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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

BIOFUELS SUSTAINABLE END USE

BIOSES

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BIOFUELS SUSTAINABLE END USE

BIOSES

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SUMMARY

A. Context

Biofuels are today one of the only direct substitutes for oil in road transport, available on a significant scale. They can be used today, in existing vehicle engines, unmodified for low blends, or with cheap modifications to accept high blends. Biofuels are expected to represent a substantial part of the 10% target for renewable energy in transport by 2020, set by the European Commission in its Renewable Energy Directive 2009/28/EC. With biofuels reaching a visible scale at the European level, discussions have emerged about the sustainability of biofuels compared to fossil fuels. It is clear that policy should make sure that the use of biofuels in the transport sector should happen in a sustainable way that balances the main transport related challenges of greenhouse gas reduction, reducing oil dependency and improving air quality. Specifically for the Belgian situation, BIOSES is a research project assisting the Belgian government in setting a roadmap for biofuels and analysing the potential impact that biofuel introduction may have on greenhouse gas emissions, energy use and air quality.

B. Objectives

The project develops different scenarios for the introduction of biofuels, based on the technological evolution in vehicle models, the likely biofuel blends on the European markets, and the possible interest of certain end user groups. Based on up-to-date data (complemented with own measurements) of energy use, emissions and cost projections, the practical feasibility and the ecological and economic impact (on micro and macro level) of the introduction of biofuels in Belgium are analysed. Results are used to create a roadmap for the introduction of biofuels in Belgium.

C. Conclusions

The main biofuel options for Belgium on the short term are biodiesel (methyl ester) from vegetable oil, to be blended with diesel fuel (up to B7), potentially supplemented with hydro-treated vegetable oil (HVO) in the future, and bio-ethanol from sugar or starch crops, to be blended with gasoline fuel (up to E10). Next to general blending, also options of high blends or pure biofuels could be envisaged (such as E85, ED95, B30, B100, PPO, bio-methane).

On the longer term, more advanced technologies could be introduced, and feedstock can be broadened to include waste and ligno-cellulose based resources. Typical "2nd generation" fuels could be Fischer-Tropsch diesel (so-called BTL), cellulose ethanol, bio-SNG, bio-DME, etc., with their major potential roll-out after 2020. The project started with an analysis on the technological evolution in vehicle models, the likely biofuel blends on the European markets, and the possible interest of certain end user groups, to come to realistic biofuel introduction scenarios.

For the main biofuel options, the environmental impact was studied, both in terms of well-to-tank (WTT) and tank-to-wheel (TTW) emissions. For WTT level, the assessment was based on data from the Swiss Ecoinvent database, which includes complete figures on various emissions for different biofuel pathways. Comparison was also made with other methodologies, mostly focussed on greenhouse gas emissions, in particular the methodology presented in the Renewable Energy Directive. It turns out that how part of the emissions is allocated to co-products is a very important issue. This was also concluded when using the SPA (System Perturbation Analysis) tool, which was further elaborated and optimized within this project. Another crucial parameter for the WTT greenhouse gas balance is the estimation of N_2O emissions in agriculture, which is a very powerful greenhouse gas (300 times more intensive than CO_2). According to the model of the nitrogen cycle used, estimation of N_2O emissions can differ three-fold. For some biofuels, N_2O emissions can represent up to one third of the overall WTT greenhouse gas emissions, so this certainty creates large differences between calculation methods. The Ecoinvent figures give a lower greenhouse gas performance for current biofuels when compared to the values mentioned in the Renewable Energy Directive. It should however be emphasized that Ecoinvent figures are based on average conventional agricultural practises in Europe, and complete reliance on synthetic fertilizers. The current trend towards taking more and more environmental principles into account for agricultural practices and more use of organic fertilizers will have a serious impact on improving the overall environmental impact of biofuels.

On TTW level, public data was collected on the effect of biofuel blends on vehicle emissions and energy consumption. While there is quite some information and test data available for older types of vehicles and engines (especially for biodiesel), the effect on new engine types, in combination with modern emission control systems, is not well documented in literature. This is why extra measurements on the effect of biofuel blends on new types of vehicles were performed within the project. Four diesel vehicles were tested on biodiesel blends, one of these also on HVO blends, three gasoline type vehicles on ethanol blends, and four converted diesel vehicles on PPO. Results are documented in a dedicated public report.

WTT and TTW data were then combined to derive Ecoscore figures for vehicles driving on biofuel blends. The Ecoscore methodology includes a combination of greenhouse gas emissions, emission related to air quality, and noise of the vehicle. Greenhouse gases and other emissions are considered on well-to-wheel (WTW) basis. The main advantage of biofuels is in the reduction of greenhouse gas emissions and a reduction of fossil energy in the pathway. On the other hand, harmful emissions – in particular particulate mass (PM) - are in some cases substantially increased through inclusion of the feedstock and fuel production pathway. All together the Ecoscore performance of vehicles running on biofuels is generally in the same order as for fossil fuel. In that sense, new technologies like electric or hybrid vehicles perform much better.

The emission data were also used to calculate overall emissions of the Belgian transport system, when shifting part of the fuel to biofuels. Distinction is made between direct emissions in transport (vehicle emissions), and indirect emissions related to the production pathway of the fuel. One clear observation is that energy saving in the transport system could have much more impact on greenhouse gas and other emissions than biofuel introduction. So energy saving should have first priority and it requires much efforts and substantial changes in our habits and energy system. Next to that, biofuels can lead to some additional greenhouse gas savings, also including indirect emissions. For NO_x emissions, the direct impact of biofuel blending is negligible, while there is some increase through the biofuel production pathway. The effect of these indirect NO_x emissions is however rather small. The situation for PM emissions is different as indirect emission are in the same order as direct emissions, and there is an overall increase of PM emissions when introducing biofuels.

When looking at the practical feasibility of biofuel introduction for end users, cost is of course a major factor. In terms of vehicle purchase cost, the impact of low biofuel blending creates no additional cost. Fuel flexibility to be able to drive on higher blends may create some costs, although the additional cost is generally quite modest. Pure biofuels like ED95, bio-methane of PPO require substantial changes in the engine, and the additional cost of the conversion or of the dedicated technology may be substantial. In terms of fuel cost it is clear that biofuels are more expensive than fossil fuels and it is anticipated that this will remain the case in the following decade (the only exception is Brazilian ethanol). So policy (tax reductions or mandates) is needed to overcome this cost disadvantage. Only after 2020 biofuels may become competitive with fossil fuels. It should however be stressed that the project looked at long term trends. In practise high short term fluctuations may be expected, both in fossil fuel prices and on biofuel feedstock prices.

Ligno-cellulose based biofuels at least have the potential to compete with fossil fuels by 2020 as they are based on more abundant and cheaper feedstock than current biofuels. However there is still a lot of uncertainty in the technology cost and it is most probable that 2nd generation biofuels will still need policy support after 2020.

In order to design appropriate policies, it is important to capture the dynamics that determine the biofuel market. In the framework of the project, a 'system dynamics' (SD) model was developed to gain insight in the long-term dynamic behaviour of biodiesel over time. The model deals with internal (positive and negative) feedback loops, stocks and flows, time delays and non-linearities to describe the dynamic, long term behaviour of aggregated social systems. The purpose of the model developed in this project was rather exploratory, as a full simulation of the market would take integration of worldwide linkages with other sectors (mainly energy and agriculture), including possible uncertainties in terms of weather and climate conditions, stakeholder risk aversion and variations in the investment climate. Within this exercise the focus was restricted to the Belgian policy system.
Policy should focus on overcoming the economic disadvantage of biofuels with fossil fuels before markets will take off (through tax or mandates). When demand takes off, a shock in biodiesel demand might lead to a positive shock in feedstock price, which consequently affects biodiesel prices. On the longer term, scale advantages will gain more weight.

Biofuel sectors often cope with many concerns related to economic, environmental, legal and technical issues which should be addressed to get a successful market penetration of biofuels. A common approach that integrates the stakeholders' visions into the evaluation process of biofuel options is currently lacking. In order to gain understanding in the stakeholders' point of view for several biofuel options, a multi-actor multi-criteria analysis (MAMCA) was performed within the frame of this project. The options analysed were (1) only fossil fuels, so exclusion of biofuels, (2) general blending of biodiesel (FAME & HVO) to diesel fuel, (3) general blending of bio-ethanol to gasoline fuel and in addition introduction of E85 and flexifuel vehicles, (4) bio-methane in a number of niche markets, (5) general blending of Fischer-Tropsch diesel to all diesel fuel. With insights from the MAMCA, additional policy measures can be established to tackle the barriers and disadvantages which could emerge once policy makers decide on which biofuel options to implement and for which stakeholders.

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

The BIOSES project has contributed actively to the elaboration of the Belgian National Renewable Action Plan (NREAP) for 2020, to be submitted to the European Commission in the frame of the Renewable Energy Directive. The consortium provided input in terms of projections of diesel and gasoline consumption in a baseline and an energy saving scenario, providing realistic biofuel introduction scenarios, and consulting, involving and informing biofuel stakeholders, of which several representatives were part of the BIOSES follow-up committee, on the potential framework of biofuel introduction in Belgium.

To fulfil the 2020 targets fixed by the NREAP, policy around energy consumption in transport should be a combination of:

1. *Increased general blending*: general blending will play a major role in reaching the national targets. In this view, the current blending obligation of $4\%_{vol}$ should be progressively increased according to quality standard publications.
2. *Promote the use of biofuels with good greenhouse gas performance*: the revised Fuel Quality Directive 2009/30/EC requires fuel suppliers to reduce the life cycle greenhouse gas emissions per unit of energy from fuel and energy supplied of 6 % by 2020 compared to 2010, and biofuels with a high greenhouse gas reduction are essential in that sense.
3. *Support for innovative and advanced biofuels*: although the contribution of advanced biofuels to national targets is expected to reach significant volumes only after 2020, the promotion of such technologies is crucial from now on.
4. *Promotion for market development of higher blends:* support should be given to the deployment of high blends and pure biofuels, especially E85 and bio-methane, both in terms of compatible vehicles, fuel infrastructure and fuel price. Deployment should start in niche markets, but may widen afterwards.
5. *Sustainability assurance*: this is a major issue for societal acceptance of biofuels. The practical implementation of the sustainability requirements in legislations should be based on relevant, transparent and science-based data and tools.

Regarding long term transport policy, there should be the following focus: (1) energy saving in transport and (2) introduce renewable energy in transport. Energy saving should clearly be given priority. For the second pillar there are actually two options: electric mobility and biofuels. On the long term, a balance will appear between these options. While in the next ten years current biofuels (based on agricultural crops) are still the basis in biofuel roadmaps, further growth afterwards will have to come from other feedstocks, like waste & residues, ligno-cellulose and possibly algae (long term).

This opens a far higher biomass potential on a global scale as biofuel resource. Nevertheless energy efficiency & energy saving in transport remain key, in terms of limited resources of fossil resources, biomass & materials (batteries).

E. Keywords

Biofuel policy, stakeholder consultation, transport scenarios, WTT emissions, allocation, vehicle emissions, emission measurements, life cycle analysis (LCA), impact assessment, Ecoscore, cost projections, life cycle cost (LCC), system perturbation analysis (SPA), substitution allocation, system dynamics, multi-criteria analysis (MAMCA), transport modelling, biodiesel, bio-ethanol, 2nd generation biofuels, biofuel roadmap, transport policy, electric mobility, energy saving in transport.

