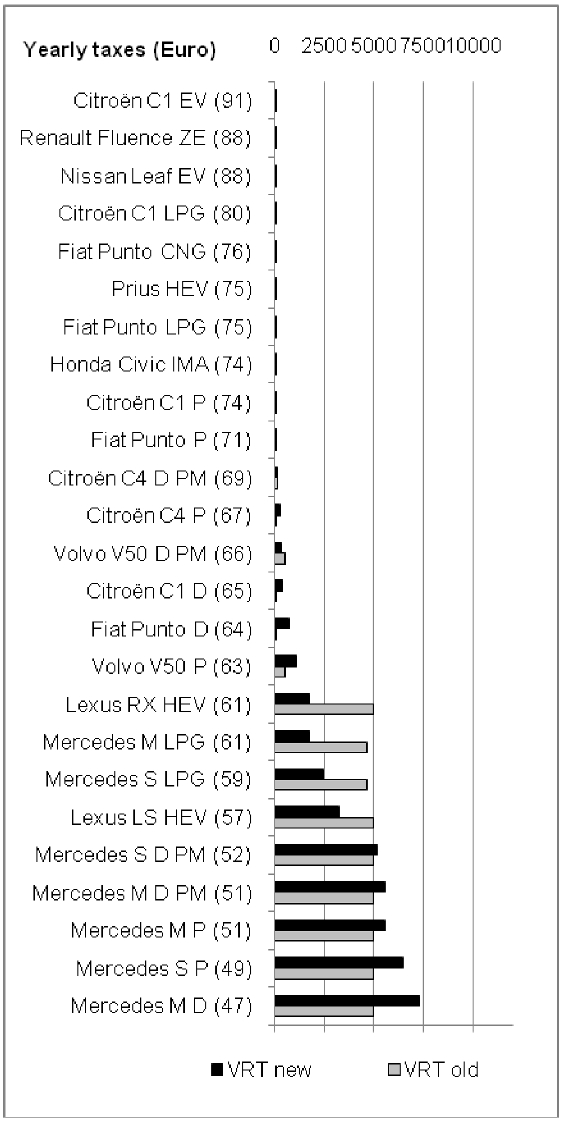
3.4 Tax reform based on the Ecoscore

The elaboration of the tax reform is based on the following functional form (see equation below). Here, it is important to mention that there has been a transformation of the total environmental impact (TI) based on an exponential function. The new tax reform is calculated as (one or more) linear functions, based on the Ecoscore of the vehicle.

$$TAX = a * TI + b$$

TAX represents the vehicle registration tax (VRT) or the annual circulation tax (ACT), TI is the total environmental impact of the vehicle (LN(Ecoscore/100)/-0,00357) and “a” and “b” are parameters defined in a way that polluting cars (Ecoscore < 70) pay more taxes and environmentally friendly vehicles (Ecoscore > 70) pay less taxes compared to existing taxation levels. In this application, a Brussels tax proposal is taken as an example (Macharis *et al.*, 2007). Figure 13 and Figure 14 show a comparison of the VRT and ACT in the old and new vehicle taxation system for the Euro 4 vehicles, included in the LCC analysis.

In general, a discrepancy between current taxes and the environmental performance of vehicles can be noticed. In the new taxation system, sustainable vehicles (Ecoscore > 70) are favoured, whereas for other vehicles, taxes increase along their environmental damage. As a result, diesel and petrol vehicles are more equally taxed in the new system (e.g. Mercedes M Petrol & Diesel). There is also a clear differentiation between diesel vehicles with and without PM-filter (e.g. Mercedes M Diesel & Diesel PM). Vehicles on alternative fuels (LPG, CNG) and drive trains (EV, HEV) are more encouraged by a lower tax burden on an annual basis (like Renault Fluence, Lexus LS & Lexus RX, Mercedes M & S LPG). The overall decrease in taxation levels is explained by the fact that only new (Euro 4) vehicles (and no second-hand vehicles) are covered in this analysis.



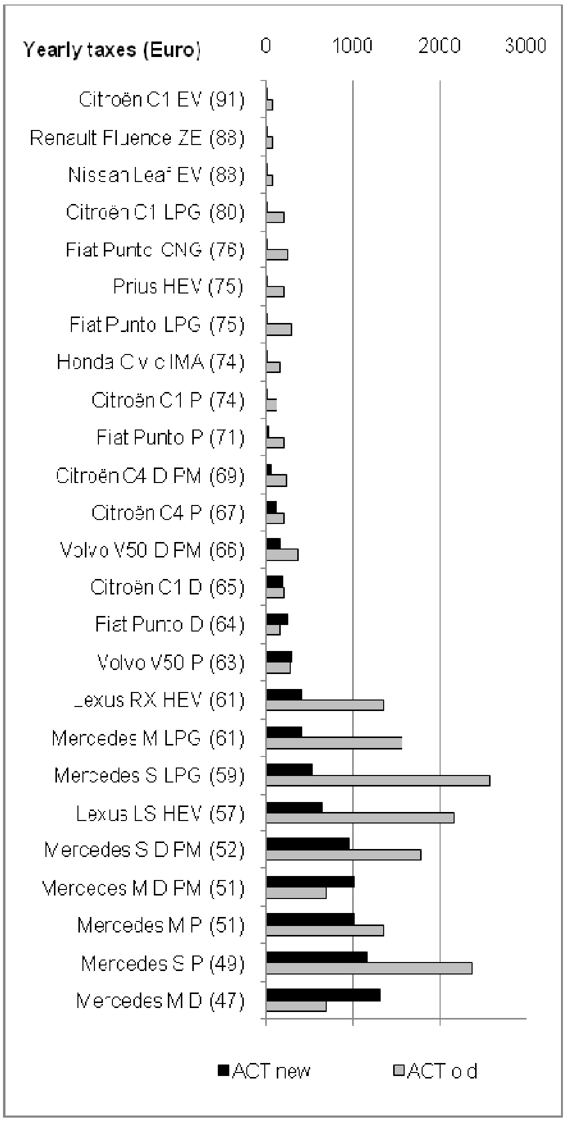


Figure 13: Old and new vehicle registration tax (VRT). Figure 14: Old and new annual circulation tax (ACT)

(Note: The number between brackets represents the Ecoscore)

Figure 15 illustrates whether these new taxes are reflected in the LCC of the vehicle and hence might provide an incentive to promote a more sustainable vehicle choice.

In the new taxation system, petrol vehicles become 1 to 4% less expensive on a cost per kilometer basis, whereas the LCC of diesel vehicles without PM-filter increases up to 10%. Yet diesel vehicles remain more cost-efficient than petrol vehicles, which is the result of their great fuel tax advantage. In the ideal situation, excise duties for diesel and petrol cars should be brought in line with one another. This proposal was also brought forward by the European Commission in 2002, where they suggested a tax convergence of taxes on diesel and petrol fuels with special tax arrangements for diesel used for commercial or private purposes. This proposal was however rejected by the European Parliament (Kunert and Kuhfeld, 2007; EC, 2002). Diesel vehicles, equipped with a PM-filter are more incentivized in the new taxation system. The LCC for the Mercedes M with PM-filter increases with 3%, whereas the Mercedes M without PM-filter faces an increase of 10%. Thanks to the tax reformation which also includes the abolishment of their additional ACT, retrofitted LPG and CNG vehicles encounter LCC reductions from 5% (Fiat Punto CNG) to 13% (Mercedes M LPG). In most cases, they now provide a cost-competitive alternative with respect to petrol as well as diesel vehicles. The better environmental performance of HEVs results in LCC reductions from 3 to 11% which considerably enhances their cost-competitiveness. The financial attractiveness of EVs only increases with 1 to 2% as these vehicles already get minimum taxation tariffs in the existing taxation scheme. Additional governmental support remains very important to encourage these vehicles for the end-user.

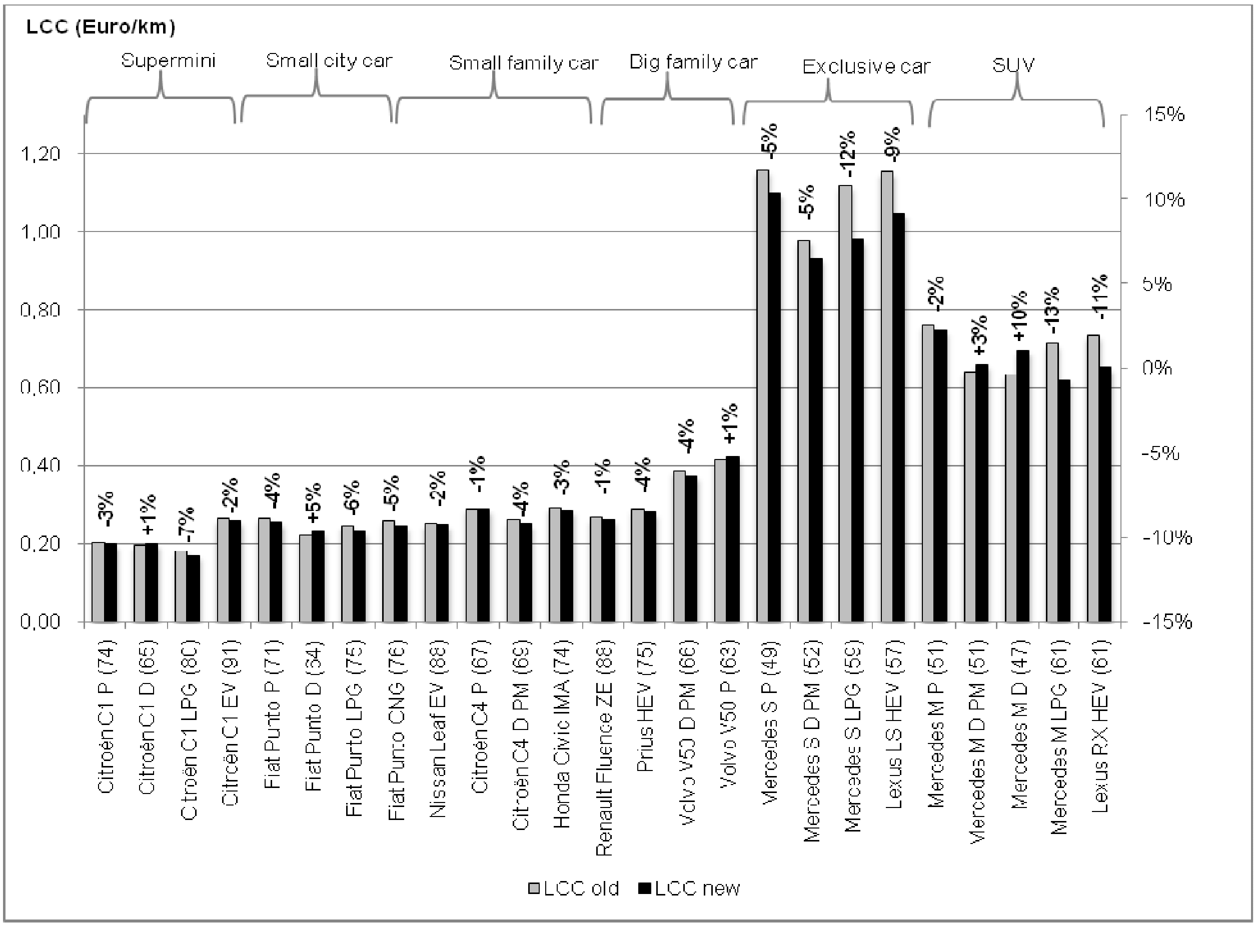


Figure 15: Life cycle cost in new vehicle taxation system.

(Note: The percentage change between the old and new LCC (in €/km) is denoted above each bar.)

Overall, the new taxation system based on the Ecoscore appears to be a useful means to differentiate the taxation system along the environmental performance of vehicles and eliminate existing tax distortions. In this way, the new system is more fair and it will better reflect the cost that each vehicle imposes on society.

However, the steering effect of such a tax reform and other pricing measures should not be overestimated. Pricing measures (like taxation) only act on a small fraction of the overall vehicle costs. Moreover, it has a smaller weight in the purchase decision than for instance purchase costs or fuel costs, so it will only indirectly affect the consumers' purchase decision. Moreover, other purchase factors determine the purchase decision too (see §3.1). That is why additional research is necessary to examine the effectiveness of pricing measures on purchase behaviour (see next section 4).

4. Price elasticities

4.1 Introduction from literature review

A literature review of price elasticities has been performed to investigate the impact of several policy measures on the purchase of vehicles. It was, amongst others, shown that the effectiveness of pricing measures depends on many factors, such as :

- ***Type of price change***: vehicle taxation and fuel prices rather affect vehicle ownership whereas kilometre charging, congestion charging and parking tariffs mainly affect vehicle use;
- ***Characterististics of the pricing policy:*** policy measures are only effective if they are accepted by the public;
- ***Type of trip and traveller***: high income travellers tend to be less price elastic than low income travellers;
- ***Availability of alternative routes, modes and destinations***: pricing measures are more effective if alternative routes, modes and destinations are of good quality and affordable;
- ***Scale and scope of pricing***: most policy measures are found to be price inelastic as these extra costs represent a small share within the total user cost (LCC) of the car.

Next to this literature review, a survey has been set up to emperically determine the effect of single and combined pricing measures on the shift to more environmentally friendly vehicles. Section 4.2 explains the methodology, whereas the applicability of this «green vehicle demand model» is shown in section 4.3.

4.2 Methodology

In the last decade, economists have been increasingly using stated preference surveys to unveil true preferences for environmental goods presented in a hypothetical scenario (Hanly *et al.*, 1998; Bateman *et al.*, 2002; Veisten, 2007). The most common stated preference techniques are the choice modeling (CM) method and the contingent valuation (CV) method. CM originates from conjoint analysis and uses a choice experiment to indirectly elicit attribute values based on either ranking or rating of products described by a number of attributes in several choice sets (Green and Srinivasan, 1978). In CV, value elicitation is whole-product based by asking respondents to express their maximum willingness to pay (WTP) for a given improvement of a public good provision level (e.g. cleaning up a lake) or for public good aspects of a market good (e.g. eco-labeled goods) (Mitchell and Carson, 1989; Hanly *et al.*, 2001; Veisten, 2007). CV and CM offer rather different merits and their use entirely depends on the purpose of the study under investigation. CM is particularly suited to measure the marginal value of changes in various characteristics of environmental programs, whereas CV is a better technique than CM when the main objective of the study is to value an overall policy package and for assisting in policy evaluations (Hanly *et al.*, 1998; Hanly *et al.*, 2001; Carson, 2000). The CV method (Mitchell and Carson, 1989) is the most frequently used method for environment-friendly policy evaluation. It has been used for setting eco-taxes in the UK to justify the tax and for determining its level (Hanly *et al.*, 2001).

In this task, the CV approach is used to evaluate whether separate pricing measures (registration tax, annual circulation tax, kilometre charge, congestion charge, parking tariff, fuel prices, scrapping premium), based on the environmental performance of vehicles, will bring along a substantial change in purchase behaviour towards green vehicles and subsequently a decrease in vehicle emissions. However, recent literature suggest that one single policy measure is unlikely to change behaviour and that a range of policy measures is required to encourage the adoption rate of green vehicles into the market (Hickman *et al.*, 2010) (see also section 7.1). Consequently, it can be assumed that the total shift to environmentally friendlier vehicles would be much higher when applying a multi-faceted price strategy. A potential drawback of CV might arise with the cognitive difficulty associated with expressing a WTP given information on multiple pricing measures (Harris *et al.*, 1989). People only have a “bounded or limited rationality” indicating that too much information adversely affects the ability to solve complex decision problems (Simon, 1955). Moreover, Nisbett and Ross (1980) present considerable evidence that people tend to weight the relevance of the information when making judgements. Given these limitations of human information processing and judgement abilities, the accurate measurement of contingent values might be affected and hence the reliability and validity of the CV results (Harris *et al.*, 1989). That is why Harris *et al.* (1989) advise to perform more multidisciplinary studies by incorporating psychological theory into CV studies. Here, a new multidisciplinary approach has been elaborated by applying the CV method according to the principles of Information Integration Theory (IIT), a theoretical and methodological framework to algebraically describe the sequence from the presentation of multiple information carriers to an actual behavioural response. This combination results in “a policy based model to predict green vehicle purchase” and enables the decision maker to estimate the population distribution willing to switch to an environmentally friendlier car based on different pricing levels of combined policy measures.

4.3 Results

1183 respondents have been collected by use of a web-based survey, hosted by the Market Research Institution IVOX in June 2010. The survey is representative for the Belgian population (in terms of age, gender and living area). First, the WTP results of individual policy measures are shown in

Table VIII, indicating the amount induced by the pricing measure at which the average consumer would find its conventionally fueled car so expensive that he or she would consider a switch to respectively a low CO_2 emitting car (corresponding to the definition of a clean vehicle in the realistic scenario, see section 7) or a vehicle on alternative fuels or drive trains (AFV) (corresponding to the definition of a clean vehicle in the progressive scenario, see section 7). Additionally, the arc elasticity indicates the amount at which the greatest shift will be realised.

Table VIII: Willingness to Pay (WTP) of individual measures.

(Note: More information on the realistic and progressive scenario can be found in section 7.)

