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CLEVER

Clean Vehicle Research: LCA and policy measures

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FINAL REPORT PHASE 1
SUMMARY

CLEVER
CLEAN VEHICLE RESEARCH: LCA AND POLICY MEASURES

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Promotors

Joeri Van Mierlo
Vrije Universiteit Brussel (VUB)
Department of Electrotechnical Engineering and Energy Technology (ETEC)
Research Group Transportation Technology

Leen Govaerts
Vlaamse Instelling voor Technologisch Onderzoek (VITO)

Cathy Macharis
Vrije Universiteit Brussel (VUB)
Department of Mathematics, Operational Research, Statistics and Information
Research Group Transport and Logistics (MOSI-T)

Walter Hecq
Université Libre de Bruxelles (ULB)
Centre d'Etudes Economiques et Sociales de l'Environnement (CEESE)

Bernard De Caevel
RDC-Environment

Researchers
Fayçal Boureima, Nele Sergeant, Vincent Wynen &
Maarten Messagie (VUB-ETEC)
Tobias Denys, Michiel Vanderschaegh (VITO)
Laurence Turcksin (VUB MOSI-T)
Marion Englert , Fanny Lecrombs, Frédéric Klopfert (ULB-CEESE)
Marc De Vos (RDC Environnement)

Belgian Science Policy Office
belspo

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: Igor Struyf
+32 (0)2 238 35 07

PROJECT WEBSITES:

Public website: http://etec.vub.ac.be/CLEVER.htm
Intranet: http://etecmc10.vub.ac.be/clever/index.php

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Objectives

How environmentally friendly are 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? This project intends to analyse and answer these different questions, with a focus on the passenger car market. The objectives of the project can be described as follows:

- 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.

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, bio-fuels, 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.

Within the 'Clean Vehicle Research' (CLEVER) project an LCA methodology is being developed with per-model applicability instead of an average vehicle LCA. This will allow 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.
In order to have a global comparative view of the different vehicle technologies, conventional and alternative vehicles have been mutually compared on the basis of the same provided service to the user. This 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. The results include all the life cycle steps (production, use phase, recycling) of a vehicle in a Belgian context.

LCA results are always linked to impact calculation methods used in specific conditions. The results should be understood and interpreted in the context of the used calculation methods and assumptions. For each specific impact calculation method, only the pollutants involved in the method are taken into account with respect to the equivalence factor attributed to each pollutant.
The impact methods available in this report are [i,ii]: the IPCC (Intergovernmental Panel on Climate Change) 2007 Greenhouse Effect (GHE), the human health impact from Impact 2002+ and the air acidification from 'Centrum voor Milieukunde Leiden' (CML). The other impact methods are presented in the scientific report: eutrophication, chemical toxicity indicators, depletion of the ozone layer, consumption of renewable and non-renewable energy, waste production and land use.

One of the most interesting conclusions of this analysis is that Battery Electric Vehicles (BEVs) always score better than all other vehicle technologies for the three considered impact categories. Only the sugar beet Ethanol 85 (E85) vehicle has a better score than the BEV when dealing with human health. This is due to the high capacity of sugar beets to extract heavy metals from the agricultural soil. However, the fate of these extracted heavy metals can change the score of the sugar E85 vehicle. In this approach it is assumed that the retained heavy metals are treated as hazardous waste. When a rye based ethanol instead of the sugar beet one is used for the E85 vehicle, its impacts on human health and climate become higher than all the other assessed vehicles. This bad score is essentially due to the rye production which requires high amounts of fertilizers and pesticides on the one hand and several agricultural processes (fertilising, tillage, sowing, harvesting, drying…) on the other hand. It is important to mention that a less intensive