LIST OF ACRONYMS

ACT	Annual circulation tax
BAS	Baseline scenario
B5, B10, B30	diesel fuel containing 5, 10, 30% biodiesel
B100	100% biodiesel (FAME)
BTL	Biomass-to-Liquid (biomass-based synthetic liquid fuel)
CED	Cumulative Energy Demand
CEN	European Committee for Standardization
CH_4	methane
CHP	Combined heat and power
CNG	Compressed Natural Gas
CO	carbon monoxide emissions
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent (towards climate change)
DDGS	Dried Distillers Grains with Solubles, co-product of the ethanol production process
DME	Di-Methyl Ether
DUBDC	Dutch Urban Bus Driving Cycle, developed by the Dutch institute TNO
E5, E10, E20	gasoline fuel containing 5, 10, 20% ethanol
E85	fuel mix of 85% ethanol and 15% gasoline
ED95	pure ethanol with ignition improvers, so it can be used as diesel fuel
EC	European Commission
ECE15	part of the NEDC simulating urban traffic
EN	European Norm
ES	Energy Savings scenario
ETBE	Ethyl-Tertiary-Butyl-Ether (ethanol-based oxygenate, contains 47% ethanol)
EUDC	part of the NEDC simulating extra-urban traffic
EV	Electric Vehicle
FAME	Fatty Acid Methyl Ester
FFV	Flex-fuel vehicle
FIGE cycle	test cycle for heavy duty vehicles, developed by the German institute FIGE
FQD	Fuel Quality Directive (2009/30/EC)
FT diesel	Fischer-Tropsch diesel = synthetic diesel fuel produced via gasification of biomass and subsequent Fischer-Tropsch synthesis
GDI	gasoline direct injection
GJ	Giga (10^9) Joule
GHG	greenhouse gas
GWP	Global Warming Potential

HDV	Heavy duty vehicles
HEV	Hybrid electric vehicle
HVO	hydro-treated vegetable oil
ICE	Internal Combustion Engine
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LCC	Life cycle cost
LDV	Light duty vehicles
LPG	Liquified Petroleum Gas
MAMCA	Multi-actor multi criteria analysis
MJ	Mega (10^6) Joule
MOL30	test cycle, based on real traffic recordings around Mol, Belgium
MTBE	Methyl-Tertiary-Butyl-Ether (methanol-based oxygenate)
N_2O	di-nitrogen oxide
NEDC	New European Driving Cycle (for emission homologation of passenger cars)
NG	Natural gas
NGO	Non-governmental organisation
NH_3	ammonium
NMVOC	Non-methane volatile organic compounds
NO_x	nitrogen oxides (combination of NO and NO_2)
NREAP	National renewable action plan (in the frame of the Renewable Energy Directive)
PAH	polycyclic aromatic hydrocarbon
PHEV	Plug-in hybrid electric vehicle
PM	particulate matter emissions
PPO	pure plant oil
RED	Renewable Energy Directive (2009/28/EC)
RME	Rapeseed Methyl Ester
SD	System Dynamics model
SNG	synthetic natural gas
SO_2	Sulphur dioxide
SORT	Standardised On-Road Test Cycles, designed by the International Association of Public Transport UITP
SPA	System Perturbation Analysis
THC	total hydrocarbon emissions
TOE	Tonne oil equivalent
TTW	Tank-to-wheel
VAT	Value Added Tax
VRT	Vehicle registration tax
WTT	Well-to-tank
WTW	Well-to-wheel

CHAPTER 1 INTRODUCTION

The transport sector has a serious impact on the environment because of greenhouse gas emissions and other vehicle emissions. Besides the emission problem, energy consumption in transport creates a problem of energy dependency as it relies almost completely on petroleum. Today biofuels are one of the only direct substitutes for oil in road transportation that is available on a significant scale. Biofuels can be used in existing vehicle engines, either unmodified for low blends, or with cheap modifications to accept high blends.
This is why one of the action points of the European Commission in this frame is to introduce biofuels in transport (see directive 2003/30/EC). An intermediate target was to reach 2% biofuels in 2005 and 5.75% in 2010, which Belgium has also accepted. Meanwhile a new European 'Renewable Energy Directive' (2009/28/EC) has been accepted, which includes a binding target of 10% renewable energy (mostly biofuels) in transport in 2020. Different scenarios are possible to reach this.

With biofuels reaching a visible scale at the European level, discussions emerged about the sustainability of biofuels compared to fossil fuels. They focus mostly on the origin of the feedstock and the greenhouse gas emissions associated to its production; however the effects due to the use of vehicles running on biofuels should also be considered. The use of biofuels in the transport sector should happen in a sustainable way that balances the main transport related challenges of greenhouse gas reduction, reducing oil dependency and improving air quality.

The BIOSES project, which started in 2007, analysed the impact of different market introduction scenarios of biofuels in the Belgian transport system, with the focus on the end user perspective (demand side). Time horizon for the analyses goes from short term (2010) over medium term (2020) up to long term (2030).
Based on up-to-date data of energy use, emissions and cost, the project looked into the practical feasibility and the ecological, socio-economic and macro-economic impact of the introduction of biofuels in Belgium. The final outcome of the project is a policy roadmap for the introduction of biofuels in Belgium up to 2030.

The following figure shows the structure of the project.

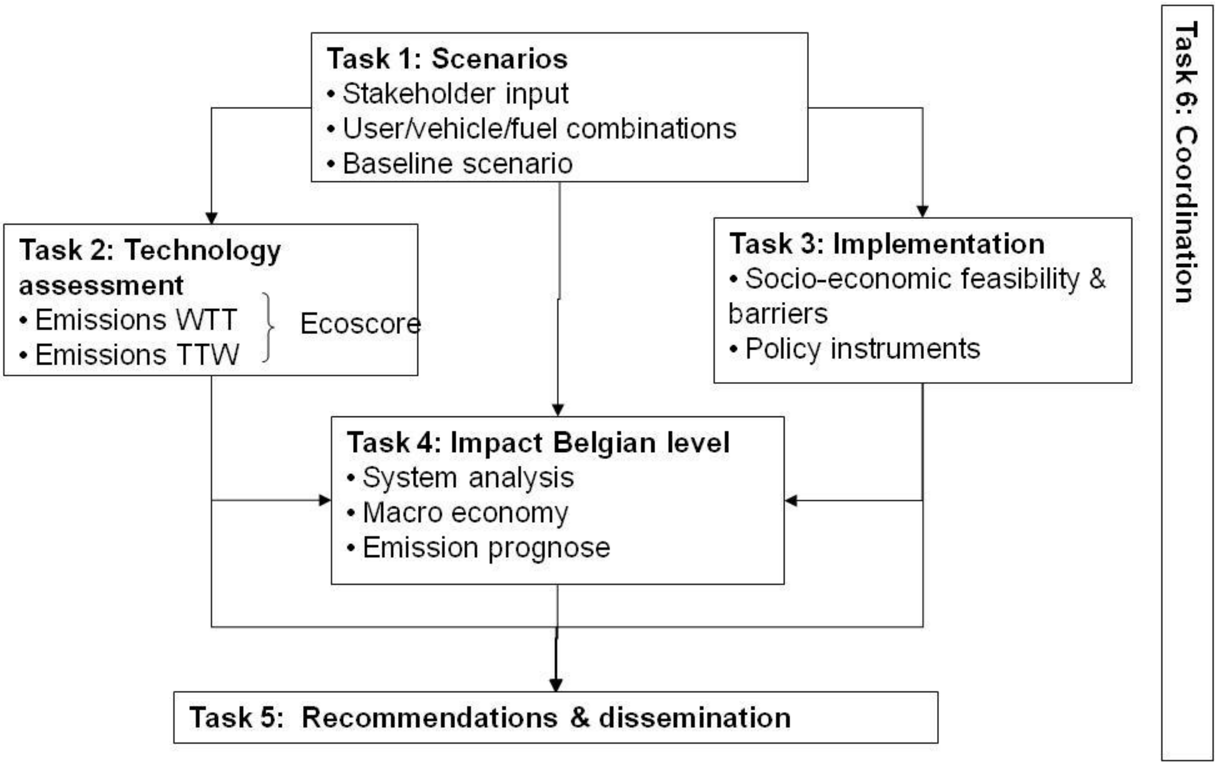


Figure 1: structure of the BIOSES project

This work in the project focused on:

- defining possible biofuel options and introduction scenarios, in consultation with stakeholders (task 1);
- gathering up-to-date data on energy use and emissions on well-to-tank (WTT) basis for different biofuel pathways (task 2.1);
- collecting public information on tank-to-wheel (TTW) energy use and emissions. This also includes own emission measurements on vehicles (task 2.2);
- extension of the Ecoscore database with biofuel options; impact assessment on the WTW impact and Ecoscore of vehicles with different fuels and different drive train technologies (task 2.3);
- gathering cost figures and estimations for future costs of different biofuels, from a user perspective; life cycle cost calculations for different fuels and vehicle types; feasibility and practical barriers for the introduction of biofuels (task 3.1);
- multi-actor multi-criteria analysis of different biofuel pathways; design of a roadmap for the implementation of biofuels in Belgium, including input to the Belgian National Renewable Energy Action Plan (task 3.2);
- extension and optimization of the SPA model (system perturbation analysis, first version developed in the Libiofuels project) and calculations regarding greenhouse gas emissions, energy use and land use (task 4.1);
- development of a system dynamics model to gain insight in the long-term dynamic behaviour of biofuel markets (task 4.2);

- extension of VITO's road emission model with first and second generation biofuels (new market, including impact of blends) and a detailed indirect emission module; emission prognoses of the different developed biofuel scenarios for the different considered time horizons (2010, 2020, 2030) (task 4.3);
- drawing up recommendation documents for policy makers and stakeholders and targeted discussions through workshops (8 June 2009, 15 December 2010) (task 5.1 & 5.2).
- general dissemination actions to present the project findings and the policy options regarding biofuels (website, presentations, publications) (task 5.2).

The main results will be described in the following chapters.

CHAPTER 2 METHODOLOGY AND RESULTS

2.1. BIOFUEL OPTIONS

Biofuels are usually categorised into 'conventional' and 'advanced' biofuels (often also referred to as 1st and 2nd generation) (Pelkmans et al., 2007).

The term 'conventional biofuels' refers to ethanol from sugar or starch crops, biodiesel from vegetable oils, as well as bio-methane and pure vegetable oil. The production of these biofuels is based on traditional chemistry like fermentation and esterification and other well-established processes that in essence are quite mature.

'Advanced biofuels' are the product of more technology-challenging processes that are still in the research or demonstration phase, at the same time implying great potentials with respect to life cycle energy, greenhouse gas emissions and cost reduction, especially on the feedstock side. Their main advantage lies in their ability to use a broad range of feedstock, including by-products, woody materials etc.

Bio-ethanol is mainly produced by fermentation of sugar or starch crops, such as sugarcane, corn, sugar beet and wheat. It can be used in different ways to replace fossil based gasoline: as low blends in the car fleet (up to 25% in Brazil, 10% in the USA and currently 5% in Europe) or high blends (up to 85%) in dedicated flexi-fuel vehicles, or as a component in ETBE (ethyl tertiary butyl ether) to replace MTBE in the fuel production processes. ETBE is less volatile than ethanol, but requires an additional production process step with isobutylene. Bio-ethanol and ETBE share the advantage of being high-octane products. The European gasoline norm EN228 accepts up to 5%volume ethanol and up to 15%volume ETBE (ethanol share of ETBE is 47%). An increase up to 10%volume ethanol and 22%volume ETBE is accepted in the revised Fuel Quality Directive (2009/30/EC), and a specific EN228 norm is prepared for 'E10'.
Advanced or *ligno-cellulosic ethanol* does not depend on a sugar- or starch-based feedstock but can use a much broader variety of feedstock, such as straw, maize stalks and woody material. The ligno-cellulosic biomass is firstly pre-treated (acid or vapour process), then treated with enzymes and hydrolysis in order to extract sugar for ethanol production by fermentation. While this is still a process in R&D and demonstration phase, it can build on major parts of conventional bio-ethanol plants.