Policy measure	Scenario	Mean WTP	Current mean tax	Arc elasticity
Registration tax	Realistic	1107 €	123 €	950 - 1000 €
Registration tax	Progressive	1185 €	123 €	900 - 1000 €
Circulation tax	Realistic	858 €/year	243 €	450 - 500 €/year
Circulation tax	Progressive	925 €/year	243 €	450 - 500 €/year
Congestion charge	Realistic	5 €/time	n/a	4-5 €/each time
Congestion charge	Progressive	6 €/time	n/a	4-5 €/each time
Km-charge	Realistic	740 €/year	n/a	200 - 400 €/year
Km-charge	Progressive	779 €/year	n/a	250 – 400 €/year
Parking tariff	Realistic	3,3 €/hour	2,5 €/hour	2,5 – 3 €/hour
Parking tariff	Progressive	3,5 €/hour	2,5 €/hour	4,5 – 5 €/hour
Scrapping PR	Progressive	3207 €	n/a	4750 – 5000 €
Fuel prices	Realistic	1,8 €/L	1,2 €/L	1,9 – 2 €/L
Fuel prices	Progressive	1,9 €/L	1,2 €/L	1,9 – 2 €/L

Overall, it is shown that the mean reported WTP values are higher than the average taxation levels in the current Belgian legislation (e.g. RT, ACT, etc.). Consumers are thus willing to pay additional money to keep the conventionally fueled vehicle of their choice despite a higher imposed financial load. This illustrates that besides financial aspects, other attributes also considerably affect the adoption of green vehicles (see also section 3 of this report). Moreover, it is also shown that respondents are more likely to switch to low CO_2 emitting vehicles in comparison to AFVs, even though AFVs often benefit from payment exemptions or minimum tariffs, whereas the others can only enjoy from a reduced tariff under the proposed pricing measure. Nowadays, most large car manufacturers offer a range of low CO_2 emitting variants of existing conventionally fueled vehicles (e.g. Volkwagen BlueMotion, Ford EcoNetic, …) for which there is virtually no trade-off for other important purchase attributes besides reduced performance. On the other hand, the current offer of AFVs is less extended, meaning that consumers still have to give up on more features determining their car purchase decision (e.g. in case of electric vehicles: range, recharging time, etc.). The transition to low CO_2 emitting vehicles requires less "effort" from the consumer and is therefore more likely to happen when a tax reform or new pricing measure is installed.

Secondly, the relative importance of pricing measures in the purchase decision was measured by means of weight elicitation on a 0-10 rating scale. In line with literature (EPA, 1998; Mairesse *et al.*, 2008; Lehman *et al.*, 2003), fuel prices will mainly affect the car purchase decision (6,98), followed by annual circulation tax (5,91), kilometre charging (5,81), registration tax (5,40), urban congestion charge (5,09) and parking tariffs (4,76). On average, these weights illustrate that pricing policies do have an impact on the purchase decision (>0), but that this impact is limited to a certain level (+/- 63% for the highest mean importance).

Third, the results on the individual WTP values and weight values have been used to construct the "policy based green vehicle demand model" (see Table IX for an example). The goal of this model was to measure the distribution of a small, but representative sample of Belgian respondents willing to switch to an environmentally friendlier car based on different weighted pricing levels of combined policy measures.

Table IX: Example of the policy based green vehicle demand model.

Policy based green vehicle demand model Realistic scenario			
Policy measure	**Price Level**	**Switch**	**Weight**
Registration tax (Euro)	500	30,61	4,63
Annual circulation tax (Euro/year)	500	31,02	5,03
Urban congestion charge (Euro/entrance)	-1	0	0
Kilometre charge (Euro/year)	-1	0	0
Parking tariffs (Euro/hour)	-1	0	0
Fuel prices (Euro/L)	1,5	18,07	5,94
Total switch (%)		**25,967**	

Note: The pricing levels and the associated switch are based on the WTP results of the individual measures. The weights are based on the weight elicitation on the 0-10 scale. The total switch (here 26%) is the switch that consumers would make to a more environmentally friendly vehicle with lower CO_2 emissions if the level of the registration tax is 500 €, the level of the annual circulation tax is 500 €/year and fuel prices are 1,5 €/L.

Overall, it is shown that combined pricing measures will affect the adoption rate of environmentally friendlier vehicles, but to a certain extent. A possible reason for this outcome is that (1) as mentioned before, other factors besides operating costs might be of particular relevance too in the purchase decision (such as purchase price, quality) (see section 3.1) and that (2) some pricing measures rather affect vehicle use (such as congestion pricing, parking tariffs etc.) than vehicle ownership (see section 4.1). This means that a further adoption of environmentally friendlier vehicles will depend on additional supply-sided measures and additional governmental incentives that act on the other important aspects that determine the purchase decision and this confirms the need for an entire policy package which not only consists of pricing measures (sticks), but also of subsidies (carrots) and regulations (see also section 7.1).

5. External Costs

5.1 Introduction

An external cost, also known as a negative externality, arises when the social or economic activities of one group of persons provide damage to another group and when that damage is not fully accounted, or compensated for, by the first group. In order to take the external costs of transport into consideration within the transport costs, the European Commission has supported the development and application of a framework for assessing external costs of energy use, by continued funding of the ExternE project. The purpose of this project is to provide a general framework for assessing impacts that are expressed in different physical units into a common unit – the monetary value. For this purpose, the ExternE project has developed an impact pathway methodology (IPA). Within the scope of this project, the impact pathway methodology has been updated and a transferability approach has been used in order to reduce the time-consuming estimation.

5.2 Methodology

The ExternE methodology aims at covering all relevant (*i.e.* not negligible from the monetary viewpoint) external effects. In this logic, the impacts to consider are related to health (mainly particulate matter and ozone), building damages (particulate matter and SO_2), global warming (greenhouse gases) and amenity losses from noise. The pollutants to take into account are therefore limited to exhaust PM_{10}, NO_x, SO_2, non-exhaust PM_{10}, O_3, CO_2, CH_4, N_2O and noise.

IPA relies on a four steps bottom-up sequence, that can be summarized as follows: (i) emissions identification and characterisation; (ii) ambient air pollutant concentration by dispersion modelling; (iii) impact assessment in physical units; (iv) monetisation of these physical impacts.

Definition of the emission sources and characterisation of air emissions have been performed by ETEC-VUB. A sample of 53 cars, covering a wide range of car sizes, fuel types or propulsion systems is considered and analysed for the pollutants listed above.

The contribution of the car fleet to the pollutant concentration in the air is assessed through emission-air concentration modelling. This task was done using a statistical dispersion model based on daily concentration measurements and taking both economic and meteorological variables into account (Favrel *et al*., 2001). The dispersion model allowed us to create new emission-immission relationships characterising the global car fleet. These emission-immission relationships have been used to calculate the increase in immission caused per kilometer driven, for each car of the fleet sample (µg/m³.km). This modelling applies within the geographical zone of the Brussels Capital Region and for TTW emissions only. WTT emissions' contribution to local air immission levels could not be assessed. Indeed, these emissions occur higher up, in locations often separated from where the TTW emissions take place, and therefore require the development of specific dispersion models.
For amenity losses due to noise emission, the actual state of knowledge on sound emission, propagation, and receptor density within the geographical zone of this study didn't allow us to follow the IPA. A second best approach is proposed.

For greenhouse gases (mainly CO_2, N_2O, CH_4), IPA is not yet relevant, as climate change impacts are complex, they have been assessed globally and for long periods with a top-down approach including WTW emissions.

In order to take into account the methodological options in the external costs assessment, two sets of three scenarios were defined for some main components of the total external costs per vehicles, i.e. GHG, PM_{10} and noise impacts. As GHG emissions impacts have been considered as a priority, the two sets correspond to the price of a tonne of CO_2. The first set is based on the valuation of 90€/tonne CO_2, while in the second set we assume a price of 25€/tonne CO_2. For each set, three scenarios were proposed that correspond to a few options about the impacts of non-exhaust particulate matter emissions on health and the soiling of building walls. Indeed, characteristics of non-exhaust PM are lacking scientific measurements and analysis, resulting in important uncertainties both for health and building soiling impacts. Choices for assessing noise impacts are also taken into account.

5.3 Results

Given the number of parameters and uncertainties in the assessment of the external costs, we have defined two sets of three scenarios for computing the total external costs.

For the baseline scenario, **health** costs are mainly related to particulate matter. The largest contribution to these costs comes from mortality due to airborne particulate matter (54.8% of the total PM health costs). The second most important contribution arises from chronic bronchitis due to particulate matter (22% of the total health costs). These observations are in line with the ExternE predictions.

It shows that the impacts of PM_{10} emissions on health are important for all types of cars, even for electric vehicles. This is a direct consequence of the fact that non-exhaust emissions are taken into account for the modelling of health damages. For the average marginal external costs, two clear correlations are observed with the weight of the vehicles. Diesel cars without particulate filters (c€ 4.1 - 9.5/km) are roughly twice as damaging as other cars (c€ 1.9 – 5.95/km), including electric vehicles. This ratio remains true for all scenarios.

Finally, we can observe that the cost of health impact related to the ozone induced by NOx emission is associated with positive externalities for all cars, at the urban level. These benefits remain however very low with regards to the total external costs. The highest value for the selected diesel cars amounts to c€ 0.41/km. For the other types of vehicles, the values do not go beyond c€ 0.2/km.

Building soiling is a result of PM emissions. The average marginal external costs are again important for all types of cars (c€ 1.5 – 10.5/km), and are well correlated with the weight of the cars. Diesel cars with their high exhaust PM emissions are roughly three times as damaging as electric cars.

However, all cars emit non-exhaust particulate matter as a result of tyre, brake and road wearing. Although there is a lack scientific studies on these emissions, this assessment shows that they are far from being negligible. These values are about 4 times more important than the exhaust PM emissions of diesel cars with filters.

Building degradation costs are caused by SO_2. Our assessment shows that this impact is negligible. The highest value calculated for all cars in this survey is c€ 0.0031/km.

Noise impacts are only dependent on noise emissions. The data provided by ETEC shows that they are not linked to car size, fuel type or propulsion system except for electric cars that are among the quietest. Marginal external noise costs range from c€ 0.32/km to c€ 1.59/km and are quite similar for most cars.

From the **global warming** perspective, N_2O and CH_4 contributions to marginal climate change costs are small, as they remain between 1.1% and 2.5% of the total GHG external costs. However, for vehicles running on CNG, CH_4 WTW emissions account for 10% of the total emissions. In the case of electric vehicles, 100% of the greenhouse gas emissions occur during the WTT phase and come from CO_2 releases associated with electricity production. Overall, CO_2 TTW contribution to global warming marginal costs is by far the most pre-eminent.

Taking the car segmentation view angle, we can observe that the WTW climate change costs tend to increase with the car size, from c€ 1.01/km for the superminis to c€ 2.93/km for sports cars. The ten cars with the highest climate change costs (above c€ 2.00/km) are all sports, SUVs or exclusive vehicles. The lowest climate change costs are by far the electric cars (below c€ 0.45/km), followed by supermini vehicles with different motorisation systems (petrol, LPG, hybrid or diesel).

Costs discussed here have been obtained using the €90/t CO_2 eq. scenario.

Considering **the total external costs** for the most realistic scenario (greenhouse gas emissions valued at €90/t CO_2 eq.; noise emission valued as urban day time emissions; 50% of PM_{10} non-exhaust emissions added to the exhaust PM_{10} emissions), health impacts arising from PM_{10} are the main cost driver (**39 %**), followed by the building soiling impacts (**33 %**). PM_{10} is thus the main cost driver, accounting in total for **72** % of the total external cost. For diesel cars without filter, this proportion even reaches 80 %.

The second main cost driver is climate change impacts, with **17%** of the total average external cost, followed by noise costs (**9 %**). Except for electric cars, WTT contribution to the climate change costs range from 7% to 14% of the total costs for all vehicles. The highest ratios of 14% are all related to the CNG engines. This comes from the important CH_4 emissions in the WTT phase of CNG preparation. Health impacts arising from ozone are small and positive. Building damage related to SO_2 is negligible.

Diesel cars without particulate filter are associated with the highest total external cost, reaching c€ 22.6/km for an SUV in the most realistic scenario. Diesel vehicles equipped with particulate filters have the second highest total external cost (up to c€ 14.39/v.km for an SUV), though they are much closer to those of the petrol, LPG, CNG, flexifuel and biofuel engines (c€ 7.23/v.km to c€ 9.87/v.km). At the opposite side, electric cars generate the lowest impacts (c€ 4.75/km). Hybrid cars also prove to have lower external costs than any other technology for vehicles of the same weight. This assessment does not allow direct comparison of flexifuel and biofuel vehicles as the emissions have been measured according to different homologation procedures.

Globally, external costs are proportional to the weight of the vehicle for a given motorisation system and are thus highly correlated with the car size (see Figure 16).

The study also clearly shows the predominance of PM related impacts in the total external costs. More specifically, non-exhaust PM could be the main cost driver. At the current stage of knowledge, however, non-exhaust PM emissions and their specific impacts on health and building damage are surrounded by a great margin of uncertainty. Further scientific evidence in these matters should be taken into consideration in future similar studies. The effects of re-suspended particles, especially in densely populated areas, should also be included in such analyses.

Other ways of refining the results may be: (i) to enlarge the area covered by the dispersion model - this can be done either through developing new models (for other cities, for the countryside, or on a national scale) or by applying an updated benefit-transfer method to the present results; (ii) to improve integration of TTW emissions in the overall assessment - this also implies developing long-range/high altitude dispersion models; (iii) to include more impact categories in the overall assessment, particularly impacts on ecosystem degradation.

This study demonstrates that the implementation of impact pathway methodology for assessing external costs of air pollution remains a delicate exercise, given the amount of uncertainties and unknown features surrounding the mechanisms associated with the impact of pollution by vehicles. The results of this study should therefore be considered with great caution.

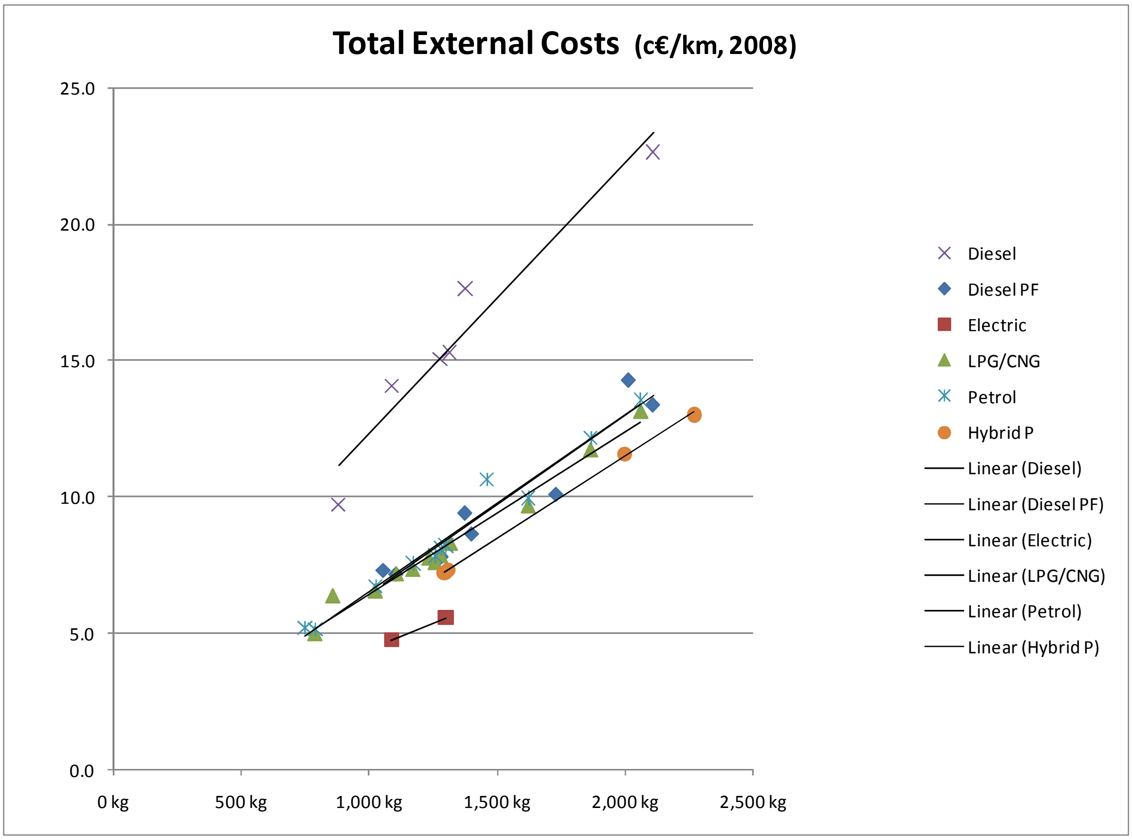


Figure 16: Total external cost per engine type and vehicle weight (PF = Particulate Filter).

6. Social barriers

6.1 Introduction

Main barriers to the development of alternative vehicles in Belgium have been identified through the consultation of different groups of stakeholders, and a systemic diagram with the interrelations between barriers (and possible levers to overcome those barriers) has been derived. It has to be noted that in the detailed report of this subtask, a distinction has been made between barriers that prevent the development of alternative vehicles in general and those that more specifically apply to certain technologies or fuels. Here, only barriers in general are presented.

6.2 Methodology

The first step consisted of performing a literature review on barriers to the development of alternative vehicles. A series of barriers have been pre-identified and classified by category with a typology inspired by literature (for more information on definitions and examples, see Englert *et al.* (2009)). Those referred studies generally identify barriers in an independent way, in such a manner that they are all considered in a same level, without taking interrelations into account.

The literature review helped to draw up the questionnaires for the consultation of the stakeholders. As all the stakeholders are not confronted with the same barriers or will perceive differently the importance of barriers, they have been classified in the different groups listed below: Demand-side stakeholders (individual consumers, fleet managers), Supply-side stakeholders and “Experts” (universities and research centres, NGO’s and associations, and politicians).

For the individual consumer’s group, a survey was carried out at the Brussels Motor Show in January 2008. For the supply-side stakeholders and the experts, a more detailed questionnaire was drawn up. In those cases, smaller samples of stakeholders (about 20 for each group, with various contributions) were met to answer the questionnaire directly and to allow for an in-depth interview-discussion. For the companies and administrations with a fleet of vehicles, a sample of 14 fleet managers was sounded out by phone. The majority of them were from public institutions, from Brussels in particular. The data and information collected from the stakeholders’ consultation have been treated trough statistical and/or qualitative analysis.

In a third and last step, a systemic diagram representing the interrelations between barriers expressed by the different stakeholders has been derived from a transversal analysis of the results. This analysis has been complemented by elements of the literature about the “technological lock-in” concept.