and/or biologic production of the rye will allow a reduction of the impacts of the E85 vehicle. The impact of the rye based E85 on climate change is not only due to the carbon dioxide (CO_2) emissions. In fact, the use of the different nitrogen based fertilisers induces important dinitrogen oxide (N_2O) emissions and the global warming potential of N_2O is almost 300 times higher than the one of CO_2. Additionally, shifting from petrol to E85 has increased the fuel consumption by more than 39%. This is due to the relatively low LHV (lower heating value) of the bio-ethanol.
When dealing with the acidification, the Fuel Cell Electric Vehicle (FCEV) will have the worst score. This is due mainly to the platinum contained in the fuel cell. However the recovery of the platinum in the end-of-life fuel cell with a pyrometallurgical process will reduce the acidification impact of the FCEV by more than 68%. The FCEV will then have the second best score after the BEV. Like the BEV, the FCEV is a zero direct emission vehicle. Additionally, the hydrogen consumption per km is relatively low (0,0086 kg hydrogen/km). The rye-based E85 has a higher acidification impact because of the high emissions of ammonia (NH_3), sulphur oxides (SO_x) and N_2O during the rye production.
However, shifting from first to second generation bio-ethanol (wood ethanol) will reduce all the impacts of the E85 which will then score better than the gasoline car for all the three considered impact categories. This will be particularly interesting for human health and acidification for which the reduction potential is higher.
Thanks to the reduction of the gasoline consumption in hybrid vehicles compared to gasoline vehicles and the nickel recovery at end-of-life, the hybrid vehicle is always scoring better than all the Internal Combustion Engine (ICE) vehicles assessed in this analysis. As the production of Liquefied Petroleum Gas (LPG) emits less nitrogen oxides (NO_x), SO_x and particle matter (PM), as a consequence the impacts of an LPG vehicle on human health and air acidification are lower than for diesel and petrol cars.

Life Cycle Cost Assessment

To compare the cost-efficiency of different vehicle technologies, the **Life Cycle Cost** (LCC) methodology has been chosen. From a user perspective, the LCC is often a crucial factor. Financial factors such as the purchase price and operating cost turned out to be decisional purchase factors [iii]. Moreover, it has been found that the environmental friendliness of the car is not taken into consideration at the purchase of a new car. 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).
With the help of an LCC model, the cost-efficiency of different vehicle technologies can be compared, market opportunities discovered and necessary fiscal support identified. The purchase of an environmentally friendly car may become a rational economic decision if these cars provide lower or equal private consumer costs compared to conventional diesel and petrol cars. Secondly, by comparing the external costs (environmental, congestion and accident costs) with the LCC calculations, it can be identified whether the current Belgian fiscal system is promoting the purchase and use of environmentally friendly vehicles.

The following fiscal strengths and distortions have been identified. Private consumer costs of LPG cars are lower compared to their petroleum equivalents thanks to the exemption of excises on these fuels (strength 1). Nevertheless, these cars are still confronted with an additional circulation tax which causes a heavy yearly tax burden (distortion 1). Electric cars and cars with blends of bio-ethanol seem to be less cost-efficient for the end-users. Reasons for the high costs of electric cars are the high purchase costs and high battery costs. This cost is for the old Peugeot 106, for newer cars this cost can be lower due to newer battery technologies, such as Lithium batteries, which have a longer life expectancy. Bio-ethanol cars are, on the other hand, faced with high fuel costs due to a combination of a high ex-refinery price, a higher energy consumption and high excises on bio-fuels (distortion 2). The attractiveness of hybrid vehicles mainly depends on their financial costs as their low fuel consumption makes it a very cost-efficient car for the end users. The governmental support for low CO_2 emitting vehicles is in this respect a great effort to increase their attractiveness for the larger public (strength 2). Diesel cars are very cost-efficient for the end user thanks to their lower fuel consumption (-20 to -30%) and excises (-50%) relative to their petroleum counterparts. Diesel cars are however not attractive for the society as they pay less taxes while they are more polluting in terms of PM than petrol cars (distortion 3). As a result of this lower taxation, there is an increasing number of diesel cars in the Belgian car park with an increasing impact on the environment.

Diesel cars, standard equipped with a PM-filter, are however not a cost-efficient option as it is more expensive than the diesel version without filter.

Price elasticities

The proposed policy measures will only be effective if they induce the right behavioural responses. That is why **price elasticities** needs to be taken into account. The aim is to get insights in the impact of various policy measures on the purchase behaviour and usage of cars by households.

In a first part, several factors affecting price sensitivity have been identified. In a second part, a literature review of price elasticities has been performed. An overview of disaggregated elasticities has been performed with respect to several price components. Finally, a scheme for the evaluation of policy measures has been presented, based on [iv]. In this scheme, the travellers’ attitudes are linked to the price elasticities with the aim of obtaining a view on the effectiveness of policy proposals.