The final product is chemically identical with first generation bio-ethanol, but generally emits less greenhouse gas emissions on a well-to-wheel basis.

Biodiesel (also fatty acid methyl ester, FAME) is mainly produced from oil crops (such as rapeseed and sunflower), waste cooking oils or animal fats. The extracted oils are converted by transesterification with an alcohol (usually methanol) to produce biodiesel. Biodiesel is used in diesel engines and can be applied in different blend rates with fossil diesel fuel: blending up to 7% is accepted by all stakeholders to be compatible with all existing diesel vehicles; for higher blends some changes to the engine and fuel system may be necessary (mainly rubber and plastic materials in older engine types), but overall the required adjustments are minor. Currently there are also concerns on the compatibility of higher biodiesel blends with new particulate filter control systems. In Germany biodiesel represented more than 10% of diesel fuel use in transport in the period 2006-2007. Hundreds of thousands of diesel vehicles have been running on pure biodiesel. This has diminished from 2008 with the reduced support for pure biodiesel. The European diesel norm EN590 accepts up to 7%volume FAME (revised from 5%).

Hydro-treated vegetable oils (HVO): several initiatives are also emerging on hydro-treatment of vegetable oils or fats to hydrocarbon paraffins. Main example is the NExBTL process of Neste. Dedicated facilities are built on commercial scale in Finland, the Netherlands and Singapore. The end product is very similar to normal diesel fuel, and there is no blend limit. HVO can also be produced through co-processing in crude oil refineries.

Advanced biodiesel (also known as synthetic biodiesel, *Fischer-Tropsch biodiesel*, or *Biomass-to-liquid BTL*) does not rely on vegetable oil as feedstock, but can make use of virtually all kinds of biomass. The Biomass-to-Liquid combines the gasification of biomass with a Fischer-Tropsch synthesis to derive a liquid fuel from the "syngas". The focus for automotive applications lies mostly on Fischer-Tropsch diesel. A similar process is also used to produce synthetic diesel on the basis of natural gas and coal. The final diesel product is actually superior to fossil diesel fuel (no sulphur, no aromatics, higher cetane number) and can be used in all levels of blends in conventional diesel engines. BTL processes are complex engineering projects and require practical problems to be resolved before they become reliable and commercially viable. Currently, a number of pilot and demonstration projects are at various stages of development.

Bio-DME (di-methyl ether) is produced from gasification of biomass in a similar way as FT diesel, with the final DME-synthesis being less complex than the FT synthesis. So it is cheaper and less energy-intensive to produce. DME is gaseous in atmospheric circumstances, but turns liquid at modest pressure (~10 bar).

So storage and fuel handling is similar to LPG. DME can be used as a diesel fuel, but needs adapted engine technology. Volvo is involved in different test programmes on DME in Sweden.

Biomethane is refined biogas. Biogas is produced by the anaerobic fermentation of organic matter in dedicated reactors. Very often feedstock is organic waste such as livestock manure, food-processing residues, as well as municipal sewage sludge, but also energy crops (like maize) can be used. Biomethane can replace natural gas in gas-powered vehicles. So the introduction of biomethane in the transport market relies simultaneously on the success of natural gas technology in transport. On the other hand the application of biomethane in local captive fleets can be envisaged. So far, the use of bio-methane as transport fuel has been successful mainly in Sweden, and in a number of local initiatives like Lille in France.

Pure Vegetable Oils from rapeseed or sunflower can be used in diesel engines. However, these need to be adapted in order to avoid engine problems. Currently, pure vegetable oils are often used for agricultural machines, especially in Germany. The use of pure vegetable oil as fuel for adapted private passenger cars, trucks or agricultural machinery is also most advanced in Germany, with an estimated consumption of 700,000 toe of PPO in 2007, which was however reduced afterwards because of reduced incentives for PPO (down to 90.000 toe in 2009). (Eur'ObservER, 2010).

The biofuel consumption in the EU has increased from somewhat less than 3 Mtoe in 2005 to almost 12.1 Mtoe in 2009. The share of biofuel in total road fuel consumption is around 4% in the EU in 2009. Biodiesel constitutes the major part of this share, with 80% of energy content of road biofuels, while bio-ethanol represents 19% and the other biofuels (PPO and biogas) only 1%. (Eur'ObservER, 2010)

The following table shows the major biofuel options, with their potential applications (fuel blends).

Table I: overview of biofuel options and potential applications [derived from SenterNovem, 2009]

Biofuel	application	description	fossil fuel replaced	modification needed ?
Bio-ethanol	E5 – E10	5 - 10% ethanol in petrol	petrol	no (**)
	ETBE15	15% ETBE in petrol (47% of ETBE is ethanol)	petrol	no

	E85	85% ethanol + 15% petrol	petrol	flexfuel technology
	ED95	95% ethanol + 5% additives	diesel	dedicated technology
Biodiesel (FAME)	B5 – B7	5 - 7% biodiesel in diesel	diesel	no
	B10	10% biodiesel in diesel	diesel	*
	B30	30% biodiesel + 70% diesel	diesel	*
	B100	100% biodiesel	diesel	*
HVO	any blend with diesel	Hydrotreated Vegetable Oil	diesel	no
FT-diesel	any blend with diesel	Fischer-Tropsch diesel / Biomass-to-Liquid (BTL)	diesel	no
PPO	in pure form	Pure plant oil	diesel	yes
Bio-DME	in pure form	di-methyl ether	diesel	dedicated technology
Bio-methane	in pure form or blended with natural gas	Derived from biogas, upgraded to high methane content	natural gas	no (for natural gas vehicles)

* depends on manufacturer and warranty

** some older gasoline models (from before 2005) may be incompatible to E10

The analysis in the following paragraphs will focus on the biofuel types which are most likely to come to the Belgian market, namely in the first place biodiesel and bio-ethanol, to some extend (for niche markets) also PPO and bio-methane, and on the longer term also FT-diesel and cellulose bio-ethanol.

When considering emissions, within the project distinction was made between well-to-tank (WTT) emissions on the one hand, and tank-to-wheel (TTW) emissions on the other hand. This is visualised in the following figure.

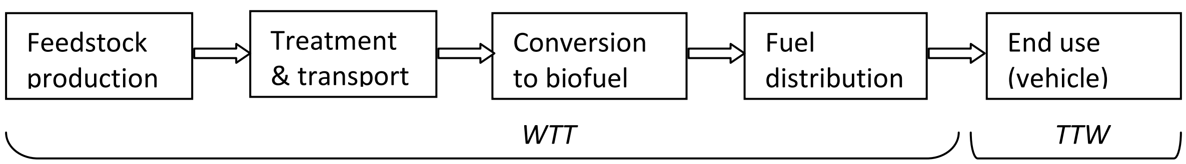


Figure 2: the biofuel chain and its well-to-tank (WTT) and tank-to-wheel (TTW) parts

2.2. WELL-TO-TANK EMISSIONS

2.2.1. Methodology

At the beginning of the BIOSES project, a dedicated template was distributed to the partners to provide the VUB-ETEC team with WTT data for the different biofuel chains. But none of the partners had a complete WTT data set with all the Ecoscore parameters (emissions) for one given biofuel. Most of the time, only CO_2 emissions and/or greenhouse gas emissions are available. We have finally decided to perform a complete WTT assessment of biofuels by using the Ecoinvent database[1].

A detailed overview of the most important biofuels as well as their production stages has been made on the basis of the information contained in the Ecoinvent report entitled "life cycle Inventories of Bioenergy" [Jungbluth et al, 2007] and the Ecoinvent website (www.ecoinvent.org). In general, three stages of production can be distinguished: (1) feedstock production, (2) conversion to a fuel and (3) distribution. The transport phase between the feedstock production and the conversion is included in the conversion stage. According to the type of feedstock, the biofuels have been classified into first and second generation. The first generation biofuels are produced from food crops such as sugar cane, sugar beet, corn, rye and wheat, while the second generation biofuels are produced from the residual non-food parts of crops and different types of waste such as waste cooking oil, whey, manure,.... Four groups of biofuels have been assessed: oil-based biofuels (methyl ester or biodiesel), biogases, ethanol and gasification based fuels like methanol.

Typical bio-fuel production routes or pathways have been assessed. The most important ones are:

- Oil-based biofuels: feedstock production, solvent and cold-press oil extraction, esterification and distribution
- Biogas: feedstock, gasification or digestion, purification and distribution
- Ethanol: feedstock, fermentation, distillation and distribution
- Methanol: feedstock, gasification, synthesis to liquid fuel and distribution

[1] Swiss Centre for Life Cycle, ecoinvent Data V2.01, CD-ROM, ISBN 3-905594-38-2, Dübendorf, 2007

After gathering all the background information, one should extract the Ecoscore parameters (CO_2, CO, HC, NO_x, SO_2, CH_4, PM and N_2O) from the Ecoinvent database which contains more than 1500 types of emissions emitted to different compartments (air, water, soil) divided into sub-compartments (air with high density population, air with low density population, ocean, lake, river,...). Moreover, the location of the needed emissions should be found in 9 Excel files with 6 sheets per file. Two special Excel programs allowing the localization and the extraction of the needed emissions have been developed for that issue. The Emissions are from on-site measurement and estimation. A dedicated data quality management process has been used by the Ecoinvent team to estimate, to measure and express the uncertainty on the data. When uncertainty informations are not available for average data coming from one single source, a qualitative approach called the 'pedigree matrix' [Frischknecht, 2007] is used.

The CO_2 emissions include the fossil CO_2, the biogenic CO_2, and the CO_2 from the land transformation and the CO_2 uptake from the air (negative emission). In general, when data availability is poor, stoichiometric balances are used to determine the raw materials demand for a given process. All the results include the infrastructures, land use and transformation as well.

When no information is available for particulate matters about the size and or the distribution, standard references from the Coordinated European Programme on Particulate Matter Emission Inventories, Projections and guidance (CEPMEIP) database[2] are used. For Non-Methane Volatile Organic Compound (NMVOC), the equivalence factors of NATO/CCMS weighting schema are applied [Frischknecht, 2007]. SO_x and NO_2 are respectively reported as SO_2 and NO_x. The emission of sulphur dioxide is based on the sulphur content of fuels. N_2O, NO_x and NH_3 are calculated according to the the application of the fertilizers (N content) and the Nitrogen fixation by the vegetation [Nemecek, 2007].

2.2.2. Allocation

A special attention has been paid to the allocation of emissions to the different co-products during the conversion phase. Indeed, the emissions in the Ecoinvent database were allocated to the co-products according to their unit price and their carbon content for CO_2 emissions. We have re-allocated them according to the energy content (Table II and Table III) of each co-product, as it is also suggested in the Renewable Energy Directive.