6.3 Results

6.3.1 Barriers to the purchase and use of alternative vehicles for the individual consumer

The survey at the Brussels Motor Show has highlighted several types of barriers to the purchase and use of alternative vehicles from the individual consumer's point of view: economic (high price…), supply (short supply of vehicles and fuel…), market (lack of development…), technical (technical immaturity and limited range…), etc. While economic barriers appear to be very important[2], results have shown that other aspects have also a significant impact on consumer behaviour about alternative cars, sometimes more important than economic aspects. Non-economic factors are potentially stronger than economic ones. More specifically, results have shown that psychological barriers

[2] This is in line with the results from the survey on price elasticities in the CLEVER project, which show that the first selection criteria of a new car are based on rational factors, economic factors in particular (most important car attributes according to the "spontaneous" answers of the respondents).

have a significant impact on consumer behaviour about cars. Economic, market and supply barriers appear to be the most important categories of barriers to the purchase/use of alternative vehicles in general when considering "conscious" motivations of people. However, while the barrier “lack of confidence in safety” (psychological barrier) is not highly quoted when asking people to evaluate its importance, it appears that this barrier does influence their purchase intentions.

About the importance of barriers mentioned by the respondents, it came out that barriers related to the short supply (of vehicles and fuel) are of course a major brake to the purchase/use of alternative vehicles. Market barriers appear also to be important; this group includes the lack of development of the market, the competition with low emission conventional cars and the lack of information. Statistical analyses have revealed the presence of an interaction between barriers.

This implies that measures aiming at overcoming the barrier “lack of information” will have a positive effect on the reduction of the perception of other barriers. However, while the lack of information is a very important barrier, overcoming it would not always guarantee a better development of the alternative. Finally, the survey has also revealed the presence of doubts and scepticism about the environmental advantages of those vehicles; in particular, the “true ecologists” prefer not to have a car and use other ways of transportation (bike, public transport, car-sharing…) rather than owning a private car, even cleaner than the average. So, if even the “green people” are not supporting alternative cleaner cars, it is difficult to find a market segment for this category of vehicles.

6.3.2 Barriers to the introduction of alternative vehicles in vehicle fleets

Interviews with fleet managers have highlighted that it is the combination of several barriers (supply, economic, technical and market) that make alternative vehicles particularly unattractive for introducing them in vehicle fleets (except hybrid, for which the main barrier is economic). Also, some previously bad experiences (technical problems) with some types of vehicles (like electric, CNG and LPG vehicles) imply a lack of confidence in those vehicles. The short supply (and the short number of suppliers) creates sometimes the impossibility for companies to buy or to lease alternative vehicles. The lack of supply of alternative vehicles in leasing companies and also the inexistence of alternative for intervention vehicles or vans limit greatly the development of alternative vehicles in some vehicle fleets. In this last case, barriers don’t come from the companies but from the supply-side of the market.

6.3.3 Barriers to the supply of alternative vehicles

An important barrier which prevents vehicle makers from developing alternative vehicles in their supply is related to the fact that they expect no (or not enough) demand for those vehicles, as they are not competitive with conventional vehicles for several reasons: economic, technical and psychological (consumers are used to conventional cars), and because of the actual trend of the characteristics of the demand (more and more requirements of the consumers for more comforts and options at an acceptable cost). Also, the lack of fuel availability (e.g. CNG or biofuel) is a major brake for vehicle makers to develop and commercialise alternative vehicles.

Some supply-side stakeholders mentioned also that there are too many possible alternatives and too many uncertainties about the sustainability of the different options. Their current strategy is rather to focus on the improvement of conventional fossil fuel cars -diesel in particular- in terms of efficiency and reduction of emissions.

Given the current context, alternative vehicles would not spontaneously emerge from the market but need an impulse trough policy intervention. The lack of coherent, clear and harmonised policy measures to promote alternative vehicles is thus a major barrier to their introduction. Moreover, there are a lot of uncertainties about the evolution of future legislation. This lack of a clear, global and long-run defined policy scheme prevents the industry from defining a strategy[3]. In the same line, there is a lack of clear policy for the introduction and the promotion of alternative fuels: policy measures should ensure alternative fuel distribution. More generally, policy makers have to promote alternative vehicles/fuels and take a clear position.

6.3.4 Barriers at society level

Currently, the market is “stuck” because supply-side stakeholders expect no demand and demand-side stakeholders wait for supply development. This implies a need for policy intervention to release this locking mechanism. However, there is a lack of policy measures to promote alternative vehicles. Interviews of "experts" have brought several types of barriers "upstream", and also gave some reasons why there is a lack of policy and supportive measures for alternative vehicles. On the one hand, according to some NGOs and politicians, there would be a lobbying from the automobile industry and oil companies against some environmental measures. On the other hand, we noticed through the interviews a kind of lobbying from environmental NGOs against many alternative vehicles. Also and importantly, it appears from the interviews that alternative and clean vehicles do not constitute a political priority for green politicians. Like environmental NGOs, green politicians would rather act for a more structural change of

[3] The need for a stable framework for the car industry has also come out from the stakeholders consultations led by VITO (Vanderschaeghe *et al.*, 2009).

the society: reduction of the use of cars, promotion of the use of bikes etc., because alternative technologies are still bad for the environment (environmental barrier) and make agents think that we don't have to change our habits of consumption. This lack of social support for alternative vehicles from green activists and green politicians (that would rather orientate their policies for a reduction of the number of cars) is in line with the result from the survey at the Motor show, where it has been noticed that “true ecologists” prefer not to have a car than buying a vehicle, even a cleaner one.

6.3.5 Technological lock-in and interrelation between barriers

The consultation of the different groups of stakeholders typically illustrates a technological locked-in situation. Some evolutionary economists have studied and described the characteristics and the consequences of the technological lock-in process. This description appears to correspond to the barriers to alternative vehicles mentioned by the stakeholders, which brings a theoretical framework to our conclusions.

It is necessary to better depict the context wherein alternative vehicles have to develop in order to identify the potential triggers that could help to overcome the barriers preventing their wider diffusion (“lock-out” situation). Alternative vehicles do not come up and operate in a “virgin” environment. Indeed, conventional cars with internal combustion engines working with fossil fuels have been used for decades. This implies that alternative vehicles must compete with this old and well-developed pre-existing technology for which the linked technologies, economic sectors, institutions, infrastructures etc. are well established.

The automobile market belongs to the "fossil fuel energy system”, which can be considered as a “Techno-Institutional Complex” (TIC)[4]. In the case of the automobile system, it is composed of the following interconnected elements: cars, refueling infrastructures, garages, firms, lobbies, culture (e.g. automobile sport), shaped mentalities (symbolic of the car and representation of what should be a car), etc. So, all these components of the system are related to fossil fuel vehicles; we speak about a “locked-in” situation (inertia) when the technological system follows a trajectory which is difficult and costly to change (path-dependent process).

Technological lock-in emerges from a path-dependent process with increasing returns to scale, improving efficiency, and narrowing relationships between the different stakeholders that become interdependent. In this context and due to increasing returns to adoption, the technology which has gained an initial lead will gradually exclude other

[4] Note that the description of the energy system and the lock-in process that we made here are based on studies by Maréchal (2007); Del Rio and Unruh (2005).

competitors (as its advantages intensify with development). Four types of increasing returns identified by the lock-in literature can be mentioned: “scale economies”, “learning economies”, “adaptive expectations” and “network externalities”. The network starts with the development of firms and infrastructures resulting from the production, the distribution and the services linked to the technology/fuel (roads, refuelling infrastructures, garages…). Then, other relations between firms or industry are created (for example, the plastic industry uses by-products from oil refineries). So, strong relations and interdependencies between firms and industries emerge. Development of the network goes together with development of various lobbies.

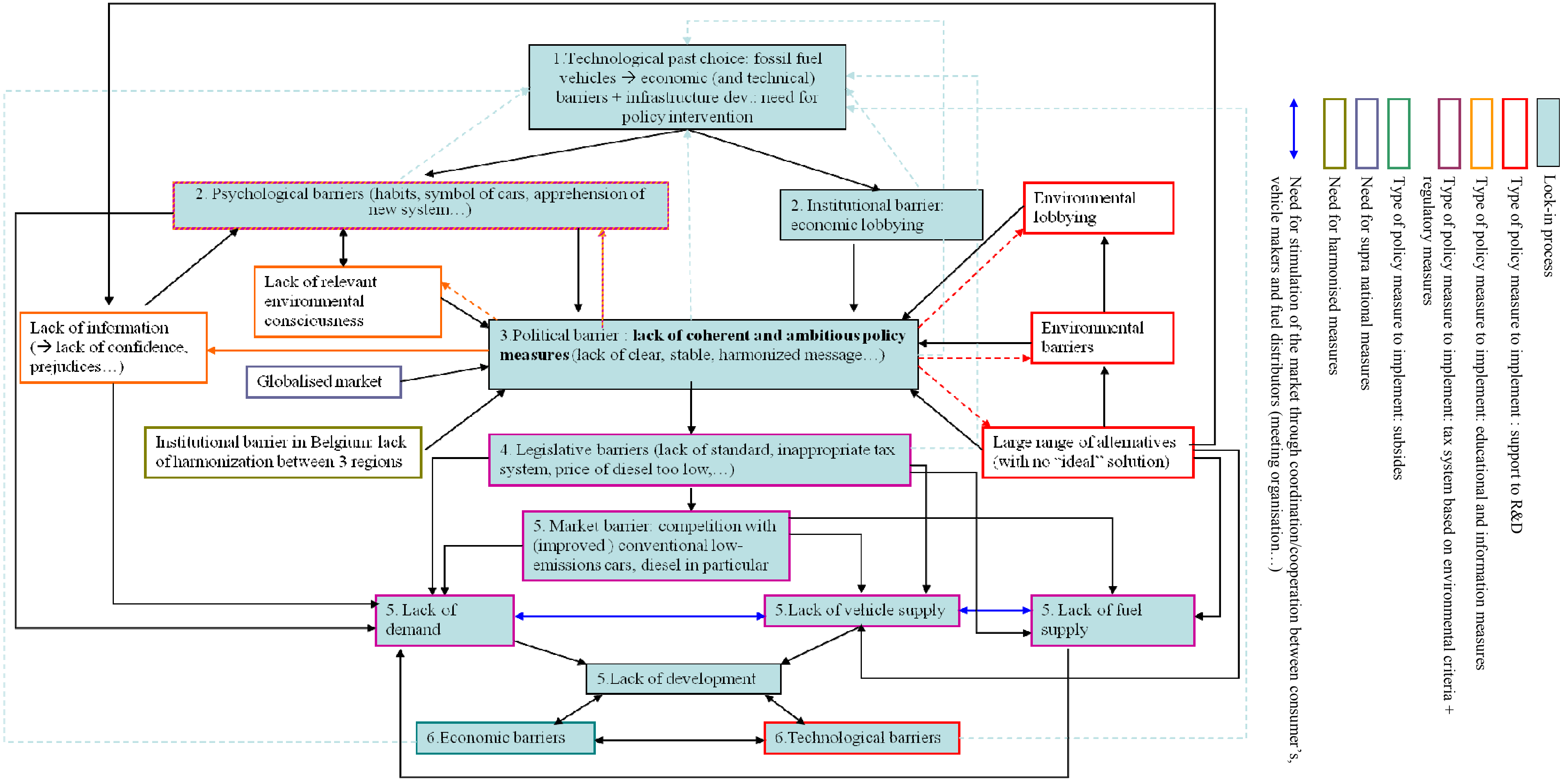
Also, beside the decreasing costs mentioned, the building of the system also implies a decrease of the “social cost” because of a “use effect” (habits) to the technology. Indeed, agents adopt “routine” behaviour in their purchase decision to avoid mental effort and to ensure satisfaction (no uncertainties). So, it results that agents are “locked-in” in routine consumption patterns, which have often been observed in the energy field (and can explain non-rational behaviour and non-efficient decision). Routine behaviour can also expand to firms and institutions.

The lock-in process implies that society at large is “stuck” in a specific technology because of past choices, as it has reached a point where economic and social costs are low enough because of network externalities[5]. The entire society is designed in accordance with the general use of fossil fuel technology, with strong links between the different components of the system and reinforcing lock-in effects.

The lock-in situation, the interrelations and causality relations between barriers have been presented in the systemic diagram below (Figure 17). It is derived from a transversal analysis of the results from the stakeholder's consultation and from elements of the literature about the lock-in process. Detailed explanations about this diagram can be found in Englert *et al*. (2009).

[5] It has to be mentioned that those externalities can eventually lead to a lock-in in a non-efficient technology. However, the consideration whether internal combustion engines working with fossil fuel were (at the beginning of their development) the most efficient choice is beyond the scope of this study.

Figure 17: Interrelation between barriers, lock-in process and examples of policy measures to implement to overcome barriers



7. Policy measures

7.1 Introduction

Recently, policy measures supporting cleaner vehicles have been introduced on several governmental levels, for example the European legislation on cleaner vehicles for public fleets, European legislation for reducing CO_2 consumption of passenger cars, the European ongoing legislative process for fiscal measures based on CO_2 emissions, federal support on vehicles with particulate filters and low CO_2 emissions, regional discussions on greener car taxation, and local measures for environmental zoning. In this multi-level policy context, the analysis of effective measures supporting the market introduction of cleaner vehicles is extremely important to come to a consistent and efficient policy mix. The objective of this chapter on policy analysis is to investigate the effectiveness of different policy instruments in guiding the market towards the purchase and use of more environmentally friendly vehicles and to seek for stakeholder support for the introduction of such measures in the Belgian context.

As an input for the following sections, an inventory of measures for the support of environmentally friendly vehicles was made, based on a literature review of different national and international sources. The emphasis lies on measures initiated in Europe, but international measures (if relevant) were included in the inventory as well. Main obstacle in the analysis of policy instruments is the lacking information on the impact of the different instruments. Even if vehicle sales data are available, several instruments are put in place simultaneously which makes it harder to distinguish market trends and the impact of specific instruments. Post-evaluation of the implementation of policy instruments is no common practice by the responsible authorities.

The following conclusions were drawn from the inventory (for more details see Denys and Govaerts (2007)). A mix of policies which integrates carrots (incentives), sticks (disincentives) and regulations works best. This includes a mix of target audiences: steer industry and final consumers, both public and private. For private consumers, tax systems based on environmental performance are getting more and more common. No mandatory systems towards private fleet consumers exist today, voluntary systems are in place and the market starts offering green products. Company car taxation seems the appropriate instrument to influence that market. For public consumers, mandatory targets for clean vehicles seem to have an effect on the overall market and are a suitable instrument to open the market.

Monitoring and impact assessment results from different implemented policy measures are lacking most of the time. However, this is essential in the evaluation of how the market reacts to the different measures. Policy towards cleaner vehicles is dynamic, so governments should be aware of the impact and redefine the measures whenever necessary.

A similar assessment of policy measures was made in the Ecoscore project in 2004. The main evolution over 3 years time is that classic car taxation paid for vehicle ownership is decreasing in favour of more place- and time-based road charges, also depending on environmental performance of vehicles. Classic subsidy programmes are abolished because they are not in line with EU legislation on subsidies or because of the higher management costs of the system.

In the next paragraphs, the methodology used to construct the policy scenarios from the international overview and stakeholder meeting results is described. Furthermore, the adaptations made to VITO's emissions model 'E-motion' are briefly discussed. Finally, the results of our own policy scenarios are considered in terms of fleet composition, vehicle use and environmental impact.

7.2 Methodology

7.2.1 Input from literature review

Policy pathways, comprising the implementation of policy instruments for the support of purchase and use of clean vehicles in Belgium, were designed based on the assessment of existing policy measures and the results of the research on barriers, life cycle costs and LCA. From the previous tasks of the project, the following measures were selected to develop the policy pathways (for more information, see Denys and Govaerts (2007)):

- Green car taxation
- Road pricing ('kilometre charge')
- Congestion charge
- Subsidies
- Green public fleets
- Availability of green vehicles and fuels
- User (dis)advantages (parking and restricted zones)

7.2.2 Stakeholder meetings

The second phase of the policy scenario construction aimed at seeking stakeholder support for redesigning the policy pathways adapted to the Belgian situation. For this purpose, stakeholder round tables were organised to discuss effectiveness, feasibility and priority of a whole range of policy measures (based on the above list). In total, four round tables were organised, each with 10 to 15 participants from four different stakeholder groups in the field of cleaner vehicles: conventional industrial actors, alternative industrial actors, NGOs and users of the project output, and policy makers. The round tables were prepared by distributing a discussion paper to the participants in advance. The discussion started by sketching a confronting policy decision, followed by the elements relevant to the impact and feasibility of specific policy measures. The round tables were concluded by the completion of a questionnaire for scoring the policy instruments on effectiveness, feasibility and priority.

A list of all the measures proposed in the questionnaire is given below. The abbreviations used refer to the measures depicted in Table X.
The first point of discussion was how a clean car (CC) had to be defined (based on CO_2 emissions and/or Euro standard, technology list, ecoscore, etc.). Afterwards, the various policy measures were discussed:

- Differentiating the registration tax (RT) based on environmental characteristics of the vehicle.
- Annual circulation tax (ACT) differentiated according to environmental characteristics.
- Kilometre charge (KC) based on a set of parameters, like the environmental characteristics of the vehicle, the time of day and the road type.
- Toll collection before entering environmental city zones, where the tax level depends on the environmental characteristics of the vehicle.
- Fiscal incentives for vehicles complying earlier than necessary with future emission standards.
- Stimulating or even forcing car manufacturers (CM) to launch environmentally friendly models.
- Improving the supply side of clean fuels (CF) by standardising and granting excise benefits (e.g., E85 and CNG).
- Stimulating or even forcing fuel distributors (FD) to offer clean fuels.
- User's benefits, like free parking spaces for clean vehicles.
- Installing environmental city zones with limited access for polluting vehicles.
- Granting subsidies (SUBS) for retrofitting polluting diesel vehicles with particulate filters and older petrol vehicles with LPG installations.
- Assignment of scrappage premiums to let owners substitute their polluting vehicle by a more environmentally friendly one, or not to replace it at all.
- Stimulating or forcing public fleet (PF) managers to include a certain share of clean vehicles in their fleet.
- The same as the previous one, but then for private fleets (i.e., company fleets).