Belgian consumers are on average more sensitive for their vehicle expenses than for their public transport expenses. Household income has the largest impact on fuel consumption, followed by fuel prices. This means that fuel prices should rise faster than income to keep fuel consumption at a constant rate. Increasing fuel prices are found to have a larger effect on fuel consumption than on vehicle traffic as the rapid behavioural responses such as changes in driving speed or style, or modifying to the least energy-inefficient trips will affect fuel consumption more than traffic. As a result, fuel taxes will be more effective in reducing fuel consumption than in reducing road congestion. Moreover, they are found to affect vehicle trips and kilometres more than parking charges. Fuel taxes alone are however not politically attractive. That is why [v] advises to introduce fuel-efficiency regulations too as it would promote technological improvements whilst evoking vehicle-mix shifts towards more fuel-efficient vehicles. Such a system will on the other hand hardly affect safety, congestion and noise. From these perspectives, it may be desirable to make the tax system more variable. Time-based pricing is found to produce the greatest overall benefits, followed by distance-based (kilometre) charging, congestion pricing and cordon pricing**.** Kilometre charging based on real traffic emissions will have a larger impact on fuel consumption and emissions compared to kilometre charges based on measured emissions from drive cycles.

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 “ExternE” methodology for the calculation of external costs of transportation is updated and adapted for its use in a Belgian context. Attention is 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 LCC analysis of new vehicles. This approach allows a complete comparison with conventional vehicles, based on a full-cost approach.
A sample of 53 cars, covering a wide range of car sizes, fuel type or propulsion system is considered and analysed. The pollutants taken into account are mainly PM_{10}, NO_x, CO_2, CH_4, N_2O, SO_2 and noise. The contribution of the car fleet to the pollutant concentration in the ambient atmosphere is assessed through dispersion modelling.
Diesel cars without particulate filter are associated with the highest total external cost, reaching c€ 23.6/v.km for a SUV in the most realistic scenario. Diesel vehicles equipped with particulate filters have the second highest total external cost (up to c€ 15.19/v.km for an SUV), though they are much closer to those of the petrol, LPG, CNG, Flexifuel and Biofuel engines (c€ 9.98/v.km to c€ 13.21/v.km). At the opposite, electric cars 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. 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.

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 stage 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

The main barriers impeding the development of alternative vehicles 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.
While economic barriers appear to be very important[1], results have shown that other aspects also have a significant impact on consumer behaviour about alternative cars, sometimes more important than economic aspects. More specifically, results have shown that psychological barriers 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.

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). 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 shortage of supply (and the 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 alternatives for intervention vehicles or vans limit greatly the development of alternative vehicles in some vehicle fleets. In this last case, barriers not only originate from the companies but also from the supply-side of the market.

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. Also, the lack of fuel availability (e.g. CNG or bio-fuel) is a major brake for car manufacturers 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.

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

The CLEVER project will allow investigating possible **policies towards a more sustainable car choice**. Implementation pathways for a consistent policy for the promotion of cleaner vehicles are being developed. These possible policies are price policies, regulatory policy, etc. The investigated policy

[1] This is in line with the results from the survey of task 3.2 of 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).

instruments not only focus on individual vehicle-buying behaviour but also on policies towards companies and public authorities. The pathways will be developed based on the analysis of the environmental impact, the barriers for the purchase and use of cleaner vehicles.
An inventory of measures for the support of environmentally friendly vehicles was made based on a literature study of different national and international sources. Main obstacle in the analysis of policy instruments is the lacking information on the impact of the different instruments.
Following conclusions are made from the inventory. 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.

The second phase in the policy research is to seek stakeholder support for redesigning the policy pathways adapted to the Belgian situation. For this purpose, stakeholder round tables were organised to discuss the effectiveness and feasibility of policy measures. The conclusion of the stakeholder consultation process is that for the introduction of cleaner vehicles each of the actors has his responsibility and that cooperation is extremely important to support the market introduction of these vehicles. Individual actors will have to take the positions of all actors in the field 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.
Further, almost all stakeholders agree on the fact that the current tax system (based on fiscal horsepower (HP)) 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 realize 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.

[i] Pré Consultant, *SimaPro 7.1 LCA software*, The Netherlands, 2008.
[ii] Jolliet O., Margni M., Charles R., Humbert S., Payet J., Rebitzer G. & Rosenbaum R., *IMPACT 2002+: A New Life Cycle Impact Assessment Methodology*, International Journal of LCA, 10(6), 2003.
[iii] Turcksin L., Van Moll S., Macharis C. , Sergeant N. & Van Mierlo J., 2007, *How green is the car purchase decision? A Review.*
[iv] Odeck J. & Brathan S., 2008, *Travel Demand elasticities and Use Attitudes : A case study of Norwegian Toll projects*, Transportation Research A, Vol. 42(1), pp.77-94
[v] Small K. & Van Dender K., 2007, *Long Run Trends in Transport Demand, Fuel Price Elasticities and Implications of the Oil Outlook for Transport Policy*, Discussion Paper, University of California and Joint Transport Research Centre, France.