[2] www.air.sk/tno/cepmeip/downloads.php, visited on October 14, 2008

Table II: Energy and Economic allocation factors for plant oil extraction

	Economic value based allocation factor	Energy content-based allocation factor
Rape oil	75.4%	59.9%
Soybean oil	34.1%	34.1%
Palm oil	81.3%	83.1%

Table III: Energy and Economic allocation factors for esterification

	Economic value based allocation factor	Energy content-based allocation factor
Rape Methyl Ester	86.9%	95.0%
Soybean Methyl ester	92.0%	95.0%
Palm Methyl Ester	87.1%	95.0%

2.2.3. Distribution of biofuels in the Belgian context.

In the Ecoinvent database, the distribution step of all the bio-fuels is modelled in a Swiss context. To adapt this step to Belgium, new distribution scenarios have been made. All the biogases are considered to be produced in Belgium since they are produced with feedstocks such as biowaste, grass, whey which are available in Belgium. For bio-ethanol, only the sugar cane ethanol is considered to be imported from Brazil and the remaining ones (rye, wheat, sugar beet...) are produced in Belgium. RME and waste cooking oil are produced in Belgium when SME and PME are respectively imported from the U.S and Malaysia.
For imported bio-fuels, transoceanic shipping from the country of origin to the port of Rotterdam and transport by barge from Rotterdam to Antwerp are considered. Once in Belgium, biofuels will be distributed within Belgium over a distance of 100 km. The nautical miles calculator http://e-ships.net/dist.htm has been used to calculate the port-to-port distance. As the emissions per ton-kilometre (tkm) of the different transport modes are available in the Ecoinvent database, they have been used to calculate the emissions produced by the distribution of the different biofuels.

2.2.4. Results

In this study, the greenhouse gas emissions, as well as non greenhouse gas emissions (Table IV) related to the production of different biofuels have been assessed. The results include emissions of the different steps involved in the biofuel production chain. When dealing with CO_2, the feedstock production gives an interesting result. This step is the most contributing in terns of fossil CO_2 emissions. This is due mainly to the agricultural practices such as the use of machinery and fertilisers.

However, these fossil CO_2 emissions are balanced by the CO_2 uptake from the air used by the plant to produce the organic matter. As a consequence, all the considered biofuel production chains in this study have negative overall CO_2 emissions (Figure 3 and Figure 4).

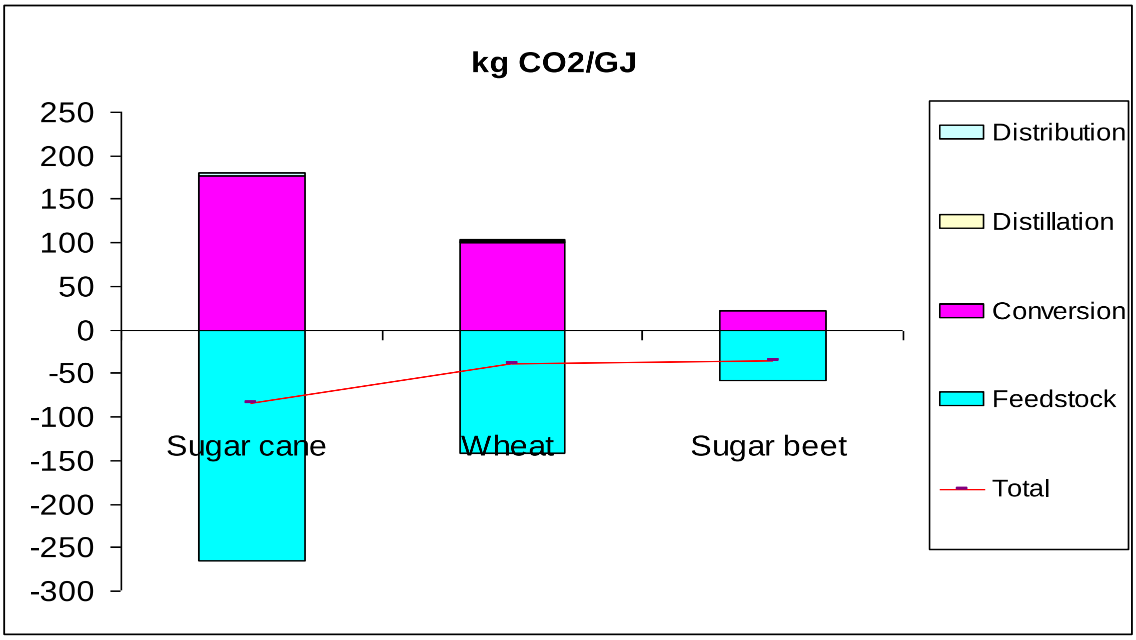


Figure 3: WTT CO_2 emissions of ethanol production from different types of feedstock

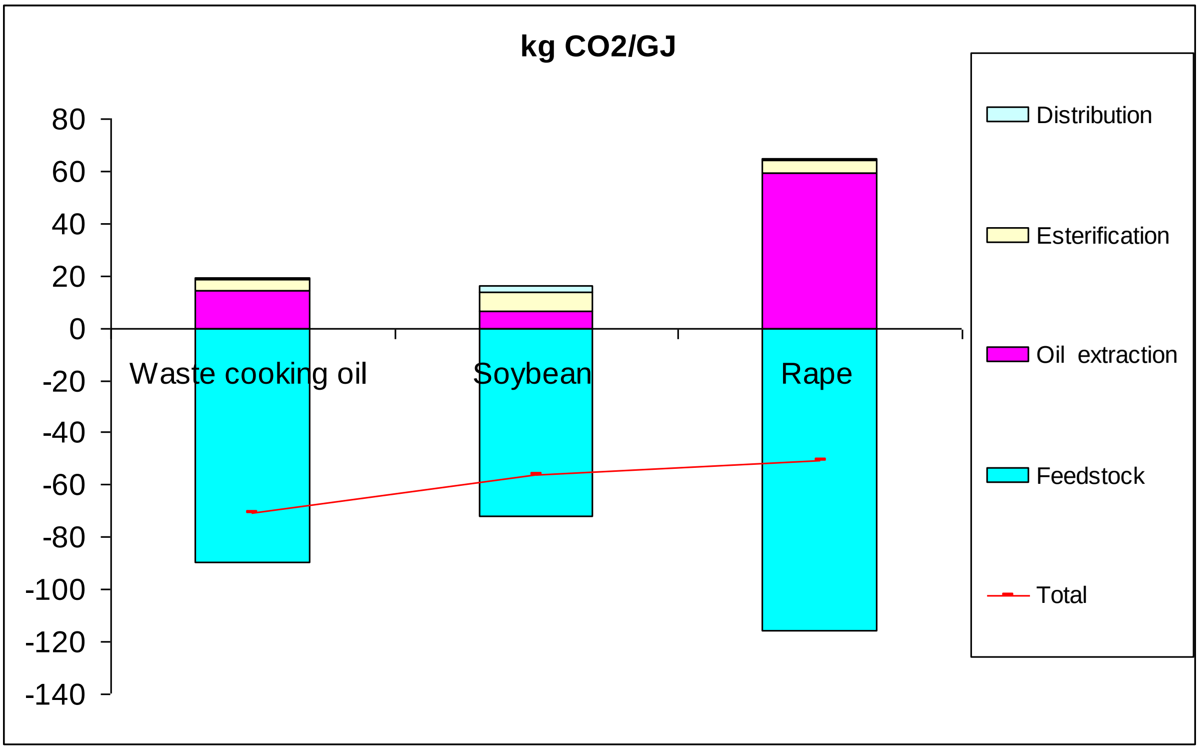


Figure 4: WTT CO_2 emissions of biodiesel production from different types of feedstock

The assessment of the overall greenhouse gas emissions shows that the benefit of the CO_2 uptake can be balanced by the N_2O emissions deriving mainly from the use of nitrogen based fertilisers (Figure 5 and Figure 6). It has been the case in this study for wheat ethanol. However, these results should be interpreted in the framework of the Ecoinvent model for the nitrogen cycle leading to the release of N_2O emissions. A different model of the nitrogen cycle could lead to relatively lower N_2O emissions. Additionally, the modelled agricultural practices in the Ecoinvent database are average conventional agriculture practices in Europe. Ecological and organic agriculture would have a lower environmental impact.

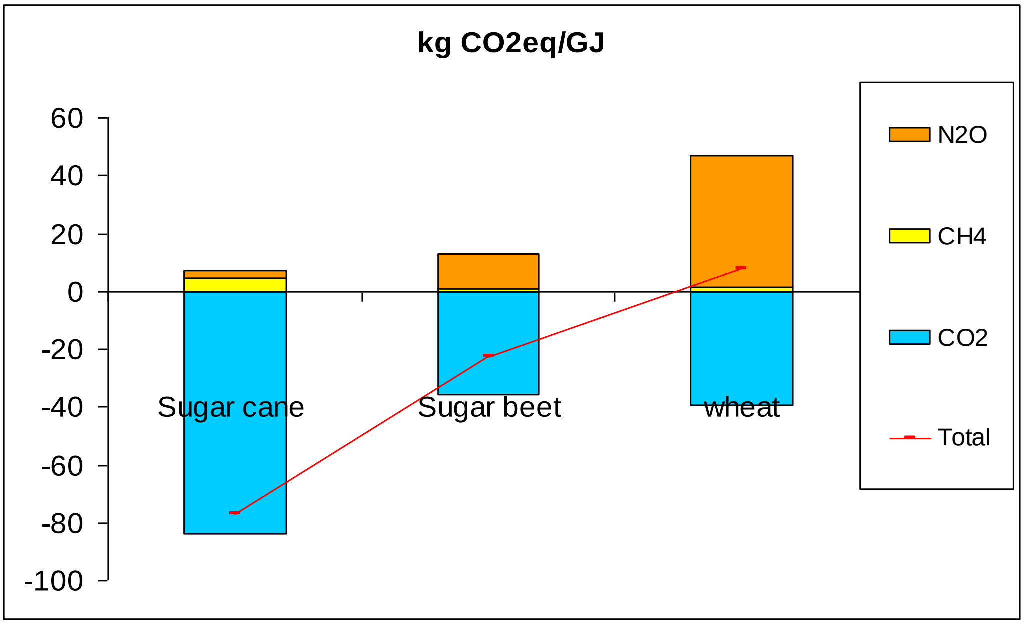


Figure 5: Greenhouse gas emissions of ethanol production from different types of feedstock

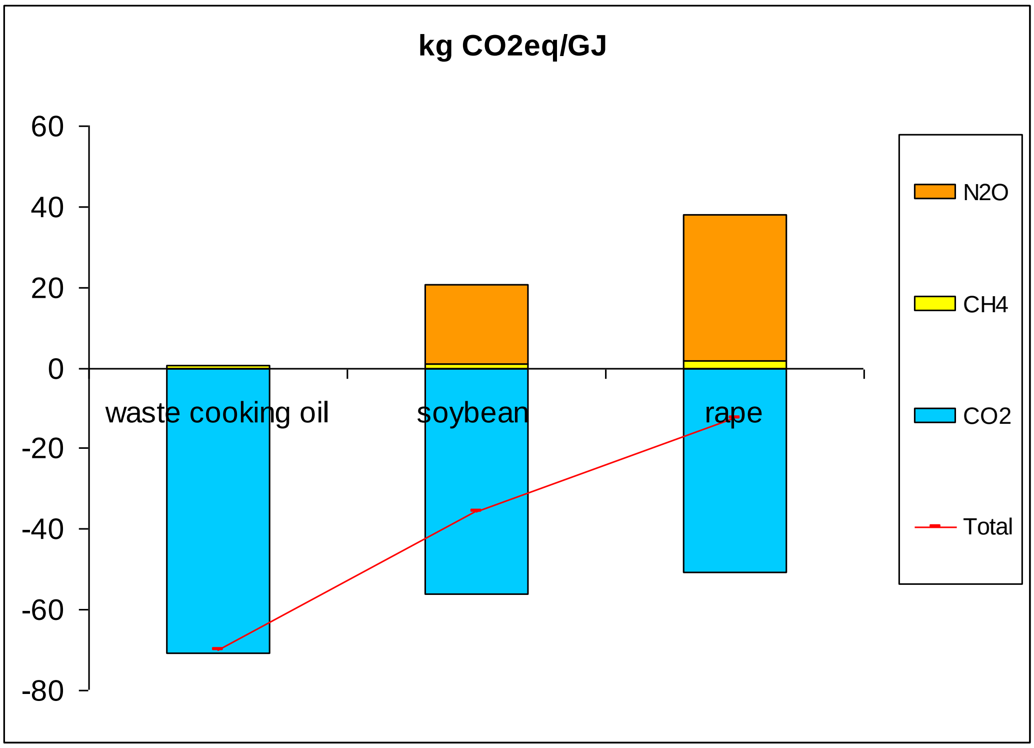


Figure 6: Greenhouse gas emissions of biodiesel production from different types of feedstock