The conclusion of the stakeholder consultation process is that, for the introduction of cleaner vehicles, each of the actors has his responsibility and cooperation is extremely important to support the market introduction of these vehicles. Individual actors will have to take the positions of all other actors into account to create a win-win situation for the whole market, based on a long-term vision. Anyhow, immediate and strong choices are needed to be able to draw up a development strategy, as a stable market is necessary. For example: there has to be a standardization of the alternative fuels and these should be stimulated with lower excise duties.

More specifically, almost all stakeholders agreed on the fact that the current tax system (based on fiscal horsepower) is outdated. It is also clear that a comprehensive mobility policy is needed, with a coherent mix of measures and valuable alternatives. To define clean vehicles and clean fuels, stakeholders realized that a well-to-wheel approach is necessary and as such, the Ecoscore may be a good indicator. However, a lot of stakeholders would stick to well-known standards like (the combination of) CO_2 emissions and the Euro emission standard.

Of course the stakeholders did not always agree. For example, some (like traditional car manufacturers) would like to abolish the registration tax, whereas others consider it as a powerful tool to steer the purchase behaviour. Anyway, this type of tax should depend on the environmental impact of the car, just as the annual circulation tax should do. In general, a kilometre charge was seen as a very effective measure, but somewhat harder to apply, so this may be a measure for the longer term and on a European scale. There was much less support for a congestion charge and only progressive voices like the idea of environmental city zones with limited access. However, it was clear that such user (dis)advantages would only have a significant effect in combination with a coherent policy mix. Older cars may be made cleaner by granting subsidies for diesel filters or alternative fuel systems. Policy makers like the idea of subsidies because they have a direct effect, but there was less consensus on a scrappage premium to promote newer and cleaner cars. For most stakeholders, it was obvious that green public fleet quota should be mandatory – and in practice, this is indeed almost realized. Most stakeholders agreed that this can be extended in the future to private fleets as well. More information on the preferences of each stakeholder group can be found in Vanderschaeghe *et al.* (2009).

7.2.3 Policy scenario design

In order to construct a set of policy scenarios, the stakeholders scored each single measure against three indicators: effectiveness, feasibility and priority. ‘Effectiveness’ was assumed to represent the potential of the measure to actually accelerate the shift to clean vehicles, whereas 'feasibility' was used to assess the possibilities towards implementation. Finally, by evaluating 'priority', the urgency of the measure was indicated. Each of the stakeholders was then able to attach a score of 1 (low), 2 (medium) or 3 (high) to the three indicators of each measure. The resulting average score within each stakeholder group is given in Table X. We assumed a score of '2' as the threshold above which acceptance was high. This was indicated in the table in bright green. The measures that were accepted by virtually all stakeholders on all indicators were marked in dark green.

Afterwards, four scenarios were arranged with inputs from the stakeholder meetings. A more thorough discussion of the scenario development phase, including the assumed tax levels and timings, can be found in Michiels *et al.* (2010).

The baseline scenario was defined as the situation with no additional measures taken on top of the currently existing and planned legislation. Some examples of the measures adopted under this scenario were:

- Euro emission standards (e.g. Euro 6)
- Maximum average CO_2 threshold per car manufacturer as from 2015 (ACEA)
- Mandatory introduction of biofuels (5% biodiesel and 5% ethanol) as from 2013
- Gradual introduction of CO_2 as coolant in mobile air conditioning systems as from 2011
- Obligation for public authorities to opt for a fleet composed of clean vehicles.

The baseline scenario served as a basis for the other three scenarios.

In the realistic scenario, the baseline was supplemented with a number of new measures which were averagely perceived as being both very effective and feasible, and to which most of the stakeholders attached a certain level of priority. Consequently, the novelties compared to the baseline are:

- Tax system based on CO_2 and Euro standard instead of power and cylinder capacity
- Advantages for early-complying-Euro 6 vehicles
- Clean fuel standardization and availability (e.g., CNG and E85)
- Change in excise duties : diesel excises rise to petrol excises, other (clean) fuels zero excise
- Subsidies for retrofitting old (Euro 3 and Euro 4) diesel cars with particulate filters
- Subsidies for converting vehicles to cleaner fuel systems (LPG and CNG)

Table X: Overview of the average score per stakeholder on effectiveness, feasibility and priority

Policy measure	Industry, conv.			Industry, alt.			Users & NGOs			Policy makers		
	Eff	**Feas**	**Prio**	**Eff**	**Feas**	**Prio**	**Eff**	**Feas**	**Prio**	**Eff**	**Feas**	**Prio**
CC Euro	2.18	2.64	2.09	2.50	2.38	2.13	2.00	2.50	1.75	1.91	2.36	1.82
CC CO_2	2.27	2.73	2.27	2.25	2.50	2.50	1.86	2.40	2.11	2.00	2.82	2.09
CC combi	2.45	2.64	2.36	2.50	2.13	2.38	2.13	2.86	2.44	2.20	2.20	2.18
CC technology	1.27	1.73	1.27	2.13	2.00	2.00	1.33	1.14	1.63	1.70	1.90	1.78
CC ecoscore	1.56	1.56	1.33	2.25	2.25	2.13	2.00	2.00	2.44	2.73	2.18	2.50
RT abolish	2.20	2.30	2.30	1.75	1.38	1.63	2.00	2.29	2.13	1.70	1.78	1.80
RT env perf	2.40	2.20	2.30	2.88	2.38	2.38	2.13	2.25	2.44	2.67	2.17	2.58
ACT abolish	2.00	1.36	1.55	1.50	1.63	1.50	2.11	2.00	1.63	2.45	1.73	1.82
ACT env perf	2.55	2.27	2.45	2.13	2.00	2.25	1.88	2.13	2.33	2.42	2.25	2.42
KC km	2.18	1.36	1.55	1.75	1.25	1.38	2.56	1.67	2.00	2.67	1.67	2.42
KC congestion	1.36	1.27	1.27	1.75	1.50	1.63	2.00	2.00	2.11	2.25	1.50	1.75
CM stimulating	2.00	2.18	2.00	1.75	2.00	1.63	1.44	2.00	1.38	1.89	1.78	1.33
CM forcing	1.00	1.09	1.00	1.50	1.63	1.50	1.88	2.43	2.33	1.89	1.89	1.56
Adv EURO5/6	2.18	2.27	2.27	2.25	2.25	1.88	1.88	2.33	2.25	2.50	2.30	2.10
CF low excise	2.64	2.64	2.55	2.50	2.38	2.63	2.50	2.29	2.13	2.60	2.30	2.50
CF standardis	2.64	2.27	2.36	2.50	2.63	2.63	2.14	1.50	2.25	2.67	2.33	2.44
FD stimulating	2.00	2.09	1.91	2.00	2.50	2.38	1.44	1.63	1.14	1.78	2.00	1.78
FD forcing	1.45	1.45	1.36	2.25	2.00	2.00	2.11	1.57	1.71	2.00	1.89	1.67
Parking fee	1.73	1.55	1.55	1.50	1.88	1.50	1.67	2.00	1.43	2.17	1.75	1.42
Limited access	1.91	1.64	1.64	1.88	1.88	1.50	2.00	2.29	2.22	2.42	1.75	2.00
SUBS retrofit	2.09	2.18	2.09	2.25	2.25	2.13	2.22	2.57	2.38	2.25	2.17	2.25
SUBS scrappage	2.82	2.73	2.73	2.29	2.14	2.43	1.78	2.43	2.00	2.25	1.92	1.83
PF stimulating	2.33	2.50	2.17	1.40	2.40	2.00	1.71	1.83	1.86	2.20	2.80	2.20
PF forcing	2.33	2.17	2.00	2.60	2.60	2.60	2.25	2.29	2.25	2.83	2.00	3.00
PF private	2.18	1.64	1.73	2.38	2.00	2.13	2.00	2.00	2.29	2.45	2.09	2.18

The progressive scenario was then considered as a step further than the realistic scenario. The effectiveness of a measure was now the most crucial factor in the selection of the measures, not so much the feasibility and priority. In the end, feasibility can possibly be overcome and priority is just an estimation of the urgency. Additional measures compared to the realistic scenario are:

- Tax system based on ecoscore and no longer on the combination CO2/Euro standard : single payment of RT based on ecoscore and time-, place- and ecoscore-dependent kilometre charge replacing the ACT
- Limited access to environmental zones in large Belgian cities (>70,000 inhabitants), dependent on ecoscore
- Mandatory green private fleet quota : 40% of company car purchases needs to reach minimal ecoscore

- Scrappage scheme : premium rewarded for a switch to a vehicle with higher ecoscore

Finally, the visionary scenario was designed as a translation of a futuristic view for the year 2060. Under this scenario, mobility was no longer perceived as a synonym for car possession, but rather as a service. No actual scenario runs were performed for the visionary scenario. For this scenario, the result section only contains the output (in terms of vehicle use and environmental impact) of some provocative assumptions, given below:

- For each trip, the best available technique is used: we assumed 100% electric vehicles on urban roads, 100% diesel hybrids on highways and 100% petrol hybrids on rural roads. Within the hybrid classes, we assumed a 60/40-ratio of charge-sustaining versus plug-ins for diesels and a 40/60-ratio for petrol vehicles.
- The total number of kilometres towards 2060 was expected to decline in line with the progressive scenario

7.3 Fleet analysis

7.3.1 E-motion Road model

The policy measures included in the scenarios acted as an input to VITO's 'E-motion Road' model. This model was used in order to make predictions on the fleet composition (number of cars), vehicle use (number of kilometres) and environmental impact (emissions and ecoscores). For the baseline, realistic and progressive scenario, we performed these calculations for the years 2010, 2015, 2020, 2025 and 2030, whereas 2060 was the arbitrary time horizon chosen under the visionary scenario.

It has to be stressed that the outcomes mentioned below are the result of the complete package of measures included in the scenarios. Consequently, the magnitude of the effects of the separate policy measures are not reported on, as this exercise would go far beyond the scope of this project. Nevertheless, the way each measure was modelled is discussed in Michiels *et al*. (2010), briefly mentioning the effects of each separate measure on new vehicles, existing vehicles and kilometres driven.

The emission model 'E-motion Road' was used to calculate both historical (up till 2008) and future (after 2008) emissions of road transport (see Figure 18).

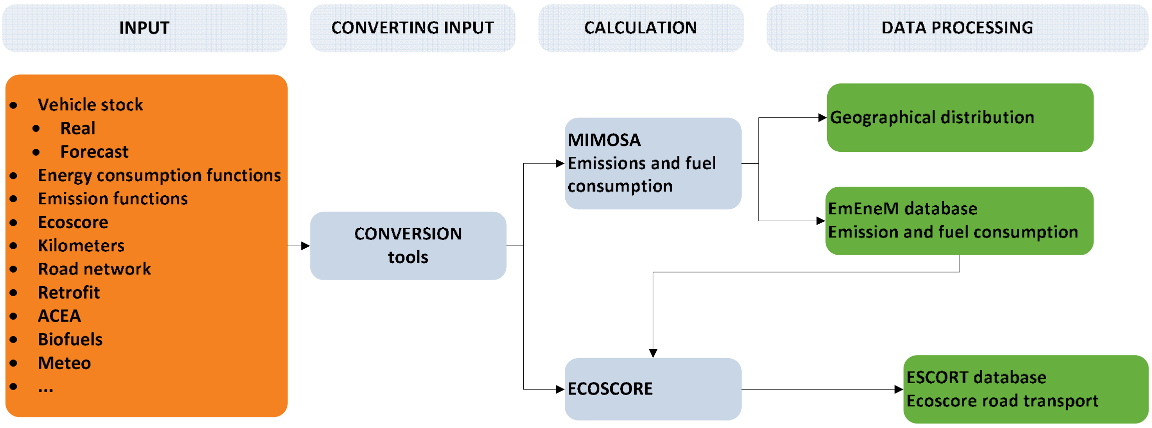


Figure 18: 'E-motion road' emission model

Concerning the calculation of historic emissions, detailed historical input data on vehicle fleet, mileages, vehicle kilometres, biofuel blends, etc. were inventoried and converted into emissions and energy consumption values by using the 'emission factor approach' from the MIMOSA module. Like most European road transport emission models, MIMOSA belongs to the 'average speed macroscopic emission models', expressing emission and fuel consumption rates as a function of average speed (related to the road type). The same emission factor approach was also used to estimate the future emission and energy results for different scenarios and years. However, this implies that first, new estimates of the future transport situation needed to be made. To forecast the vehicle stock and kilometres on the road (for different scenarios and different years), the following parameters were essential:

- *Survival rates of existing vehicles:* this parameter represents the percentage of existing vehicles (per vehicle type and age category) that will 'survive' to the next year and will therefore belong to an older age category the following year. By analyzing the historic trends of the survival rates and the specific measures applied in each scenario, this parameter was estimated for future scenario years. This parameter was allowed to differ according to the scenario.
- *Future vehicle technology:* this parameter represents the distribution of the vehicle technologies over the new vehicles that enter the vehicle fleet each year. By analyzing the historic trends of the technology distribution of new vehicles and the specific measures applied in each scenario, this parameter is estimated for future scenario years. Therefore, elasticity values from VUB-MOSI (see section 4) were applied for the following measures: a fiscal system based on CO_2 and Euro standard, and excises duties (for the realistic scenario) and a RT and kilometre charge based on ecoscore, excise duties, limited urban access and a scrappage scheme (for the progressive scenario). For the specific switch levels of purchases from one category to another, we refer to Michiels *et al*. (2010).

- *Total vehicle kilometres:* this parameter represents, per region, the total amount of vehicle kilometres covered on the road (originating from FPS Mobility and Transport). As a baseline estimate for this parameter, the forecasts of the Flemish traffic centre were mainly used (also used in the MIRA reference scenario from VMM), taking into account issues like socio-economic prognoses, demographic forecasts and planned transport infrastructure. The growth figures observed in Flanders could then be applied to the other regions to forecast their future vehicle kilometres. The difference in the total number of kilometres driven between the scenarios is initiated by the following measures: excise duties in the realistic scenario and a kilometre charge and limited urban access in the progressive scenario. More details on the resulting number of kilometres can be found in section Michiels *et al*. (2010).

To estimate the impact of a certain scenario/measure on the different model parameters, both existing literature and inputs from expert evaluations were used. As already mentioned above, information on the levels of the specific measures and the general impacts of these measures/scenarios on the 'existing vehicles', the 'new vehicles' and the 'driven kilometres' was already provided in Michiels *et al*. (2010). Running the model will then result in future vehicle fleet and emission data for different scenario years.

Besides fleet size, kilometres and emissions of passenger cars, the evolution of the vehicle fleet's ecoscore was modelled as well in the framework of this project. Ecoscore is a well-to-wheel indicator expressing the overall environmental impact of a vehicle, taking into account its contribution to global warming, air pollution and noise. Production processes of fuels and electricity generation will probably not be the same in 2030 as they were in 2010. However, emissions related to this well-to-tank phase (production and distribution of the fuel) of conventional fuels, were considered to remain unchanged. The reason for this is that the uncertainty on the evolution is too high (e.g., more energy efficient refineries versus less energy efficient crude oil extraction). Only for electricity generation, we considered the trend to be more positive (higher contribution of renewable energy sources in the electricity mix).

7.3.2 Scenario results

This section provides a comparison between the most eye-catching results of the baseline, realistic, progressive and (where available) the visionary scenario. In order not to overload the reader with information, the results were confined to the years 2010, 2020 and 2030. For a more comprehensive discussion of the scenario results, for more sample years, we refer to Michiels *et al*. (2011).

We subsequently discuss the results in terms of fleet composition (number of vehicles), vehicle use (number of kilometres) and environmental impact (emissions and ecoscores).

A. Fleet composition

Figure 19 depicts the total Belgian fleet size found for the three scenarios (in the visionary scenario, no predictions were made towards fleet composition). For 2020, it is clear that the most sophisticated scenario (i.e. progressive) results in the smallest amount of cars (5.58 mio). This proposition was found to be no longer valid for the year 2030, where the smallest fleet size (5.82 mio) is attained by the policy measures in the realistic scenario. The higher figure for the progressive scenario in 2030 is due to an increased purchase of small and clean (hybrid and electric) vehicles, which are on average driven less frequently. Generally speaking, the fleet size is expected to follow an increasing trend when comparing 2030 to 2020 and 2010, in spite of all the measures introduced.

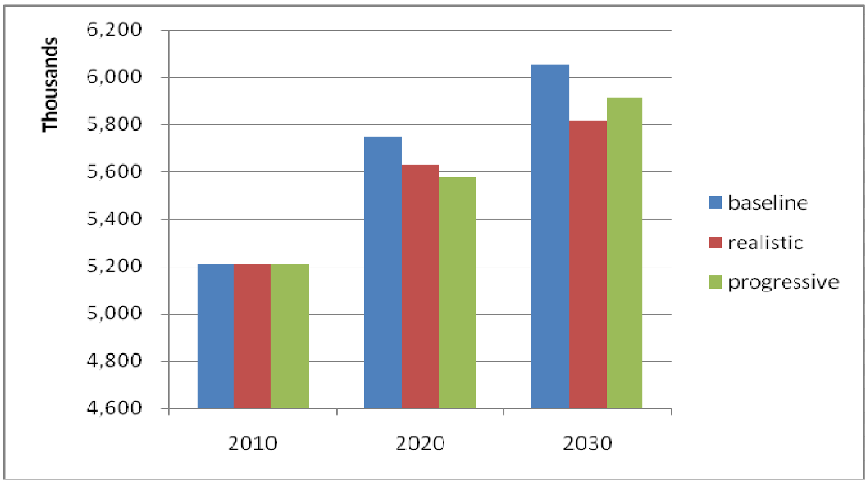


Figure 19: Total number of cars in Belgium

Another interesting result is the split of the fleet size over the various vehicle technologies. The relative shares of the technologies are depicted in Figure 20. It was seen that the more sophisticated the scenario and the further we look into the future, the smaller the share of conventional diesel engines will be. The realistic scenario is expected to have a much smaller impact on the introduction of the cleaner technologies than the progressive scenario. If we want to facilitate the market introduction of especially hybrids and electric vehicles, it seems we will have to resort to the measures from the progressive scenario. This presumption is valid for both 2020 and 2030.

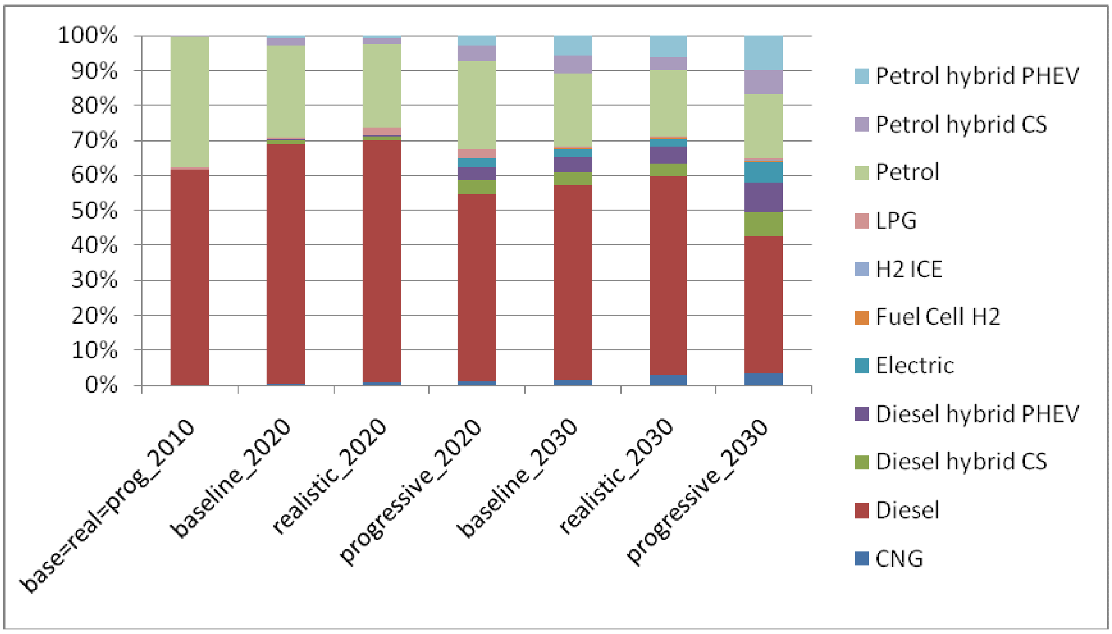


Figure 20: Relative share of cars over different technologies

B. Vehicle use

Judging a scenario by the fleet size criterion alone would result in a biased image, as not all cars are driven the same number of kilometres. Therefore, we should focus on the 'vehicle use' as well.

As can be seen in Figure 21, the total number of kilometres is expected to rise as well for all scenarios over the period 2010-2030. The distance driven under the baseline and the realistic scenario will even increase over the shorter period 2020-2030, whereas the progressive scenario predicts a decline over this period. In 2030, the benefit from the progressive scenario is no less than 6.8 billion kilometres per year vis-à-vis the realistic scenario. If we compare this with the number of cars in Figure 19, we can conclude that the diverging image for the progressive scenario in 2030 can most probably be attributed to the increased share of small and clean vehicles, which are driven less than the average vehicle in the fleet (for more information see Michiels *et al*. (2011)). The resulting number of kilometres from the visionary scenario for 2060 show a 40% benefit compared to the progressive result in 2030.

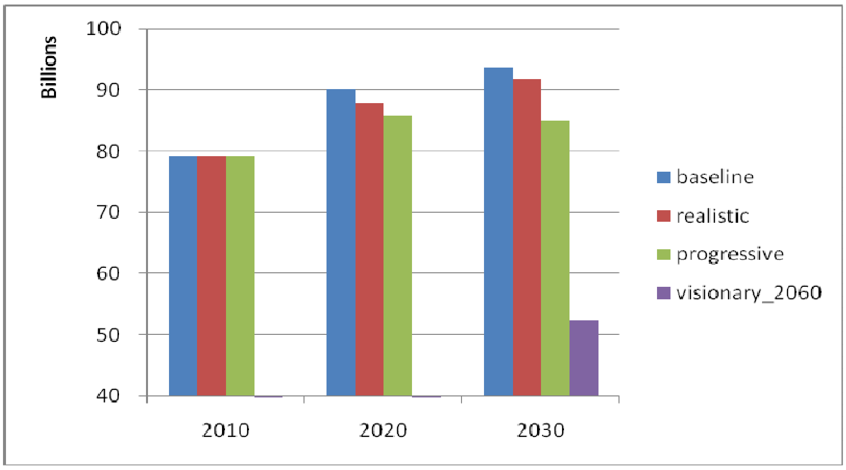


Figure 21: Kilometres driven in Belgium

The relative share of the kilometres driven by each technology is given in Figure 22. If we compare with Figure 20, it is clear that especially diesel cars are and will be driven longer distances than the average vehicle in the fleet. If we want to reduce the relative share of conventional diesel kilometres vis-à-vis the baseline, it is clear that the measures proposed in the progressive scenario are preferable to those of the the realistic scenario, which seems to be even slightly beneficial (especially after 2020) for the use of conventional diesel vehicles. In the realistic scenario, it appears that the increased excise duties on diesel are missing their effect. In fact, it seems that they are partly or completely offset by the consumption advantage of diesel engines, combined with lower taxes (compared to petrol) under the CO_2-based tax system. The share of kilometres driven by the newer clean vehicle technologies (diesel hybrid, petrol hybrid and electric) is strongly encouraged under the progressive scenario. The visionary scenario envisions a revolutionary situation for the year 2060, with all kilometres travelled by hybrids and full-electric vehicles.

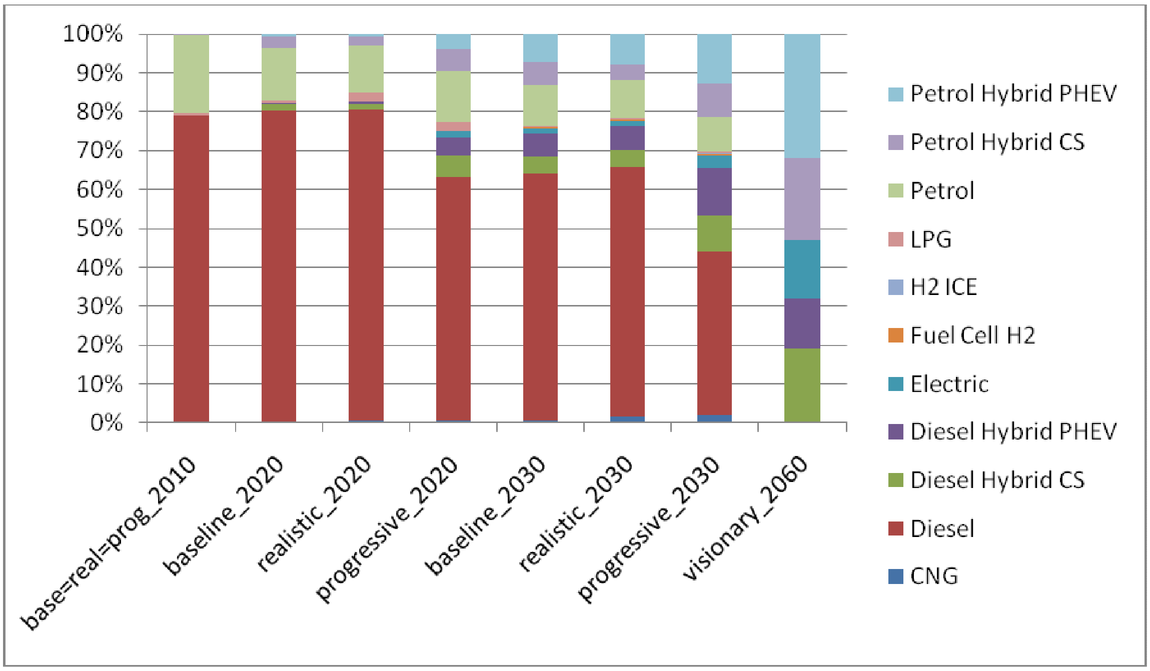


Figure 22: Relative share of kilometres driven by different technologies.

C. Environmental impact

The average ecoscore of the fleet, weighted for the kilometres driven by each car, is displayed in Figure 23. This parameter differs from an unweighted ecoscore in the sense that for the latter, each car gets an equal weight, no matter what distance is travelled.

Regarding the weighted ecoscore, we predict an obvious increase over the period 2010-2030. However, it is clear that the progressive scenario provides a substantial benefit compared to the baseline and realistic scenario (71.65 vs 69.16 and 69.59 in 2020 and 75.43 vs 73.73 and 73.77 in 2030). These values are slightly above the unweighted ones observed Michiels *et al.* (2011), which indicates that cars with higher ecoscores are driven more kilometres compared to cars with lower ecoscores, on average.

Emission levels of CO_2eq, $PM_{2.5}$ and NO_x are displayed in Figure 24 till Figure 26. We can classify these emissions in two groups: CO_2eq on the one hand and $PM_{2.5}$ and NO_x on the other hand.

Concerning emissions of CO_2eq, emission differences between the various technologies rule, rather than the (automatic) technological progress over time. This can be observed in Figure 24, where the baseline emissions in 2030 exceed the 2020 emissions under the progressive scenario. Therefore, the importance of policy measure implementation for the benefit of lowering CO_2eq emissions cannot be stressed too much. The share of CO_2eq emissions originating from diesel vehicles is substantial, but not so large as for $PM_{2.5}$ and NO_x.

Regarding emissions of $PM_{2.5}$ and NO_x, we conclude from Figure 25 and Figure 26 that all engine technologies seem to benefit from a large level of technological improvement. This happens automatically over the years, because we see for example that the total level of emissions under the baseline in 2030 is lower than emissions under the progressive scenario in 2020. Nevertheless, compared to the other technologies, diesel vehicles (both conventional and hybrid) relatively contribute a lot to the total emission levels of $PM_{2.5}$ and NO_x.

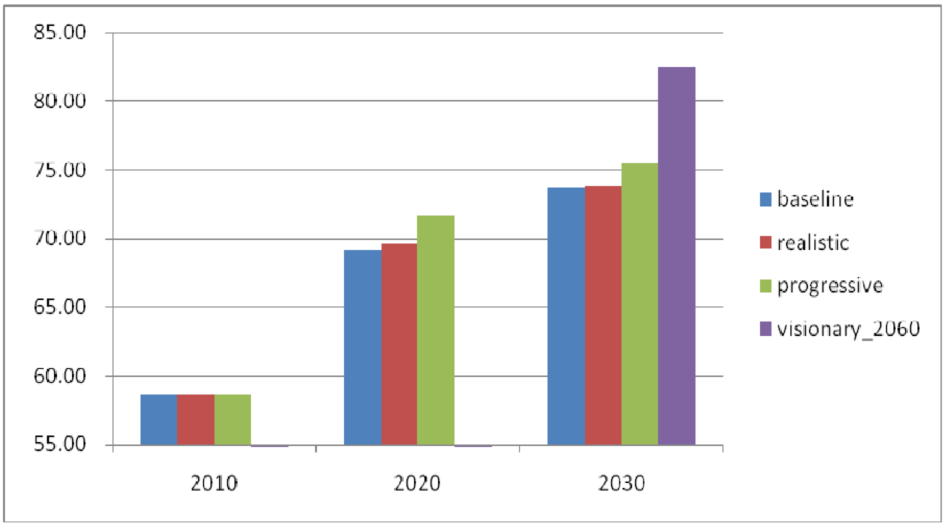


Figure 23: Average ecoscore for Belgian fleet (km weighted).

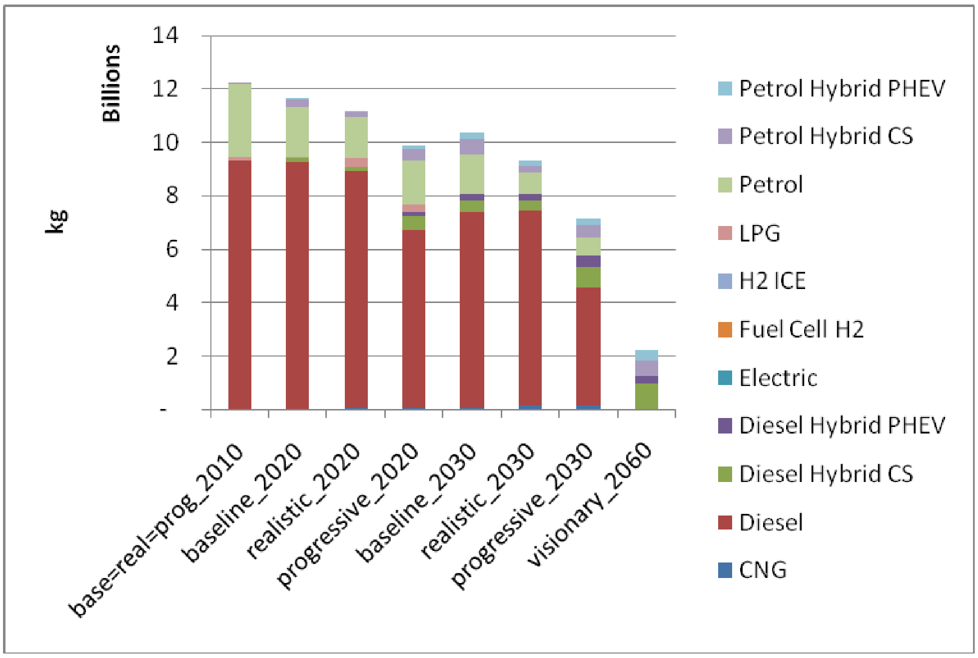


Figure 24: TTW emissions CO_2eq per technology.

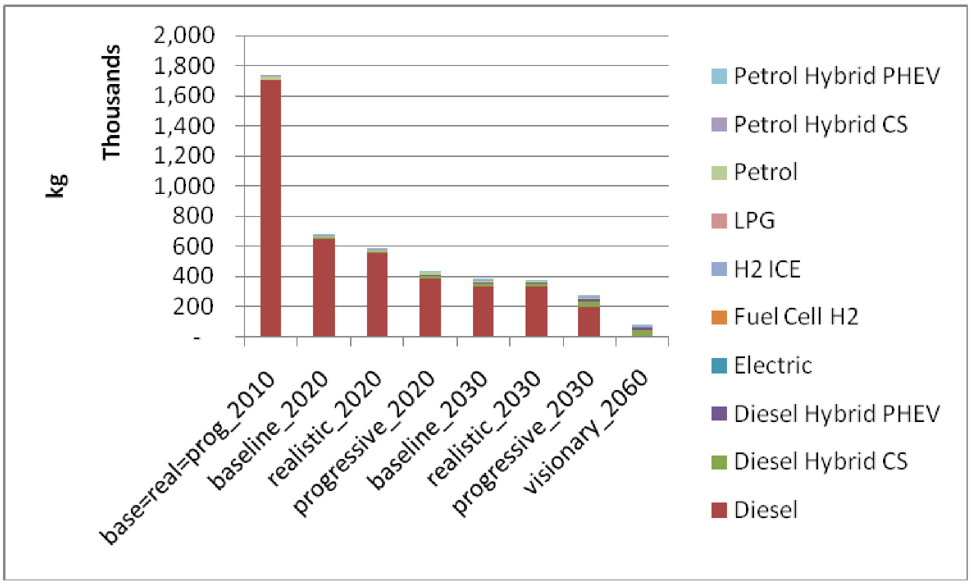


Figure 25: TTW emissions $PM_{2.5}$ per technology.

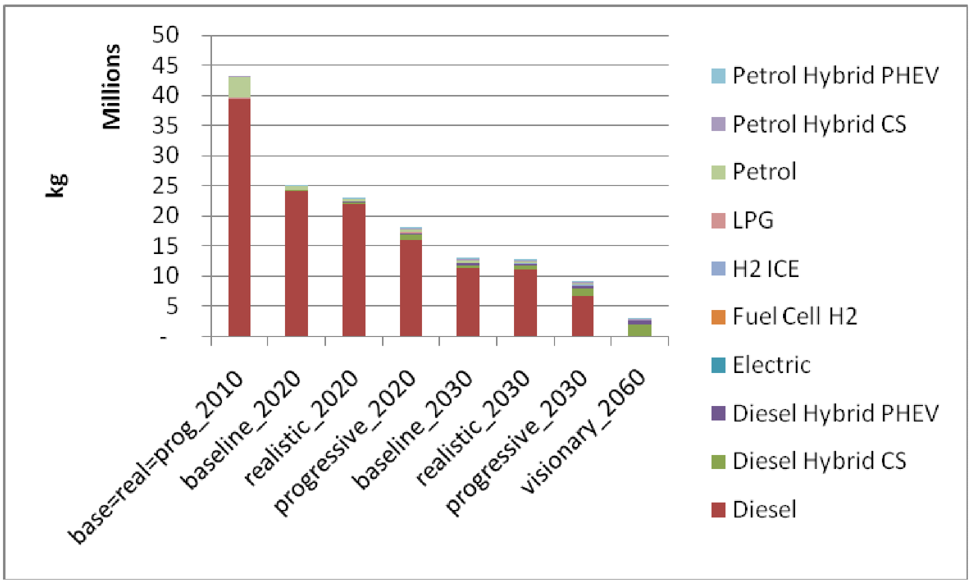


Figure 26: TTW emissions NO_x per technology.

It needs to be stressed that these scenario results not only depend on the type of measures introduced, but also on the specific level of each measure. From the figures given above, we can deduce that the progressive setup indeed yields better results than the realistic scenario, but this is only true for the specific levels of the simulated measures, described in Michiels *et al*. (2010). As a consequence, the results of the realistic scenario could have been much more encouraging, for example if the excise duties on diesel had been significantly higher than those on petrol. In conclusion, we can say that we can only judge on the impact of the complete set of measures in the scenarios, as described in Michiels *et al.* (2010).