Table IV: WTT emissions of different biofuels

	CO_2 kg/GJ	CO kg/GJ	CH_4 kg/GJ	SO_2 kg/GJ	NOx kg/GJ	N_2O kg/GJ	PM kg/GJ	HC kg/GJ	NMVOC kg/GJ
Rape									
Rape at farm	-60.8	0.050	0.045	0.076	0.147	0.1218	0.0363	0.0003	0.0166
Oil extraction	4.8	0.005	0.010	0.007	0.016	0.0001	0.0026	0.0006	0.0026
Esterification	4.9	0.004	0.019	0.010	0.007	0.0001	0.0024	0.0001	0.0017
Distribution	0.3	0.001	0.000	0.000	0.003	0.0000	0.0003	0.0000	0.0004
Total	-50.9	0.060	0.074	0.093	0.173	0.1220	0.0416	0.0009	0.0214
Soybean									
Soybean at farm	-72.1	0.013	0.007	0.016	0.045	0.0655	0.0075	0.0001	0.0050
Oil extraction	6.4	0.006	0.011	0.013	0.018	0.0001	0.0035	0.0011	0.0027
Esterification	7.2	0.004	0.019	0.018	0.008	0.0001	0.0035	0.0001	0.0017
Distribution	2.4	0.005	0.002	0.024	0.031	0.0001	0.0031	0.0000	0.0024
Total	-56.1	0.028	0.039	0.072	0.102	0.0658	0.0177	0.0012	0.0119
Waste cooking oil									
Waste Vegetable oil at plant	-75.6	0.005	0.011	0.005	0.012	0.0001	0.0019	0.0000	0.0021
Vegetable oil methyl ester	4.4	0.003	0.018	0.008	0.006	0.0001	0.0020	0.0000	0.0017
Distribution	0.3	0.001	0.000	0.000	0.003	0.0000	0.0003	0.0000	0.0004
Total	-70.8	0.009	0.030	0.014	0.021	0.0001	0.0043	0.0001	0.0042
Wheat									
Wheat at farm	-142.0	0.060	0.040	0.065	0.178	0.1510	0.0369	0.0003	0.0218
Conversion (95% Vol)	100.0	0.006	0.019	0.017	0.011	0.0001	0.0046	0.0001	0.0024
Upgrade/distillation	2.7	0.001	0.007	0.002	0.002	0.0000	0.0003	0.0000	0.0007
Distribution	0.4	0.001	0.001	0.001	0.004	0.0000	0.0004	0.0000	0.0006

Total (Wheat)	-39.1	0.068	0.066	0.084	0.195	0.1510	0.0422	0.0004	0.0254
Sugar beet									
Sugar beets	-57.4	0.015	0.008	0.009	0.050	0.0409	0.0084	0.0001	0.0061
fermentation	21.2	0.006	0.018	0.019	0.013	0.0001	0.0040	0.0001	0.0028
Distillation (sugar cane)	0.0	0.000	0.000	0.000	0.000	0.0000	0.0000	0.0000	0.0000
Distribution	0.4	0.001	0.001	0.001	0.004	0.0000	0.0004	0.0000	0.0006
Total	-35.7	0.023	0.026	0.028	0.067	0.0410	0.0128	0.0001	0.0095
Sugar cane									
Sugar cane at farm	-265.0	16.700	0.170	0.021	0.031	0.0064	1.6800	0.0001	0.0047
Conversion (95% Vol)	176.0	0.015	0.003	0.010	0.098	0.0024	0.0475	0.0037	0.0030
Upgrade/distillation (99.7% Vol)	0.0	0.000	0.000	0.000	0.000	0.0000	0.0000	0.0000	0.0000
Distribution	4.7	0.010	0.004	0.050	0.061	0.0001	0.0064	0.0000	0.0047
Total	-84.0	16.700	0.177	0.082	0.190	0.0089	1.7300	0.0038	0.0124

2.2.5. Well-to-tank GHG emissions of biofuels in Belgium through System Perturbation Analysis

The Renewable Energy Directive (EC, 2009a, annex V) contains a set of rules for calculating the well-to-tank (WTT) greenhouse gas impacts of biofuels, bioliquids and their fossil fuel comparators. In the methodology of the directive, the energy allocation method is used for the mathematical handling of multi-output processes (e.g. co-products). An alternative for such an allocation method is the substitution approach where co-products replace so-called substituted products. The energy allocation method is practical in use since no claims must be made about the nature and origin of substituted products. However, the substitution approach has the potential to produce results that better reflect reality, provided that accurate claims about the substituted products are made. The System Perturbation Analysis (SPA) method used in this section belongs to this substitution approach family. It was originally developed in the framework of the Libiofuels project (De Ruyck, 2006) and was further developed in the current project.

→ System Perturbation Analysis (SPA)

The SPA considers a given system where resources are transformed into products via a set of documented conversion routes as shown in Figure 7. These conversions lead to impacts such as GHG emissions, land requirements and energy use.

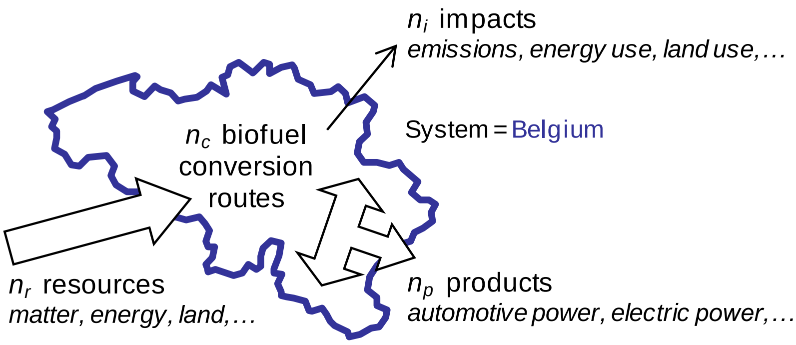


Figure 7: SPA system with resources, conversion routes, products and impacts

A single resource can be converted to different products simultaneously (e.g. co-products). Besides the major resources, each route consumes so-called utilities, which in their turn can be considered as separate types of resources. The contributions to the different kinds of impacts arise not only from resources and products but also from the utilities and must therefore be calculated in a cautious way, in order to avoid double counting. More detailed information on the SPA methodology and supporting background equations can be in found in a paper about biomass use assessment via SPA (Bram, 2009).

→ **System perturbations**

The objective of a system perturbation analysis is to determine the variations of considered impacts on a system (in casu Belgian) when conventional resources are replaced by alternative ones (e.g. 1MJ gasoline replaced by 1 MJ ethanol from wheat). To calculate these impact variations, a single resource is perturbed with a certain magnitude (e.g. import reduction of 1 ton of gasoline per year). The demand side is managed through a boundary condition which keeps all product amounts at constant level. This automatically implies necessary perturbations of other products and co-products as depicted in Figure 8.

When all perturbations are compensated, the variations of the impacts can easily be calculated. SPA can be considered as a consequential LCA where the system is expanded to the Belgian border. SPA does not use allocations within the considered system.

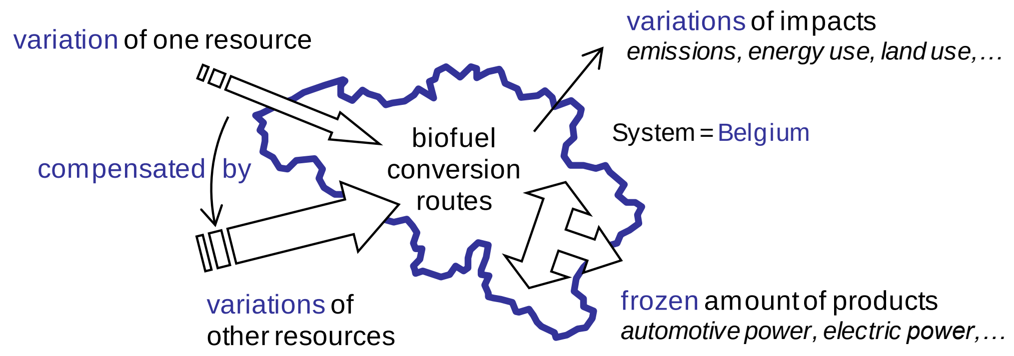


Figure 8: SPA scenario - perturbation and compensations of the system

Every scenario in SPA is a set of perturbations of resources and impacts. It is therefore possible to define evaluation criteria based on certain ratios of these perturbations. These criteria allow for a systematic comparison of different SPA scenarios. The six criteria that are used in SPA are shown in Table V.

In this table, the produced and avoided energy flows are net values, hence after compensations for consumed utilities and produced co-products. Energy and GHG balances are real, provided the used data and import compensations correspond to reality. Criteria *A* and *B* indicate to what extent the produced renewable energy really reduces fossil energy use. Criteria *C* and *D* show avoided GHG emissions as function of fossil energy use reduction. Criteria *E* and *F* show how the use of land is related to a reduction in fossil fuel dependency and to GHG emission reduction within a system.

Table V: SPA criteria and corresponding perturbation ratios

	SPA criterium	*system*	*perturbation ratio*		
A	Energy efficiency	world	GJ_{prim} avoided worldwide	/	GJ_{renew} produced worldwide
B	Energy efficiency	Belgium	GJ_{fossil} import to Belgium avoided	/	GJ_{renew} produced worldwide
C	Energy specific GHG emissions	world	kg CO_{2eq} avoided worldwide	/	GJ_{prim} avoided worldwide
D	Energy specific GHG emissions	Belgium	kg CO_{2eq} avoided in Belgium	/	GJ_{fossil} import to Belgium avoided
E	Energy specific land requirement	Belgium	hectare in Belgium	/	GJ_{fossil} import to Belgium avoided
F	GHG specific land requirement	Belgium	hectare in Belgium	/	ton CO_{2eq} avoided in Belgium

→ New software

The input of data in the original version of SPA was elaborate and took a lot of pre-processing. Therefore, the SPA code was completely rewritten. It was also necessary to redesign the internal data structure which now is able to contain the typical flow sheet like descriptions of bioenergy conversion routes, like in the Ecoinvent database structure.

The new version of the software is called SPA2 and access to data is now much more automated. SPA can now also work with two new data sources being: data from Ecoinvent (Frischknecht, 2007) and with underlying data from the RED directive (Biograce, 2009).