The results from the visionary scenario indicate that there is a huge gap between the well-founded model results for 2030 and the visionary exercise for the year 2060, both in terms of the amount of kilometres travelled and the environmental performance indicators. Seemingly, the predefined vehicle fleet distribution and the other assumptions made under this scenario promise to be quite beneficial for traffic intensities and the corresponding ecoscores and emissions. However, we should take account of the fact that direct carbon emissions still exist, so, even under this scenario, there is room for improvement.

8. Multi-Criteria Analysis

8.1 Introduction

The purpose is to perform an evaluation of the different scenarios that have been set up throughout the previous sections, namely the baseline, realistic and progressive scenario. By means of a multi-criteria analysis (MCA), these scenarios are evaluated on several criteria for which input has been gathered throughout the other tasks of the CLEVER project. For this purpose, a combination of the PROMETHEE methodology and the Analytic Hierarchy Process (AHP) is used. The overall aim is not to categorize the single best scenario, but to formulate suitable policy recommendations to the decision makers. Section 8.2 covers the stepwise procedure of the MCA and 8.3 gives the overall results. These results are used to formulate the policy recommendations in chapter 9.

8.2 Methodology

MCA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities. The main role of these techniques is to deal with the difficulties that human decision makers have in handling large amounts of complex information in a consistent way. Typically, most decision problems have a multi-criteria nature and refer to several concerns at the same time: technological, economical, environmental, social etc. As there is no alternative optimizing all the criteria at the same time, a compromise solution should be selected. In this task, the MCA Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) has been used, which has been developed by Brans (1982) and by Macharis *et al.* (1998). As PROMETHEE does not provide a specific method according to which weights are to be determined, it will be combined with the decision making software Expert Choice, based on Saaty's analytical hierarchy process (AHP) by which weights are determined by means of pairwise comparisons.

A typical MCA procedure consists of several steps: Identification of the problem and selection of the alternatives (STEP 1), translation of the objectives (concerns) into several criteria (STEP 2), quantification of the relative importance of each criterion (weights) (STEP 3), assessment of the performance of each alternative to the identified criteria (STEP 4), categorization of the alternatives based on their performance contribution to the criteria (STEP 5) and sensitivity analysis (STEP 6).

8.3 Results

Step 1 : Defining the problem

The first stage consists of identifying the possible alternatives submitted for evaluation. In this case, the alternatives to be evaluated are the scenarios that have been described in Michiels *et al*. (2010) and consist of a baseline, realistic and progressive scenario.

Step 2 : Defining the criteria

The choice and definition of the criteria (and sub-criteria) are primarily based on expert meetings with the CLEVER consortium. Out of previous tasks of the CLEVER project, it is clear that the stimulation of cleaner vehicles into the end-user market by means of several policy measures is related to many concerns: environmental (see LCA and External costs tasks), budgetary (see LCC task) and feasibility concerns (see Englert *et al*. (2009) and Vanderschaeghe *et al.* (2009)). That is why it is important to integrate these aspects in the evaluation process of the several scenarios listed above. Overall, the scenarios will be evaluated based on environmental effectiveness (fleet emissions, average Ecoscore), impact on mobility (amount of kilometres driven, modal choice) and feasibility (budgetary impact, technical feasibility and socio-political acceptance). Figure 27 represents the hierarchical decision tree, in which the multiple criteria and subcriteria are highlighted on which the baseline, realistic and progressive scenario are evaluated.

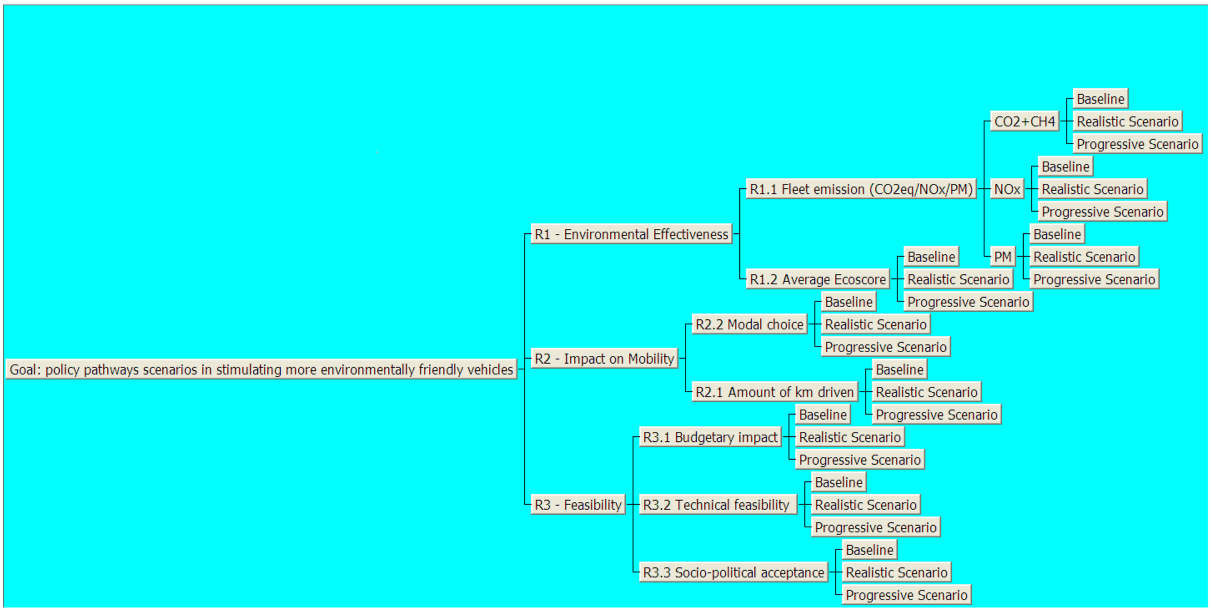


Figure 27: Decision tree.

Step 3 : Allocation of weights to the criteria

In order to express preferences for the different criteria, weights are allocated. For this purpose, the decision making software Expert Choice based on Saaty's analytical hierarchy process (AHP) was used. The CLEVER consortium and members of the follow-up committee were sent an online application, in which they were asked to pairwise compare the different criteria according to their importance. 20 respondents provided weights (5 from the consortium and 15 from the stakeholders). Figure 28 gives the results of the weight distribution of respectively the consortium, the stakeholders and the combined weight. Overall, it is shown that environmental effectiveness gets the highest preference (43%), followed by feasibility (38%) and impact on mobility (19%).

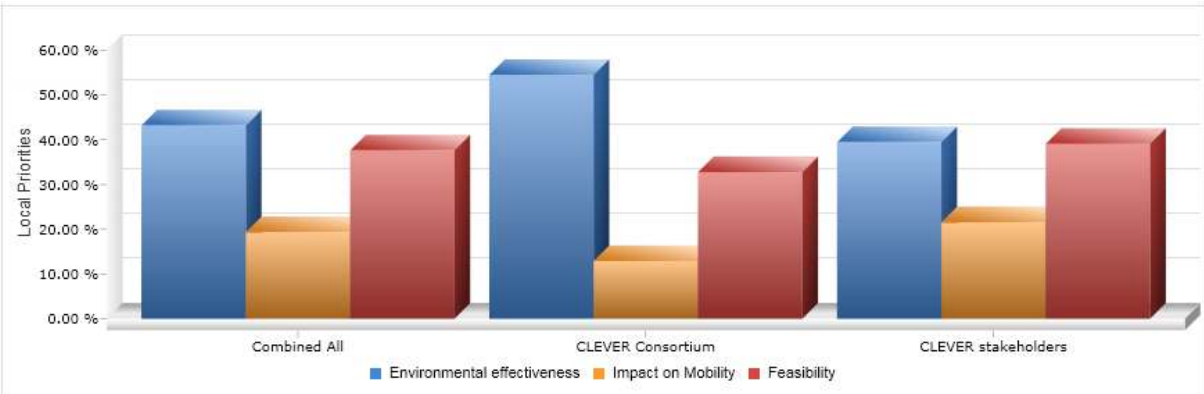


Figure 28: Priorities by the different consulted groups

Step 4: Performance assessment

In this step, the previously identified criteria are "operationalized" by constructing indicators that can be used to measure whether, or to what extent, each alternative contributes to each individual criterion. Indicators can be quantitative as well as qualitative. In this analysis, the performance assessments have been made by the CLEVER project team (Vrije Universiteit Brussel, VITO and ULB). By letting experts assign the performance values, a scientific and solid foundation in the evaluation process of the alternatives (here: scenarios) is provided. In accordance Michiels *et al.* (2011), the different scenarios have been compared for the years 2020 and 2030.

Step 5 : Categorization of alternatives

For the overall assessment and ranking of the scenarios, the PROMETHEE decision making software, D-SIGHT, has been used. This software combines the weight allocation, performed by the CLEVER consortium and CLEVER stakeholders (see step 3) with the performance valuation of the alternatives, assigned by the experts (see step 4). A complete ranking of the scenarios is shown in Figure 29 (for reference year 2020) and Figure 30 (for reference year 2030), which is based on the net outranking flow (= balance between the positive and negative outranking flows in D-SIGHT). Based on these net outranking flows, one can thus see that for the reference year 2020, the progressive scenario is ranked the highest, closely followed by the baseline scenario and the realistic scenario. The same is true for the reference year 2030, where the distance between the first (progressive) and second ranked (baseline) scenario even becomes bigger.

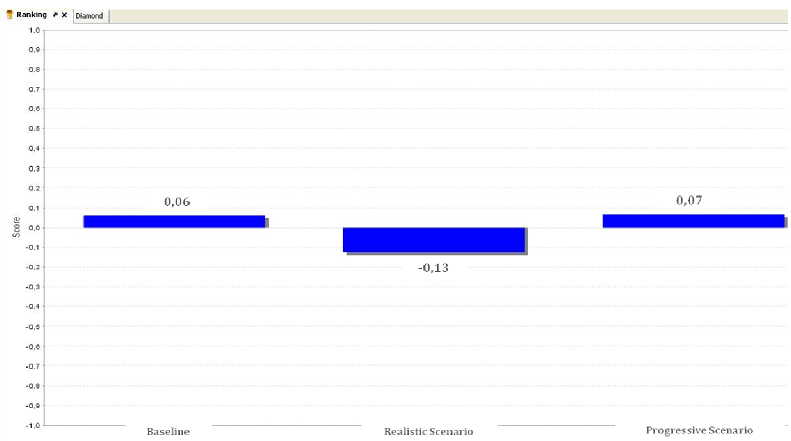


Figure 29: PROMETHEE ranking results for 2020.

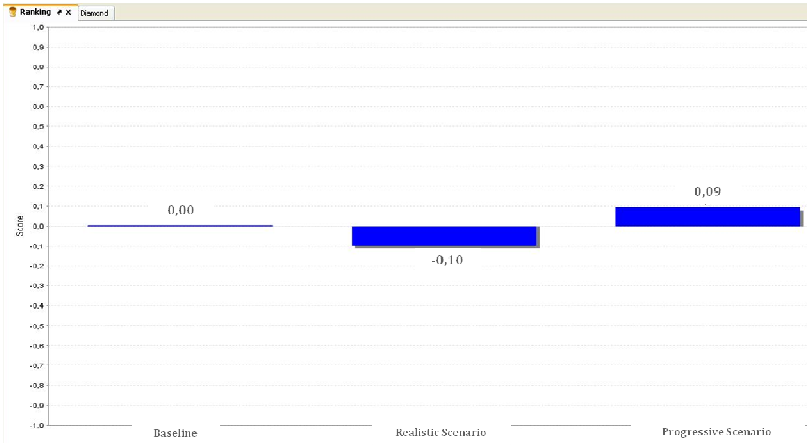


Figure 30: PROMETHEE ranking results for 2030

In order to get a deeper insight in these results and into the strong and weak points of each investigated scenario, a visualization is given in Figure 31 and Figure 32, based on the PROMETHEE GAIA plane, where the scenarios are represented as points and the criteria as the axes. Alternatives scoring high on a particular criterion are represented by points located in the same direction of the corresponding criterion axis (Macharis *et al.*, 2004). In this respect, one can clearly notice that the progressive scenario performs the best in minimizing the fleet emissions and in maximizing the average Ecoscore of the Belgian vehicle fleet (grouped under «environmental effectiveness») and in minimizing the amounts of kilometres driven and in maximizing the encouragement towards other modes of transportation (grouped under «impact on mobility»). It however scores less regarding its budgetary, technical and socio-political feasibility (grouped under «feasibility»). With respect to this criterion, the baseline and the realistic scenario have a better score. Moreover, these figures also contain a decision stick, which is the weighted resultant of all the criterion axes. By means of this decision stick, the relative position of the alternatives in terms of contributions to the various criteria can be demonstrated. Figure 31 illustrates that the progressive as well as the baseline scenario are closely located in the direction of the decision axis, which means that they are both seen as scenarios that contribute the best to the different criteria for the reference year 2020. For the reference year 2030, the situation is slightly different (Figure 32). There, the progressive scenario more clearly outranks the other scenarios.

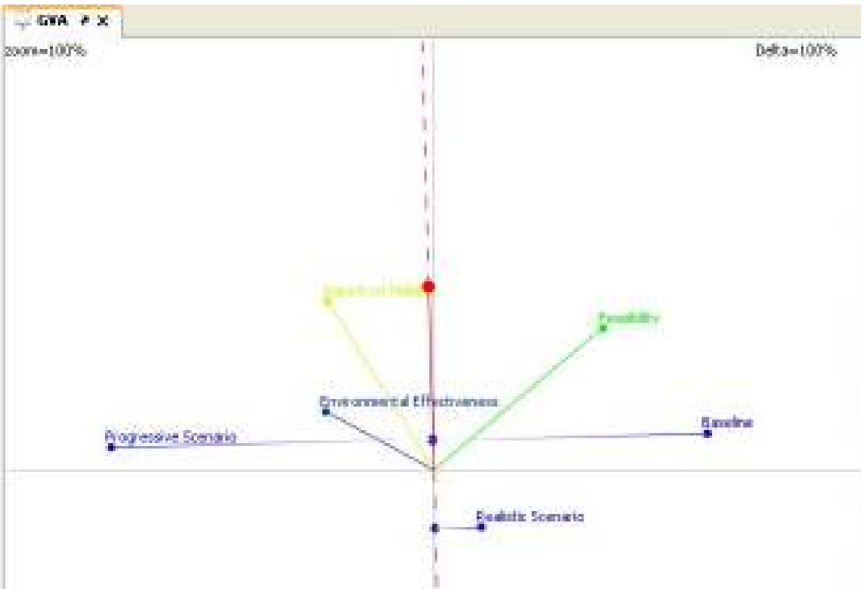


Figure 31: PROMETHEE GAIA plane for the reference year 2020

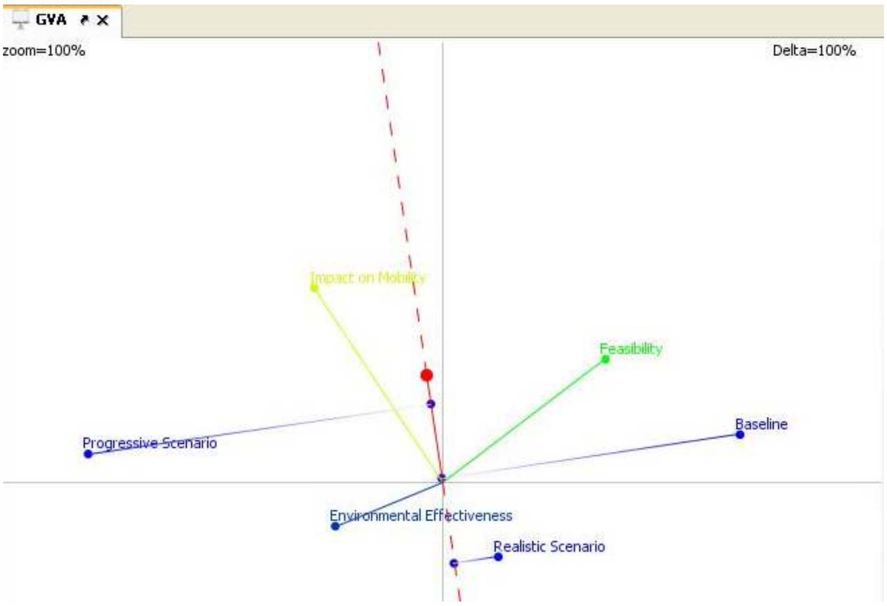


Figure 32: PROMETHEE GAIA plane for the reference year 2030

Step 6: Sensitivity analysis

The overall ranking of the scenarios, elaborated in step 5, is noticeably influenced by the established weights attributed to the criteria groups and the subcriteria. If, for example, feasibility becomes the major concern for policy makers, then the progressive scenario is clearly outranked by the baseline and realistic scenario. These sensitivities should be taken into consideration when deciding on which scenario to implement.

9. Policy support recommendations

In the CLEVER project, we sought answers to several research questions: (1) How environmentally friendly are conventional and new vehicle technologies? (2) How are they accepted by the general public and other users? (3) What are the barriers to their introduction on the market? (4) What possible incentives and policy measures could be implemented to stimulate the market? To achieve the objectives of this project, a multi-disciplinary approach has been adopted and provided the following answers:

9.1 How environmentally friendly are conventional and new vehicle technologies?

Comparing the environmental impact of conventional vehicles (diesel, petrol) has already shown to be a difficult exercise. Diesel cars for example are more fuel efficient and emit less greenhouse gases than petrol cars, but on the other hand emit more particulate matter and NOx, which have a strong impact on human health. Many environmental rating tools exist which are able to give an environmental score to different vehicle technologies, but which provide different results due to the many methodologies and weighting parameters that can be used. The Ecoscore methodology is an example of such a rating tool, which is based on a well-to-wheel approach, implying that both tailpipe and indirect emissions due to the fuel or electricity production and distribution are taken into account.

The comparison becomes even more complex with the introduction of so-called 'alternative' fuels and drive trains (LPG, CNG, HEV, BEV, FCEV, biofuels, hydrogen). To make a fair comparison of all these fuels and technologies, not only the well-to-wheel emissions should be considered, but also the emissions due to the production, maintenance and end-of-life phase of the vehicle. In electric vehicles for instance, large batteries or a fuel cell are used, which are not present in conventional ICE vehicles and which can have a significant environmental impact.

To take all these life cycle phases and emissions into account, a **Life Cycle Assessment (LCA)** has been performed on a wide range of vehicles which are available on the Belgian market. LCA is an ISO-certificated methodology, which is generally used to compare products or services on a comparable basis. In the CLEVER project, an LCA methodology has been developed with a per-model applicability instead of an average vehicle LCA. This allows taking into account all segments of the Belgian passenger car market (family car, SUV, city car, etc.) and producing LCA results per vehicle technology and category. These vehicles were compared on the basis of the same provided service to the user, which has been defined as the use of a passenger car in Belgium during 13, 7 years and a lifetime driven distance of 230.500 km.

Because of the large variety of environmental impact categories, it is almost impossible and sometimes misleading to claim that a vehicle is better than the others from all viewpoints. In this project, a list of relevant environmental impact categories has been made in order to have a good appreciation of the environmental score of conventional and alternative vehicles. The impact calculation methods used in this project are: the IPCC 2007 Greenhouse Effect, The respiratory effect from Impact 2002+, air acidification and eutrophication from 'Centrum voor Milieukunde Leiden' (CML), the mineral extraction damage from Eco-indicator and the consumption of renewable and non-renewable energy.

When dealing with climate impact, conventional vehicles have the highest impact. On average, diesel vehicles always score better than petrol vehicles but the sensitivity analysis reveals a strong overlap between these two technologies. BEV powered with the Belgian supply mix electricity, with the exception of the sugar cane based E85 vehicle, has a lower greenhouse effect than all the registered family cars in Belgium. However, extreme scenarios, where electricity produced from 100% coal or oil is considered, give higher eutrophication and acidification impacts to the BEV. Moreover, the climate benefit of the use of nuclear and renewable electricities in BEV as well as the maintaining of this benefit when the energy consumption increases has been demonstrated.

In general, biofuels have lower CO_2 emissions due to the CO_2 uptake during the photosynthesis of the organic matter. However, this benefit of the CO_2 uptake can be balanced by N_2O emissions deriving from nitrogen contained in fertilizers. So the type of feedstock used to produce biofuels and the agricultural practices have a strong influence on the climate impact of biofuels. Contrarily to climate impact, first generation bio-fuels have a bad respiratory effect (Sugar cane ethanol and RME) and bad acidification (RME) scores because of nitrogen-based emissions (NH_3 and NOx) and/or sometimes PM emissions. However, a vehicle using sugar beet ethanol will have a respiratory effect and and an acidification impact which are comparable to conventional cars. Again, the type of feedstock used to produce the biofuel is the main influencing parameter of its environmental score. Close to the feedstock type, the agricultural practices also influence the environmental score of biofuel vehicles. For example, the respiratory effect score of sugar cane ethanol can be highly improved by avoiding burning the sugar cane before the harvest. This is why the development and production of second generation biofuels need to be encouraged. It is important to notice that petrol and diesel vehicles are better than respectively ethanol and biodiesel vehicles for respiratory effects (inorganics). For the acidification impact, petrol and ethanol vehicles are comparable while diesel vehicles are clearly better than RME vehicles.

The use of mineral resources is also a key issue in the manufacturing, the use and the maintenance of vehicles. For this impact category, the size of a vehicle and the use of specific components requiring specific materials are the influencing parameters. Hybrid vehicles and FCEV will have a higher impact for this indicator because of the use of specific and rare materials to produce components like the NiMH battery, fuel cell and hydrogen tank. The BEV has slightly lower mineral resource damage but the contribution of the battery is still high. Another finding for this indicator is the high contribution of the transport and distribution of the electricity used to power the BEV. This is essentially due to the use of copper in the electric cables. It is important to mention that an increase of the size of a BEV will quickly increase its mineral extraction damage. The RME vehicle has an impact higher than petrol and diesel and comparable to hybrid and FCEV. This is mainly due to the use of mineral fertilizers during the rape production. Petrol, diesel and ethanol vehicles have comparable results and have the best scores after BEV and CNG.

This study has also revealed how important recycling is especially for heavy and precious metals contained in specific components such as batteries and fuel cells (FCEV, Hybrid, BEV…).

For the different impact categories considered in this study, the impacts of LPG technology are comparable to diesel. However, better environmental scores are possible for LPG by using for example flare gas instead butane/propane from oil refinery to produce LPG.

FCEV are more interesting than petrol and diesel vehicles for greenhouse effect, respiratory effect and acidification. This is mainly due to the fact that the FCEV is a TTW emission-free vehicle and the fact that the hydrogen is produced with natural gas via steam methane reforming. In fact natural gas has a very low acidification impact and respiratory effect. However, the steam reforming process used to produce the hydrogen is energy intensive. As a consequence, the FCEV has a bigger WTT greenhouse effect despite its interesting overall greenhouse score.

Another interesting finding of this study is that CNG vehicles appear to be an interesting alternative for conventional vehicles. It has a low climate impact (comparable to hybrid technology) and the best score for respiratory effects and acidification. It also has the lowest mineral extraction damage after BEV. However

CNG is produced with a fossil fuel. So, CNG vehicles will become more interesting with the development of the biomethane sector.

Finally, it appears in this study that the vehicle segment has a strong influence on the LCA results. In general, the bigger the segment (e.g. from supermini to large family car), the worse the environmental score. Additionally, when comparing the results for the different vehicle segments, the trends between the different vehicle technologies remain the same.

A completely different approach in comparing the environmental impact of vehicles, is by looking at their **external costs**. An external cost, also known as a negative externality, arises when the social or economic activities of one group of persons provide damage to another group and when that damage is not fully accounted, or compensated for, by the first group. A framework was built for assessing impacts that are expressed in different physical units into a common unit – the monetary value, through the 'impact pathway methodology' developed in the European ExternE project (ExternE, 2005). Impact categories assessed cover (i) health costs due to exhaust and non-exhaust particulate matter, and to ozone; (ii) building damage costs arising from exhaust and non-exhaust particulate matter and SO_2; (iii) noise costs; (iv) climate change costs. These external costs were assessed for two samples of cars, for the particular case of the Brussels Capital Region and compared according to the main characteristics of the car sample: car size segmentation and fuel type or motorisation system as well as expressed per weight. Only for the climate change aspects the total emissions were considered (WTT and TTW) as climate change is related to the total GHG emissions. For all other aspects, health, building soiling and noise, only the local emissions impacts (TTW) have been assessed.

Globally, for a given engine type, external costs are proportional to the weight of the vehicle and are thus highly correlated with the car size. A good correlation between the marginal external costs and the vehicle weight is also observed for PM_{10} and GHG, but not for noise. For ozone, mainly diesel vehicles are the source of local marginal benefits correlated with the car weight. As a whole, the total marginal external costs are proportional to the weight of the vehicle and are thus highly correlated with the car size for the different engine types. Diesel cars not equipped with a particulate filter are associated with the highest total marginal external cost, reaching c€ 22.6/km for a diesel SUV in the most realistic scenario. Diesel vehicles equipped with particulate filters have the second highest total marginal external cost, though they are much closer to those of the petrol, LPG and CNG engines. At the opposite side, electric cars seem to generate the lowest impacts (c€ 4.81/km). Hybrid car also prove to have lower external costs than any other technology for vehicles of same weight, but the advantage can be lost in this technology requiring more than 225 kg of additional equipments. Considering the pollution category, health represents 39% of the total marginal external costs, followed by building damage and climate change costs (33 and 17%, respectively). Noise costs account for about 9% of the total external cost. Ozone related health benefits represent ~1% of the average total amount. This last figure must probably be re-estimated because the simple dispersion model used does not reflect the reality of ozone summer peaks and concerns only the impact on the Brussels Capital Region's population.

The study also clearly shows the predominance of PM related impacts in the total societal costs. More specifically, non-exhaust PM could be the main cost driver. At the current state of knowledge, however, non-exhaust PM emissions and their specific impacts on health and building damage are surrounded by a great margin of uncertainty.

This study demonstrates that the implementation of transfer approach for assessing external costs of air pollution remains a delicate exercise, given the number of uncertainties and unknown features surrounding the mechanisms associated with the impact of pollution by vehicles. The results of this study can give an interesting signal to the decision makers concerned about the quality of the urban environment and its relationship with vehicles categories but should be considered with great caution.

9.2 How are clean vehicle technologies accepted by the general public and other users?

The adoption of environmentally friendlier vehicles primarily depends on the factors that determine the car purchase decision. A literature review on the state-of-the-art on purchase behaviour and a survey at Auto and Motor show in Brussels disclosed that many attributes determine the car purchase decision. Vehicle quality, such as reliability, security and comfort are the most important determinants of car purchase. Financial factors, such as the purchase price and operating costs come in a close second and when taken together as the vehicle's life cycle cost (LCC), they even outweigh qualitative aspects. Although positive attitudes towards the environment exist, environmental performance is outweighed by vehicle quality and financial attributes in the car purchase decision.

Consequently, in order to increase vehicle sales of environmentally friendlier vehicles, environmental aspects could be associated with attributes carrying a greater weight in the purchase decision. In this respect, acting on the LCC of clean vehicles by means of economic instruments may be an effective way to promote the purchase of clean cars. The LCC analysis (see section 3) revealed that (more) sustainable vehicles are at present not financially attractive for the Belgian end-user (LCC of clean vehicles ≥ LCC of conventional vehicles), especially with respect to diesel vehicles. The fiscal system discourages them (by an additional ACT for LPG and CNG vehicles; by high excise duties for biofuel vehicles), whilst favouring polluting vehicles (e.g. diesel cars). The existing incentives (exemption of excises for LPG, CNG, EVs; governmental support for vehicles with low CO_2-emissions and PM-filters), should be complemented with other policy measures to enhance their attractiveness. In this respect, a reformed taxation system, based on the Ecoscore of the vehicle, will better reflect the cost that each vehicle imposes on society and hence increase the financial attractiveness of clean vehicles.

However, the steering effect of such a tax reform should not be overestimated. First of all, most pricing measures (tolls, parking charges, fuel taxes, vehicle taxation) are price inelastic as these extra costs only represent a small share within the total LCC of a vehicle. Secondly, individual characteristics determine the effectiveness of pricing measures too, such as income and attitudes. A large scale survey of 1183 Belgian respondents not only revealed that income is positively associated with the willingness to pay (WTP) to keep using the conventionally fueled vehicle under the proposed pricing measure, but also that people having positive attitudes towards the environment will make a quicker shift to cleaner vehicles than so-called "non-environmentalists". Thirdly, other vehicle attributes determine the car purchase decision too. The same survey also showed that consumers express a higher WTP to keep using their conventionally fueled vehicle above a clean vehicle although they will be confronted with a higher financial load. This suggests that besides financial aspects, other attributes, less prone to being affected by pricing policies, still govern car purchase behaviour. Additionally, consumers are more likely to switch to low CO2 emitting vehicles than to alternatively fueled vehicles (AFVs), although they get higher price reductions or even exemptions for AFVs under the proposed pricing measures. A possible reason for this outcome is that a transition to low CO2 vehicles requires no trade-off of other important attributes, whereas this is the case for AFVs (e.g. reduced driving range, longer recharging times for EVs, etc.). Besides financial aspects, the acceptance of clean vehicles by private consumers and other users, will thus be largely determined by their perceived non-economical barriers too (see section 6). Finally, the effectiveness of policy measures also depends on the acceptance of the policy measure itself, which is largely determined by its feasibility (e.g. road users prefer schemes where the additional receipts are used in the same domain rather than using it for general public funds; politicians prefer budgetary-neutral schemes) and its perceived effectiveness (e.g. policy measures have to be effective in obtaining the desired results). The input from multiple actors in the field as well as from policy makers is essential in the evaluation process of policy measures and requires a dedicated stakeholder consultation (see section 7).

9.3 What are the barriers to the introduction of clean vehicles on the market?

The survey at the Auto and Motor show in Brussels (see section 6) highlighted several types of barriers with regard to the purchase and use of alternative vehicles from an individual's point of view, namely economic (higher purchase price, etc.), supply (small offer, etc.), market (lack of development, competition with low emission conventional vehicles, lack of information, etc.) and technical barriers (technical immaturity and limited range, etc.). While economic barriers appear to be very important, it is confirmed that other aspects have a significant impact on the purchase decision too. More specifically, results have shown that psychological barriers, such as the lack of confidence in safety, might have a decisive influence on the car purchase decision.

Besides barriers for the individual consumers, the involved stakeholders in the field of alternative vehicles face many barriers too. Interviews with fleet managers highlighted that a combination of barriers (supply-sided, economic, technical and market related), and some bad expericiences make AFVs currently unattractive. Especially the lack of supply of AFVs in leasing companies and the inexistence of certain required vehicle types (intervention vehicles or vans) greatly limits the introduction of AFVs in vehicle fleets.

For vehicle manufacturers, the lack of demand is a major concern, which is the result of several barriers at the individual consumer level (see above). As a result, the focus is more on the development of low CO_2 emitting vehicles than on AFVs. Additionally, the lack of fuel availability (e.g. lack of standardization of biofuels) and the lack of an appropriate taxation system to create a favourable context for AFVs underline the need for a harmonized and clear policy framework to enable vehicle manufacturers in defining a comprehensive strategy.

At societal level, the market is "stuck" because supply-sided stakeholders expect no demand and demand-sided stakeholders wait for supply. The identified barriers reflect the lock-in situation in fossil fuel energy systems (the technological system has followed a trajectory which is difficult and costly to change). This supports the need for policy intervention to release this locking mechanism. There exist several interrelations and causality relations between the barriers so policy measures will only be effective if they are combined or if they have an effect on the different elements that are part of the system.

A mix of policy measures acting on the supply and the demand side of the market as well as on the broader environment in which the automobile market operates will give the best results. The need for a policy mix has also been put forward in the literature review on policy measures, in which a combination of carrots (incentives), sticks (disincentives) and regulations including a mix of target audiences (industries, public and private consumers) is presented as best working.

9.4 What possible incentives and policy measures could be implemented to stimulate the market?

As an input for other research questions, an inventory of measures for the support of environmentally friendly vehicles was made, based on a literature review of different national and international sources. The emphasis was placed on measures initiated in Europe, but international measures (if relevant) were included in the inventory as well.

Some general conclusions were drawn from the inventory. A mix of policies which integrates carrots (incentives), sticks (disincentives) and regulations works best. This includes a mix of target audiences: industry and final consumers, both public and private. For private consumers, tax systems based on environmental performance are getting more and more common. No mandatory systems towards private fleet consumers exist yet today, but voluntary systems are in place and the market starts offering green products. Company car taxation seems the appropriate instrument to influence that market. For public consumers, mandatory targets for clean vehicles seem to have an effect on the overall market and are a suitable instrument to open the market. However, monitoring and impact assessment results from different implemented policy measures are still lacking most of the time.

In order to get a better insight into the acceptance level of different policy measures, a series of stakeholder meetings was organized with participants of all sorts and conditions: conventional industrial actors, alternative industrial actors, NGOs and users, and policy makers. The list of policy measures from the literature review served as an input for the discussions.

On some measures, (e.g. tax system based on CO_2 and Euro standard) stakeholders easily agreed; on others (e.g., environmental city zones) they did not. However, it is clear that for the introduction of cleaner vehicles, each of the actors has his responsibility, and cooperation is extremely important to support the market introduction of these vehicles. Individual actors will have to take the positions of all other actors into account to create a win-win situation for the whole market, based on a long-term vision. Anyhow, immediate and strong choices are needed to be able to draw up a development strategy, as a stable market is necessary.

At the time of the stakeholder round tables, the opportunity was seized to inquire about the performance of each measure on three indicators: effectiveness, feasibility and priority. Starting from these results, four scenarios were conceived. The baseline scenario only includes current and planned measures, for example (1) Euro 5 and Euro 6 emission standards for passenger vehicles, (2) CO_2 legislation for new passenger cars, (3) Low blends of biofuels (ethanol and biodiesel), (4) Implementation of EU directive on coolants in air conditioning and (5) Mandatory quota for green public fleets. The realistic scenario includes measures that got a high score on effectiveness, feasibility and priority, indicating that these measures are seen as potentially having a large impact, while they are relatively easy to implement in the short term. Extra measures in this scenario (on top of the baseline scenario) are: (1) Vehicle tax system based on the combination of CO_2 and Euro standard, (2) Advantages for early-complying-Euro 6 vehicles, (3) Standardization of clean fuels (e.g., CNG and E85), (4) Change in excise duties (higher excise duties for diesel, no excise duties on clean fuels), (5) Subsidies for retrofitting old diesel vehicles with PM filters and (6) Subsidies for cleaner fuel systems (LPG and CNG). The progressive scenario includes measures that could have a high impact (effectiveness as crucial factor), but are difficult to implement, and therefore not adequate to be adopted in the realistic policy scenario. Clean vehicles are now defined based on the Ecoscore. Extra measures under the progressive scenario (on top of the baseline and realistic scenario) are: (1) Vehicle taxation based on the ecoscore: registration tax based on ecoscore combined with a time-, place- and ecoscore-dependent kilometre charge, (2) Limited access environmental zones in cities, (3) Mandatory green private fleet quota and (4) Scrappage scheme. Finally, a more pragmatic visionary scenario has been elaborated in which the passenger car sector is expected to evolve in the direction of transport sharing. Mobility will no longer be an individual perception, as people are forced to use the cleanest technology available for each specific trip: EVs for urban trips, diesel hybrids for highway and petrol hybrids for rural trips. Vehicle ownership will decrease in favour of mobility service companies, pooling their available fleet to a range of customers.