→ **Selected SPA scenarios**

In SPA, every set of resource perturbations that yields the original amounts of products is called an *SPA scenario;* it thus differs from how a scenario is defined in chapter 2.6.1. About 20 scenarios were selected for comparison in this report. The considered resources and products are shown in Table VI. These scenarios were chosen to illustrate the importance of the co-product's application, by comparing the implications on GHG emissions, energy and land use. This is done for a selection of crops, being: wheat, sugar beet and corn for bio-ethanol, rapeseed and sunflower for biodiesel and rapeseed for hydro-treated vegetable oil. The unallocated underlying data from the RED directive (cultivation, transport and distribution, typical process data) were used as input data for all scenarios in this analysis. Consequently, it became possible to compare results from the two methods: the SPA results (substitution approach) with typical data in the directive (energy allocation approach).

All scenarios have compact names that are used on the figures that follow. A *local* crop is a crop that is cultivated inside Belgium using typical cultivation data. An *imported* crop is cultivated in a neighbouring country, also with typical cultivation data. If the cultivation location is of no importance (like for worldwide impacts), no reference is made to local or imported. With *co-product as animal feed* the substitution of soy meal import from the US is meant. With *co-product as fuel* the co-product is used in a 30% efficient steam turbine plant to replace electricity from a natural gas fired combined cycle gas turbine plan inside Belgium with emission factors derived from standard values (Biograce, 2009).

Table VI: considered resources and products in SPA

resources:	Hectares for corn, rapeseed, soybean, sunflower, sugar beet, set aside land, wheat Imports of corn, rapeseed, soybean, sunflower, wheat Imports of gasoline, gasoil, natural gas, hard coal, heavy fuel oil, electricity EU mix Imports of animal feed, glycerine, isobutylene, and others…
products:	MJ fuel for diesel engines, MJ fuel for gasoline engines Excess electric power from CHP or steam turbine plant DDGS, sugar beet pulp, rape/sunflower seed meal, soya meal, glycerine Hectares[1]

[1] Hectares are considered as product to automatically ensure a constant usage of the available surface

→ SPA scenario results

The effects on primary energy use, GHG emissions and the use of land for the considered scenarios are shown in Figure 9 to Figure 12.

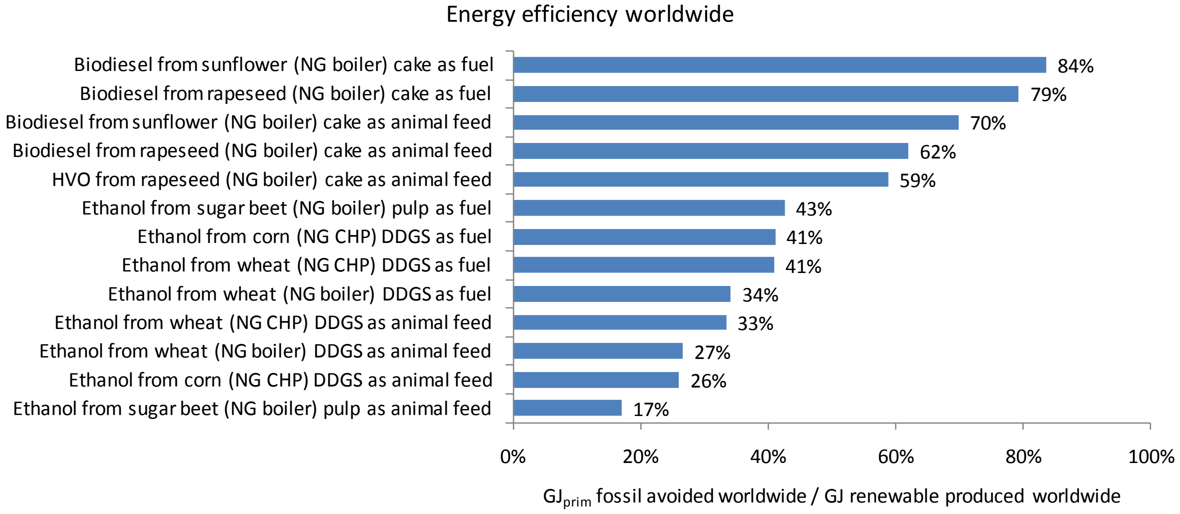


Figure 9: worldwide energy efficiency, according SPA

Figure 9 shows the global energetic efficiencies of the different scenarios. This efficiency is defined as the ratio of the avoided fossil energy use worldwide to the produced renewable energy on the field. The figure shows to what extent fossil energy is really replaced by renewable energy: this efficiency should at least be positive and preferably close to 100%. All efficiencies are quite positive and range from 20% up to 85%. Two observations can be made. First, biodiesel scenarios have higher global energetic efficiencies than ethanol scenarios because the latter combine lower conversion efficiencies with higher fossil energy demands in the conversion process. Secondly, using the co-product as a fuel systematically avoids more fossil energy being imported than when using it for animal feed replacement. Ethanol from sugar beet with pulp for animal feed shows the lowest efficiency, which is due to the low conversion efficiency combined with the high energy demand for distillation and pulp drying. Using the pulp as a fuel improves this global efficiency with more than 20%.

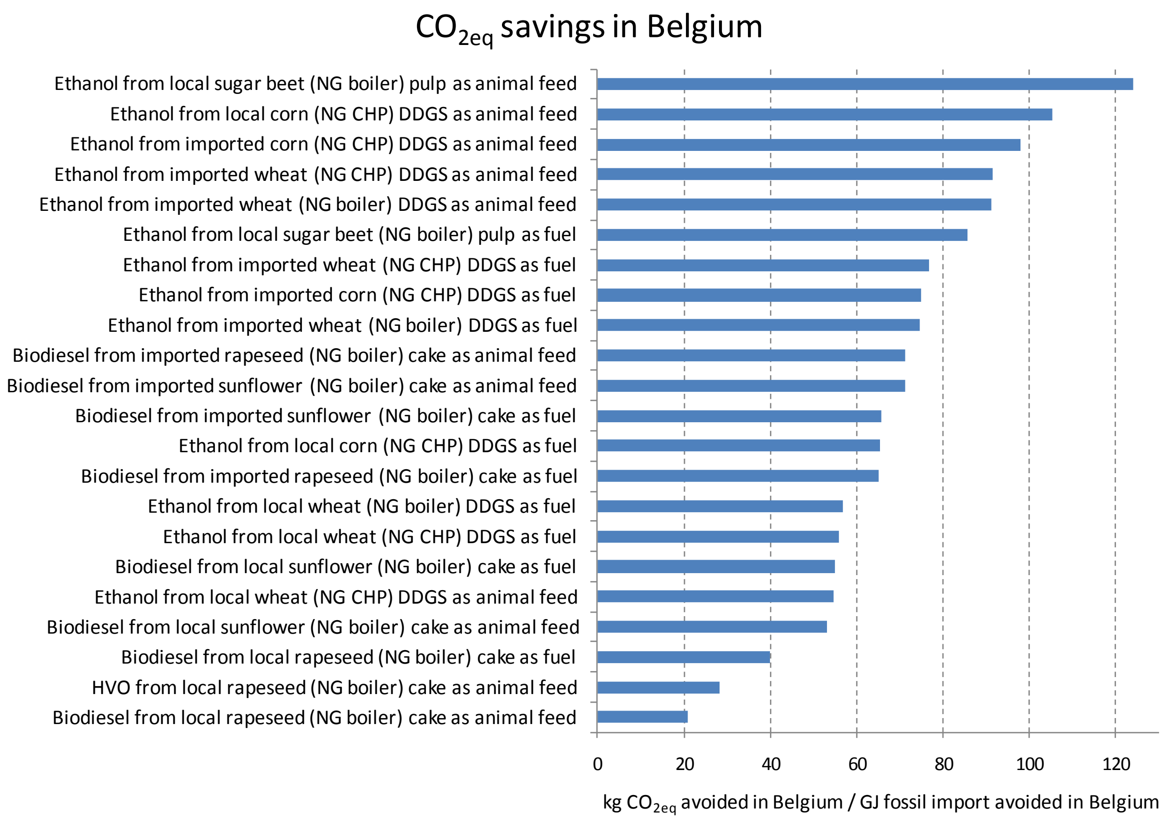


Figure 10: Energy specific GHG savings for Belgium, according SPA

Figure 10 shows how fulfilling our Kyoto commitment is linked to our fossil fuel dependency for the different scenarios. This is visualized by making the ratio of the avoided CO_{2eq} emissions inside Belgium with the reduction of fossil energy import to Belgium. This ratio indicates to what extent a scenario is capable of reducing GHG emissions in Belgium by simple keeping fossil energy of being imported in the country. Scenarios yield energy specific GHG savings ranging from 20 to 120 $kgCO_{2eq}/GJ_{fossil}$. In general this ratio is higher for the co-product as animal feed scenarios than the co-product as fuel scenarios; exceptions are local sunflower and local rapeseed. Also, imported crop scenarios tend to have a higher ratio than local crop scenarios.

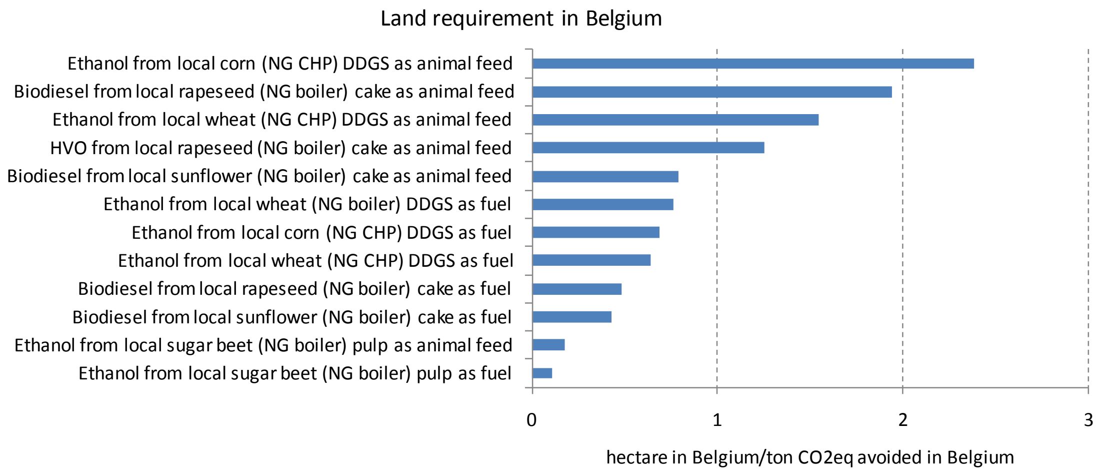


Figure 11: energy specific land requirement in Belgium, according SPA

Figure 11 shows how much land must be cultivated in Belgium per ton of avoided GHG emissions in Belgium. It is an important ratio given the limited availability of land in Belgium. Only the scenarios with local crop cultivation are shown in this figure. Values range from about 2.5 ha/ton avoided CO_{2eq} to as low as 0.2 ha/ton avoided CO_{2eq}.
Differences are large due to the combination of differences in energy yield from the field for the different crops and the differences in GHG savings for the considered conversion routes. For instance, the low GHG savings for ethanol from corn with DDGS as animal feed combined with the low energetic yield of corn from the field explains the high demand for land to avoid CO_{2eq} emissions.
The co-product for fuel scenarios outperforms the co-product for animal feed scenarios because there is no credit inside Belgium for the soy meal production for animal feed in the US.

In Figure 12 the worldwide GHG emission savings for the different SPA scenarios are calculated with the equation from the RED directive methodology section:

$$GHG\ SAVING = 100\% \left(1 - \frac{E_B}{E_F}\right)$$

Here E_B stands for the GHG emission from the considered biofuel, expressed in $gCO_{2eq}/MJ_{biofuel}$ and E_F for the GHG emission from the fossil fuel comparator having a value of 83.8 gCO_{2eq}/MJ_{fossil}. In this figure, no reference is made to local or imported because this does not matter for this comparison. Neither are the SPA scenarios sorted by GHG emission saving value. Instead, they are grouped per crop (typical values, co-product as animal feed, co-product as fuel) to better visualize the crop wise comparison.

The *typical values* scenarios are scenarios where an energy allocation is performed for the process step, according the RED methodology. This allows for a comparison with the SPA results. Also, the calculation of the GHG savings of *typical values* scenarios served as validation for the SPA2 model. Apparent from this figure is that all co-products for animal feed scenarios underperform the co-product for fuel scenarios with 20% to 30%. A second observation is that *typical values* scenarios underestimate the GHG emission savings for some crops when the co-product is used as a fuel. This is the case for corn, sugar beet, rapes seed and sunflower.

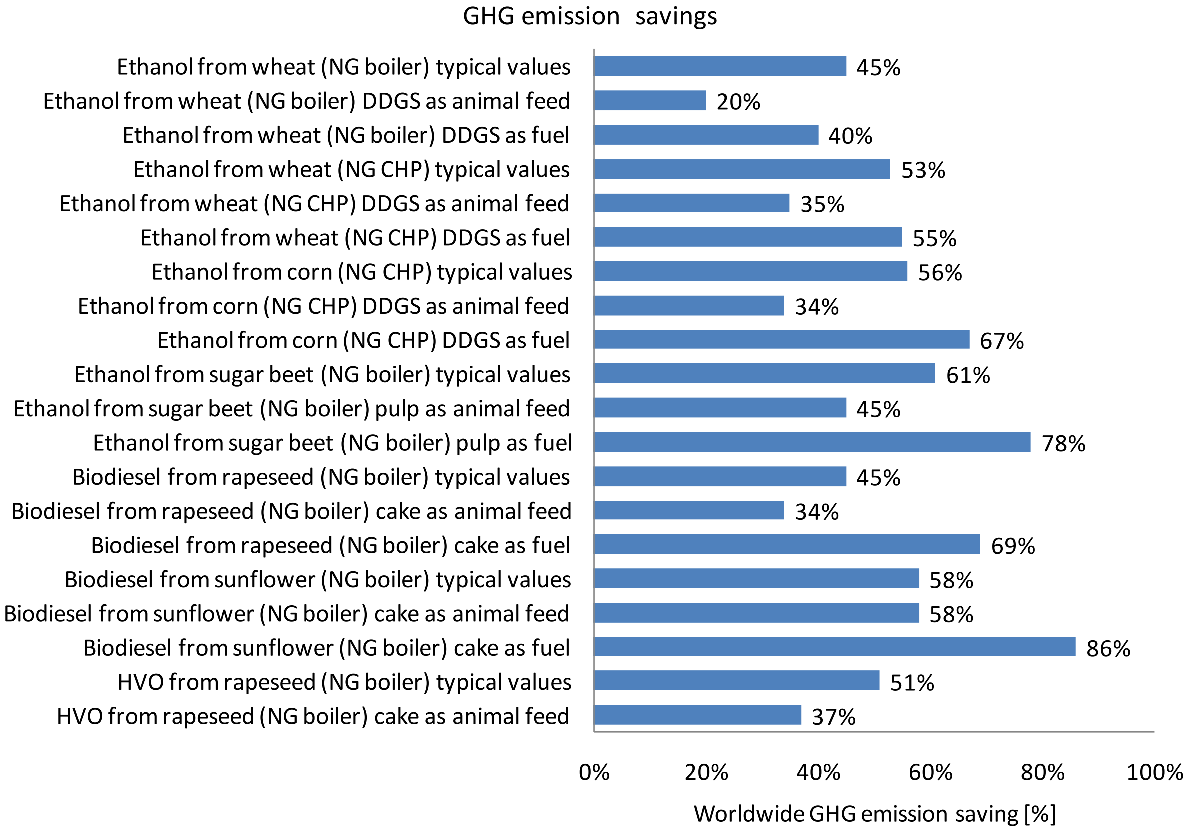


Figure 12: GHG emission savings according RED directive

As a conclusion we can say that a System Perturbation Analysis is able to show how GHG emission savings in a system (in casu Belgium) are related to the fossil energy consumption of that system. Also, the SPA shows how the GHG emission savings strongly depend on the real use of the co-product. The difference with the GHG emissions saving calculated according to the RED directive can be significant and range from minus 25% (when the co-product replaces animal feed import) to more than 30% when the co-product is used as a fuel.

2.3. TANK-TO-WHEEL EMISSIONS

For impact analyses of the different biofuel introduction scenarios, accurate data are needed to estimate the effect of the most relevant biofuel blends on vehicle emissions and fuel consumption. Next to collecting public data in literature on the effect of biofuel blends on emissions, the project consortium selected current diesel and gasoline vehicle models to be tested on various biofuel blends.

2.3.1. Vehicle tests

The following table gives an overview of all vehicle tests performed in the frame of the BIOSES project.

Table VII: overview of test vehicles within the BIOSES project

Biofuel	Test vehicle	Test fuels	Test period
Bio-ethanol			
	Flex-fuel passenger car (FFV1) Volvo V50 1.8f	Gasoline, E5, E10, E20, E85	October 2008
	Flex-fuel passenger car (FFV2) Saab 9.5 2.3t	Gasoline, E5, E10, E20, E85	April 2009
	Passenger car (GDI) VW Golf Plus 1.4TSI	Gasoline, E5, E10, E20	December 2008
Biodiesel / PPO			
	Delivery van VW Crafter 2.5TDi	Diesel, B5, B10, B30, B100	February 2008
	Passenger car Citroën C4 1.6 HDi	Diesel, B5, B10, B30, B100	May 2008
	Truck Scania P230	Diesel, B5, B10, B30, B100	September 2008
	City bus VanHool A360*	Diesel, B5, B10, B30, B100, PPO	May 2007
	Delivery van Opel Vivaro 1.9DTI*	Diesel, B5, PPO	June 2007
	Delivery van Citroën Berlingo 2.0HDI*	Diesel, B5, PPO	September 2007
	SUV Nissan Patrol GR 3.0*	Diesel, B5, PPO	March 2008
HVO (NExBTL)			
	Passenger car Citroën C4 1.6 HDi	Diesel, HVO10, HVO20, HVO100	April 2010

** jointly tested for the Flemish Administrations and BIOSES*

The tests were performed with VITO's on-board emission measurement system (VOEMLow). VOEMLow is the second generation of a dedicated system for on-road measurements. It measures fuel consumption and emission concentrations (CO2, CO, THC, NOx and PM), combined with the total mass flow of the exhaust gases, so the results are expressed in gram pollutant per second.
All tests were performed on proving ground in Lommel, Belgium. For the passenger cars in the project the European test cycle NEDC (start with hot engine) was used and a test cycle based on real traffic (MOL30 cycle, with part city traffic, part rural and part motorway). As the NEDC and MOL30 cycle are not representative for heavy duty vehicles, dedicated cycles were used for the truck and the city bus. The truck (on biodiesel blends) was tested using the FIGE cycle, which is the basis for the European Transient Cycle for homologation on engine level; on top we performed constant speed tests on 50 and 85 km/h. The city bus (on PPO and biodiesel blends) was tested on three bus cycles (De Lijn cycle – dedicated cycle of the Flemish transport company; DUBDC – Dutch Urban Bus Driving Cycle, designed by TNO in the 1990s; SORT – Standardised On-Road Test Cycles, designed by UITP).
All tests were performed at least three times.

The detailed test results are described in a dedicated report (Pelkmans, 2010), which is also available at the BIOSES website. The following paragraphs show the main conclusions.

2.3.2. Trends of WTT emissions for the different biofuels

→ Biodiesel blends

There is quite some information and test data available for older types of vehicles and engines (especially in the US). Nevertheless the effect of biodiesel blends on new engine systems, with high pressure direct injection, in combination with various systems of emission control, is not well documented in literature. This is why the BIOSES project consortium decided to perform extra measurements on the effect of biodiesel blends in new types of diesel vehicles.

These are the trends found in *literature*:

Fuel & energy consumption: When operating on pure biodiesel, a diesel engine has more or less the same (thermal) efficiency as operating on diesel. Some sources mention a slight efficiency increase (of a few %), due to the presence of oxygen in the biodiesel. So, overall the volumetric fuel consumption when operating on pure biodiesel is about 5-10% higher than for diesel (to compensate the lower energy content per litre).
Regulated emissions: generally most studies show the following trends:

- NOx (Nitrogen Oxide) emissions are generally higher (10-20% for pure biodiesel - B100), although for medium blends (B20) the effect is rather neutral on average.
- CO (carbon monoxide) and THC (total hydrocarbon) emissions tend to decrease (-10 to -70% for B100), with the effect depending on the technology. However it should be kept in mind that these emissions are already very low for current diesel engines.
- PM (particulate matter) emissions seem to go down in all cases (-20% to -50% for pure biodiesel). Also for medium blends the effect is often very positive. Even in the presence of an oxidation catalyst or PM filter the effect of biodiesel blending seems to be positive.

In the *test results* on four types of diesel vehicles, there were the following trends:

- the effect of low biodiesel blends on fuel consumption is marginal (up to 2% lower or higher), for pure biodiesel volumetric fuel consumption was 4 to 5% higher than on pure diesel, which corresponds with slightly better energy efficiency as biodiesel has about 10% lower heating value compared to fossil diesel.
- NOx emissions were clearly higher for pure biodiesel (between 5 and 15%). The results for lower blends (B5-B10-B30) are more diverse with a 10% increase for one vehicle, while the other three vehicles hardly had any impact or even a small reduction of NO_x emissions up to B30. There seems to be a reverse connection between energy consumption and NO_x emissions. Technology choice (e.g. EGR) may have impact here, but certainly for the light duty vehicles this trend seemed to be confirmed.
- effects on CO and THC emissions were diverse, with increasing emissions for one of the vehicles, and decreasing (or at least neutral) effects on the other. For the vehicle with increasing CO and THC emissions, the absolute CO and THC emission levels were actually at very low level, so this is certainly not problematic in terms of reaching the Euro IV standard.
- PM emissions were measured for the heavy duty vehicles (truck and city bus). For the truck and bus a clear decreasing trend of (mass-based) PM emissions with increasing biodiesel content was recorded, reaching up to 60% reduction for pure biodiesel (B100).

→ **Bio-ethanol blends**

Bio-ethanol is traditionally used as oxygenate, added to gasoline (blending up to 10%), with a positive effect on certain emissions (especially CO and HC), but also on thermal efficiency. Most commercial gasoline fuels currently already contain oxygenates like MTBE, and the effect of ethanol blending on thermal efficiency is similar.
Bio-ethanol only has two thirds of the energy content of regular gasoline, so an increase of ethanol blending percentage will lead to higher volumetric fuel consumption (if thermal efficiency remains the same).

These are the trends found in *literature*:
E85 will on average increase volumetric *fuel consumption* by 30 to 35%. Nevertheless there are variations between 20 and 40%, depending on vehicle type and test cycle. When converting these figures into energy use, using the lower heating value of each fuel, one can derive that E85 on average has 5% better thermal efficiency. This, however, may vary between vehicle types and test cycles, given the spread of all test results. Even the lower blends (E10, E20) have on average positive results compared to gasoline.
For *regulated emissions* there is a lot of spreading in the results, but in general the emissions are in the same range for gasoline and most ethanol blends, which is quite low as these vehicles need to comply with stringent emission limits. Only CO emissions are somewhat higher in some cases, but the emission limits are less stringent for CO.
There is a tendency of higher evaporative emissions for low ethanol blends (E5-E10) because of their higher vapour pressure. This may give an increase of around 30% in evaporative THC emissions.
Most hydrocarbon emissions go down, but there may be increases in formaldehyde, acetaldehyde and PAH emissions. This is mostly controlled when the engine is warm, but in cold condition there can be a substantial increase of these emissions.