In order to estimate the impact of these four scenarios, VITO's 'E-motion Road' model was updated. Moreover, a model extension was added for reporting the vehicles' ecoscore.

The results of the four scenarios were clustered in three groups: fleet composition (number of vehicles), vehicle use (number of kilometers), and environmental performance (WTT emissions and ecoscores). The results indicate that the benefit (compared to baseline) of implementing the realistic scenario is rather confined. It seems that the share of diesel kilometers will be even higher than under the baseline. This can be most probably attributed to the consumption advantage for this fuel type, combined with lower taxes under the CO_2-based tax system, completely offsetting the increased excise duties on diesel. On the other hand, the progressive scenario provides a clear benefit with regard to the number of kilometers driven, emissions and the average ecoscore (see section 7). The results obtained from the visionary scenario demonstrate that there is still room for more ambitious targets in the long run.

For policy makers, several concerns are associated with the choice of a specific policy package to stimulate clean vehicles into the market requiring the application of a multi-criteria assessment. From a governmental point of view, it is important to know how the market will react to different measures and if it will effectively steer clean vehicles into the market and hence increase the average Ecoscore and decrease the fleet emissions of the Belgian vehicle fleet ("environmental effectiveness"). Moreover, a policy package should also perform well with respect to decreasing vehicle kilometres driven and enhancing people to use other transportation modes inducing a modal shift ("impact on mobility"). Finally, a policy package should by preference be implemented relatively easily, without major obstructions from a budgetary, technical and socio-political point of view ("feasibility"). The overall assessment of the policy scenarios (baseline, realistic, progressive) on these three main criteria (environmental effectiveness, impact on mobility and feasibility) and their subcriteria was performed for the reference years 2020 and 2030 by a combination of the PROMETHEE and AHP decision making methodology. Besides the relative importance of the criteria (weights), also the contribution of the scenarios to the criteria (performance assessments) has been taken into account. The weight elicitation procedure showed that all stakeholders value the environmental effectiveness criterion as most important one (43%), followed by feasibility (38%) and impact on mobility (19%). The performance assessment, which was mainly based on a detailed impact assessment of the proposed policy scenarios on the Belgian vehicle fleet (section 7) including input from other tasks (section 4), mainly revealed that the progressive scenario performs the best in minimizing fleet emissions (TTW emissions of CO_2eq, $PM_{2,5}$, NOx) and in maximizing the average Ecoscore (grouped under "environmental effectiveness") and in minimizing the amount of kilometres driven and maximizing the encouragement towards other modes of transportation (grouped under "impact on mobility"). It however scores less regarding its budgetary, technical and socio-political feasibility (grouped under "feasibility"). With respect to this criterion, the baseline scenario gets the highest score, followed by the realistic scenario. The overall ranking shows that for the reference year 2020, the progressive and baseline scenario almost have an equal absolute score, which means that they are both seen as scenarios that contribute the best to the different criteria for the reference year 2020. For the reference year 2030, the situation is slightly different. There, the progressive scenario clearly outranks the other scenarios. The overall ranking of the scenarios is noticeably influenced by the established weights attributed to the criteria groups. If, for example, feasibility becomes the major concern for policy makers (50%), then the progressive scenario will be outranked by respectively the baseline and the realistic scenario. More important than the absolute ranking is thus the insight in the strong and weak points of the considered scenarios. It is thus very important to take these sensitivities into consideration when deciding on which scenario to implement. It should also be noted that the overall assessment outcome does not only depend on the type of measures introduced, but also on the specific levels of the simulated measures, which have been referred to in section 7.

10. Dissemination and Valorisation

The members of the CLEVER consortium have been very active in the dissemination of the results obtained in the project. Many papers have already been published in scientifica journals, conference proceedings or other media and some are to be published in the near future. By giving presentations and by participating at conferences and workshops on a national and international level, the results have been spread on a large scale. Through participation in such workshops and conferences, the researchers have been able to get a thorough training and learn more on the topics addressed in this project. This will lead to two PhD theses (Laurence Turcksin and Fayçal Boureima) which will be defended in the near future and the results of the project will also provide input to a two other PhD theses (Maarten Messagie and Kenneth Lebeau). Also a project website is available (http://etec.vub.ac.be/CLEVER.htm), where an overview of the project and the different partners is presented, as well as the possibility to download the final reports. To share documents and reports within the consortium, an intranet website was used as well.

A detailed overview of the different presentations and participations to conferences, colloquia, workshops or other events is given in the following sections, in a chronological order. A list of the publications made by the consortium is presented in chapter 11 of this report.

10.1 PhD theses

TURCKSIN, Laurence, « Stimulating the purchase of more environmental friendly cars: a socio-economic evaluation» (preliminary title), to be defended in 2011.

BOUREIMA, Fayçal, « Environmental assessment of conventional and alternative vehicle technologies » (preliminary title), to be defended in 2011.

MESSAGIE, Maarten, « Environmental assessment of electric vehicles » (preliminary title), to be defended around 2013.

LEBEAU, Kenneth, « Electric vehicles : investigation of purchase and travel behaviour. » (preliminary title), to be defended around 2013.

10.2 Presentations at scientific colloquia/conferences or workshops

- EET 2007 European Ele-Drive Conference, Brussels, May 30 - June 01, 2007: Presentation of paper «The Development of an LCA Tool for Vehicles with Conventional and Alternative Fuels and Drive Trains».

- Colloquium Vervoersplanologisch Speurwerk (CVS), Antwerp, 23 November 2007: Presentation of paper on « Ecoscore as policy supporting definition of clean vehicles ».
- 23rd International Electric Vehicle Symposium (EVS23), Anaheim, United States, December 2-5, 2007: Small lecture series and poster of paper: «An LCA Tool for Conventional and Alternative Vehicles».
- Vlaams Netwerk van Ondernemingen (VOKA), 24 January 2008, Ghent: Presentation on 'Environmentally friendly vehicle technology & Ecoscore'.
- EET 2008 European Ele-Drive Conference, Geneva, Switzerland, 11-13 March 2008: Presentation of paper « Market potential for 'clean' vehicles ».
- Federal Administration Personnel & Organization, 18 March 2008, Brussels: Presentation on 'Ecoscore'.
- 10th International Conference on Application of Advanced Technologies in transportation, Athens, Greece, 27-31 May 2008 : Presentation of paper « How green is the car purchase decision ? A review ».
- FEDERAUTO, Belgian Confederation of Car Traders and Repairers and Related Sectors, 13 June 2008, Brussels: Presentation on 'Policy measures for environmentally friendly vehicles'.
- Urban Transport XIV – Urban Transport and the Environment in the 21st century, Malta, 1-3 September 2008: Presentation of paper « LCA of alternative and conventiional vehicles using 'a data range-based modeling system' ».
- European Symposium on Super Capacitors & Applications (ESSCAP), Rome, Italy, 6-7 November 2008 : Presentation of the paper « Comparative LCA of supercapacitors and different battery technologies ».
- 24th International Electric Vehicle Symposium (EVS24), Stavanger, Norway, 13-16 May 2009: Presentation of paper "Comparative LCA of electric, hybrid, gasoline and LPG cars in a Belgian context", presentation of paper "An environmental analysis of FCEV and H2-ICE vehicles using the Ecoscore methodology", and presentation of paper « Life cycle cost analysis of alternative vehicles and fuels in Belgium ».
- BIVEC-GIBET Transport Research Day, Brussels, 27 May 2009 : Presentations of papers « Is the Belgian fiscal system promoting environmentally friendly cars ? » and « Policy measures for a greener private fleet : a Rasch analysis ».
- International Transport Economics Conference, Minneapolis, Minnesota, 14-16 June 2009: Presentation of papers « Rethinking the categorization of attribute importance in the private car purchase decision by means of Item-Response Theory » and « Ecoscore used in the vehicle taxation : towards a more environmentally friendly car fleet ».
- 1st Transatlantic Network on European Communications and Transport Activities Research (NECTAR) Conference, Arlington, Virginia, USA, 18-20 June 2009: Presentation of paper « A fiscal system in favour of more environmentally friendly cars : Towards first best solutions ».
- Belgisch Wegencongres, Ghent, 22-25 September 2009 : Presentation of the paper « Aankoopgedrag van wagens, speelt de milieuvriendelijkheid een rol ? ».
- Wetenschapskaravaan, 6 October 2009, Brussels: Presentation on « Clean vehicles: ecological aspects ».
- Colloquium Vervoersplanologisch Speurwerk (CVS), Antwerp, 19 November 2009: Presentation of paper « Belgian policy on clean vehicles in the past, present and future ».
- CIVITAS-ELAN workshop, 19 November 2009, Ghent: Presentation on 'Ecoscore – CIVITAS'.
- Karel De Grote Hogeschool, 9 December 2009, Antwerp: Lecture in CarEcology master programme, topic: « Environmentally friendly vehicles ».
- ING Car Lease Expert Session, 23 March 2010, Brussels: Presentation on 'Clean vehicles, ecoscore, private vs. company cars'.
- Innovation for Sustainable Production, Bruges, 18-21 April 2010 : Poster presentation on 'Environmental and economic comparison of a hybrid and a conventional city bus for public transport'.

- Vlaams Netwerk van Ondernemingen (VOKA) and Electrabel, 5 May 2010, Antwerp: “Samen duurzaam onderweg – een visie op duurzame mobiliteit.”.
- WATT Roadshow, Diest, 13 August 2010: Presentation on ‘Clean vehicle technology – Ecoscore’.
- Amelior training on Energy Manager, Mol, 2008-2010: Several presentations on ‘Policy on clean vehicles & Ecoscore’.
- Innovation for Sustainable Production, Bruges, Belgium, 18-21 April 2010 : Poster presented on « Environmental and economic comparison of a hybrid and a conventional city bus for public transport ».
- IEEE VPPC 2010, Vehicle Power and Propulsion Conference, Lille, France, 1-3 September 2010 : Presentation of paper « Life Cycle Assessment of conventional and alternative small passenger vehicles in Belgium ».
- Uitstraling Permanente Vorming (UPV), 7 October 2010, Koksijde: Lecture on Clean Vehicles (Milieuvriendelijke voertuigen).
- 25th International Electric Vehicle Symposium (EVS25), Shenzhen, China, 5-9 November 2010 : Presentation of paper « Living labs for electric vehicles in Europe », Presentation of paper « Environmental performance of a battery electric vehicle: a descriptive Life Cycle Assessment approach ».

10.3 Participations (without presentation) to scientific colloquia/ conferences or workshops

- Stakeholder conferences on the ‘European Green paper on urban transport’, European Commission, Brussels, 4 June 2007.
- 3rd International Conference on Life Cycle Management (LCM2007), Zurich, Switzerland, August 27-29, 2007.
- ERTRAC conference ‘European Transport and Climate Change’, Brussels, 26 September 2007.
- European Commission, ‘Towards a post carbon society’, Brussels, 24 October 2007.
- Capital-4E (Energy – Ecotechnology – Ecodesign - Ecobusiness), Paris, 27 November 2007.
- Round table on the ‘Green paper on urban transport’, VLEVA, Vlaams Europees verbindingsagentschap, Brussels, 19 December 2007.
- CCIM-stakeholder meeting on European environmental issues, Flemish Governement (LNE), Brussels, 25 February 2008.
- HOP-conference (Impact of high oil prices on Transport), Fraunhofer Institute, Brussels, 5 June 2008.
- Federal Ministry of the Environment, ‘Lente van het Leefmilieu’, Brussels, 2 July 2008.
- ViWTA, ‘Energie 2050’ workshop, Brussels, 12 December 2008.
- CLEPA Technology Day 2009, "The car of tomorrow: Environment, Safety and Mobility for 2020”, 11 February 2009, Brussels.
- BioreFuture 2009, Concepts and strategies for biorefineries in Europe Interactive biorefinery workshop, 30 March 2009, Brussels.
- Conference "Sustainable Development a challenge for European Research", 26-28 May 2009, Brussels.
- Fifth International conference on Renewable Resources and Biorefineries, 10-12 June 2009, Ghent.
- TEXBIAG seminar, Decision-making tools to support the development of bioenergy in agriculture: Modelling bioenergy externalities on the way towards sustainability, 17 September 2009, Brussels.
- MIP2, Milieu- en energietechnologie Innovatie Platform, Startevent, 30 September 2009, Mechelen.
- HyRaMP-European Regions and Municipalities Partnership for Hydrogen and Fuel Cells,

Local Hydrogen and Fuel Cell Development and EU Policy, 7 October 2009, Brussels.
- iTREN-2030, Integrated transport and energy baseline until 2030, 21 October 2009, Brussels.
- EARPA, European Automotive Research Partners Association, Task force Alternative Fuels Production, 4-5 November 2009, Brussels.
- European Aluminium Association, Christian Leroy, Manager Sustainability & LCA - Building & Transport, Life cycle thinking and environmental footprint of aluminium products, 9 November 2009, Brussels.
- MIP2, Milieu- en energietechnologie Innovatie Platform, Theme groups, 15 January 2010, Mechelen.
- Lighthouses of Sustainability – European Concepts for competitive Bio-based Chemicals, Representation of the Free State of Bavaria to the European Union, 3-4 February 2010, Brussels.
- Changing the way people move, 365 Energy Group, 16 February 2010, Amsterdam, The Netherlands.
- LINEAR project, Local Intelligent Networks and Energy Active Regions, Bruges, 21 April 2010.
- INESPO meeting, Belspo, 31 May 2010, Brussels.
- European Commission, International Reference Life Cycle Data System (ILCD) Handbook "Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context", 26 October 2010, Brussels.
- SSD workshop, Cluster Air Quality (aiming to integrate existing approaches towards health surveillance in relation with indoor and outdoor air quality), Brussels, 30 November 2010.
- Electromobility Event, 13 January 2011, Cologne, Germany
- Verbond van Belgische ondernemingen (VBO), « Hoe de belemmeringen voor de ontwikkeling van ELECTRISCHE VOERTUIGEN in België wegnemen? », 20 January 2011.
- Collowue Primequal-Predit, « La qualité de l'air dans nos environnements de proximité », 26-27 January 2011, University of Lyon, France (www.primequal.fr)
- Studienamiddag "CO_2 – Wat na 2012 voor de industrie", Ingenieurshuis, 31 January 2011, Antwerp.
- MIP3, Milieu- en energietechnologie Innovatie Platform, Themagroepvergaderingen, 4 February 2011, Brussels.

10.4 Others

- Mobimix.be (platform on ecological fleet management), Project of the Bond Beter Leefmilieu (BBL) financed by the Flemish Governement, 2008-2010: Participation to several meetings of the steering group.
- WATT-Roadshow (demonstration of enviromentally friendly vehicle technology), Project of the Bond Beter Leefmilieu (BBL) financed by the Flemish Governement, 2010: Participation to several meetings of the steering group.
- Life Cycle Assessment and Environmental Systems Analysis, PhD course, NTNU, 9-20 August 2010, Trondheim, Norway.
- Advanced LCA – consequential modeling, PhD course, Aalborg University Denmark, 11-12 May 2010, Aalborg, Denmark.
- "From theory to data analysis - an overview of multivariate data analysis methods and their applicability" VUB, 2 April 2010, Brussels.
- Milieuvriendelijke voertuigtechnologieën, Vrije Universiteit Brussel, 2008-2009, Brussels: Class taught by Prof. Joeri Van Mierlo .
- Verkeerskunde, Vrije Universiteit Brussel, 2008-2009, Brussels: Class taught by Prof. Joeri Van Mierlo.

11. Publications related to the project

10.1 Peer reviewed publications

SERGEANT, N., MATHEYS, J., TIMMERMANS, J.-M., WYNEN, V., BOUREIMA, F. and VAN MIERLO, J. (2007), "The Development of an LCA Tool for Vehicles with Conventional and Alternative Fuels and Drive Trains", *Conference Proceedings of the European Ele-Drive Conference EET 2007*, Brussels, May 30 - June 01, 2007.

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TURCKSIN, L., VAN MOLL, S., MACHARIS, C., SERGEANT, N. and VAN MIERLO, J. (2007), "How green is the car purchase decision? A Review", 10th International Conference on Application of Advanced Technologies in Transportation, May 27-31, 2008, Athens, Greece.

'Ecoscore as policy supporting definition of clean vehicles'. Colloquium Vervoersplanologisch Speurwerk (CVS), Antwerpen, 23rd of November 2007. Paper in CVS 2007 Proceedings (CD-Rom, 14pg), VITO

TURCKSIN, L., MACHARIS, C., SERGEANT, N. and VAN MIERLO, J. (2008), "Market potential for 'clean' vehicles", EET Ele-Drive Conference, March 11-13, 2007, Geneva, Switzerland. This paper has been nominated for the Prof. Maggetto award.

MAIRESSE, O., VERHEYEN, H., TURCKSIN, L. and MACHARIS, C. (2008), "Groene auto's? We willen ze wel maar kopen ze (nog) niet", Verkeersspecialist nr. 149

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10.2 CLEVER scientific reports

WYNEN, V., SERGEANT, N., BOUREIMA, F., ROMBAUT, H. and VAN MIERLO, J. (2008). « Overview of vehicle technologies », Deliverable report of CLEVER WP 1.1, August 2008.

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Annexes

Copy of the publications

The following publications by the consortium with results of the CLEVER project have been included as annex to this report :

SERGEANT, N., MATHEYS, J., TIMMERMANS, J.-M., WYNEN, V., BOUREIMA, F. and VAN MIERLO, J. (2007), "The Development of an LCA Tool for Vehicles with Conventional and Alternative Fuels and Drive Trains", *Conference Proceedings of the European Ele-Drive Conference EET 2007*, Brussels, May 30 - June 01, 2007.

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Minutes of the follow-up committee meetings

Different follow-up committee meetings were organised in the course of the CLEVER project on the following dates :

- 26 February 2007
- 23 November 2007
- 23 September 2008
- 3 April 209
- 25 November 2009
- 28 June 2010
- 16 December 2010

The minutes of these meetings are included as annex to this report.