In the *test results* on two flexfuel vehicles and one modern (direct injection) gasoline model, one can conclude that the figures are quite positive for ethanol blends, although it should be kept in mind that car technologies can have important impact. In terms of exhaust gas emissions, base levels on gasoline operation are usually very low, and these emissions are kept at very low level with increasing ethanol blends. For CO and THC emissions there is even a clear decreasing trend.
Fuel consumption (litre/100km) generally increases with higher ethanol blends, more or less following the energy content of the fuel.

When expressing the results in energy consumption (MJ/km), the results are neutral to positive, with up to 10% lower energy consumption for one flex-fuel vehicle on E85. Exception was energy consumption of the other tested flex-fuel vehicle on the NEDC cycle, which showed a clear increasing trend with higher ethanol blends. This however cannot be generalized, as on the real traffic based test cycle, energy consumption did not increase at all. In any case it seems that some brands will have flex-fuel models optimized for E85 operation, while others are still most optimized for gasoline operation.

→ **Pure plant oil**

Pure plant oil (PPO) can be used in diesel engines. However, opposed to biodiesel, the engine should be modified more thoroughly. The main problem is that vegetable oil is much more viscous than conventional diesel fuel. It must be pre-heated so that it can be properly atomised by the fuel injectors. If it is not properly atomised, it will not burn properly, forming deposits on the injectors and in the cylinder head, leading to poor performance, higher emissions, and reduced engine life.

There are limited data available in *literature* for the emissions of PPO converted vehicles compared to their operation on regular diesel fuel. In most cases the effect on CO, THC and PM emissions is rather positive (comparable to the effect of biodiesel), but there are also cases where problematic increases are detected. NOx emissions tend to increase up to 20 – 30%. The condition of the vehicle, the quality of the conversion system, and the fuel quality play an important role.

The *test results* on three converted vehicles (two delivery vans and one SUV) more or less confirmed these general trends. PPO has a slightly lower caloric value compared to diesel fuel on volume basis, but there was no significant difference in fuel consumption for most of the tested vehicles.
CO emissions generally show no clear trend except for the SUV which emits three times more on PPO. The THC emissions are two to three times higher on PPO for the two delivery vans, and for the SUV even up to 20 times higher. NO_x emissions are higher on PPO, from 20 to 40%. As to the PM emissions a drop of about 50 to 60% is found. On B5 there is a drop of a little less then 10%.

The SUV in the test programme shows high CO and THC emissions at idling when running on PPO. The engine management system is not able to correct this and produces a fault code indicating that the fuel is 'out of spec'. Overall this vehicle is having higher fuel consumption and emissions on PPO than the other two vehicles. This indicates that not every diesel vehicle can be converted to PPO with success.

→ **HVO (NExBTL)**

Not so many figures are available for the effect of synthetic diesel fuels on emissions of diesel engines. The general trend is that combustion is more homogenous and complete, leading to lower CO, HC and PM emissions, while at the same time NOx emissions are also slightly reduced.

Within the BIOSES project one diesel car was tested on blends of diesel and NExBTL, a synthetic fuel derived from hydrotreatment of vegetable oil.
Looking at the results it can be concluded that overall the impact of NExBTL blending on fuel consumption and emissions seems to be rather limited. For energy consumption, we do see a 1% reduction for pure NExBTL compared to diesel and a 2% increase for the lower blend of 10% NExBTL.
For total hydrocarbon emissions (THC) there is a clear decreasing trend (up to 30% reduction for pure NExBTL), however these emissions were already at very low level (~ 0.01 g/km). The other emissions (CO and NOx) show variations which are in the same order as their measurement variation, also showing reductions for one cycle and increases for the other cycle. So in general differences are hardly significant.

2.4. OVERALL COMPARISONS BETWEEN DIFFERENT FUEL OPTIONS

2.4.1. Ecoscore methodology

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

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

In the first step of the inventory, the direct (associated with the use of the vehicle) and indirect emissions (due to production and distribution of the fuel) associated with the vehicle are collected. Direct or tank-to-wheel emission and fuel consumption data are based on homologation data collected by Febiac and DIV (Federal service for vehicle registrations) and can be consulted on www.ecoscore.be. Indirect or well-to-tank emission data have been obtained from the MEET 1995 study (MEET, 1999), complemented with Electrabel data for electricity production. In the calculation of the total impact of the vehicle, the exposition of the receptors is taken into account by giving the indirect emissions a smaller weight than the direct emissions (with an exception for greenhouse gases, since they have a global effect).
Once the emissions have been calculated, their contribution to the different damage categories (climate change, air quality depletion and noise) are analysed in the classification and characterisation step. The contributions of the different greenhouse gases to global warming are calculated using global warming potentials (GWP), as defined by the Intergovernmental Panel on Climate Change (IPCC). External costs, based on the EU ExternE project (ExternE, 1997), are used for the inventoried air quality depleting emissions. Noise pollution is expressed in dB(A), a decibel scale with A-weighting to take the sensitivity of human hearing into account. To quantify the relative severity of the evaluated damages of each damage category, a normalisation step based on a specific reference value is performed. The reference point is the damage associated with a theoretical passenger vehicle of which the emission levels correspond with the Euro 4 emission target levels for petrol vehicles, a CO2 emission level of 120 g/km and a noise level of 70 dB(A).
In a final step, the normalised damages are weighted before they can be added to become the “total environmental impact”. These weighting factors reflect policy priorities and decision maker’s opinions. An overview of the methodology is presented in Figure 10. To obtain results situated between 0 (infinitely polluting) and 100 (emission free and silent vehicle), the total environmental impact (TI or Total Impact) is rescaled to the final Ecoscore indicator. The reference vehicle corresponds to an Ecoscore value of 70.

The transformation is based on an exponential function, so it cannot deliver negative scores:

Ecoscore = 100*exp(-0,00357*TI)

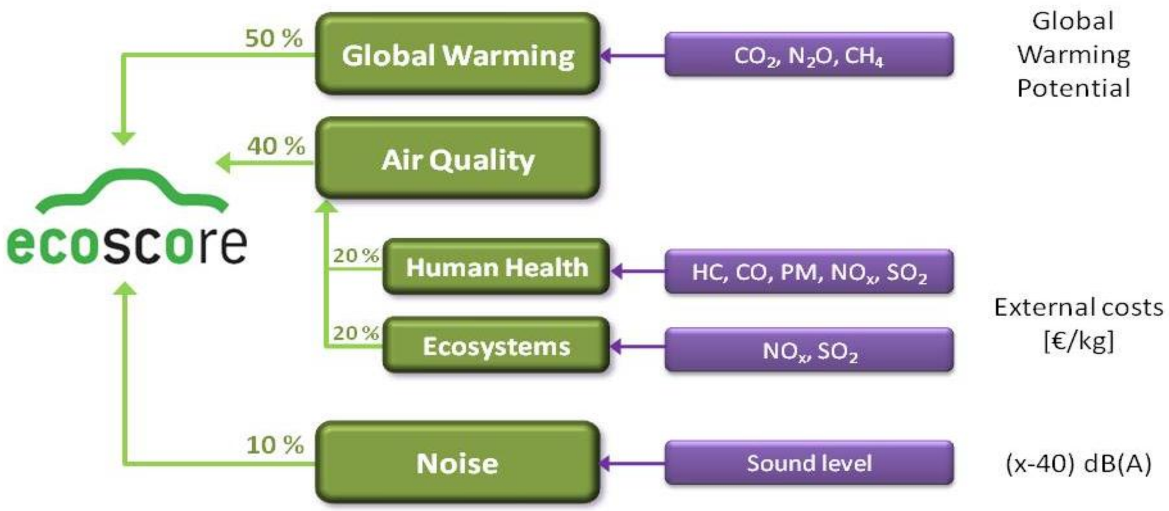


Figure 13: Overview of the Ecoscore methodology (Timmermans et al., 2006)

2.4.2. Results

In this study an adaptation has been made to the original version of the Ecoscore. In fact, the WTT emissions of the different fuels as well as the WTT emissions of the reference vehicle considered in the Ecoscore methodology are from the MEET 1995 study (MEET, 1999). In the BIOSES project, the WTT emissions of the reference vehicle are replaced by WTT emissions from Ecoinvent since the WTT emissions for all the biofuels considered in this study are from the Ecoinvent database.

As it can be seen on the Figure 6 and Figure 7, the Ecoscore results are influenced by the blending level of the biofuel and the type of feedstock used to produce the biofuel. For the different blends of beet ethanol, one can notice that all of them score better than the petrol and the higher the blending the better the Ecoscore. This is due mainly to the lower environmental impact of the beet production. Contrarily to the beet ethanol, high blend (E85) of wheat ethanol leads to lower Ecoscores. This is due to the production of wheat which emits high amounts of N_2O and NO_x deriving from Nitrogen based fertilizers. These two pollutants increase respectively the global warming and the air quality contribution to the total impact.

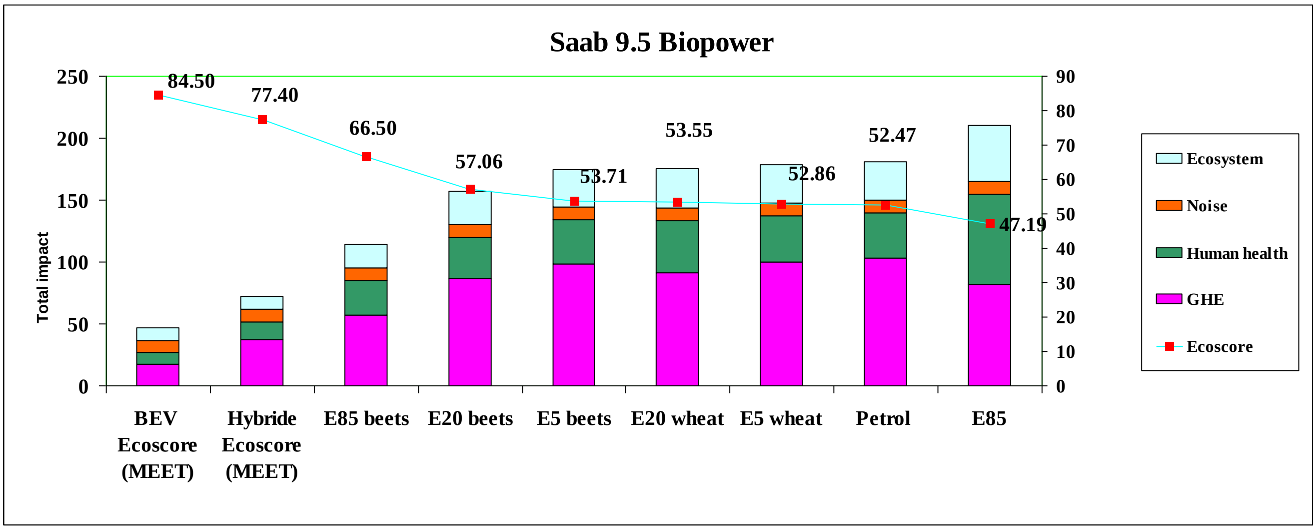


Figure 14: Ecoscore results of the Saab Biopower using different blends of ethanol

Figure 15 shows that the Ecoscore of the different blends of RME are slightly lower than for fossil diesel. This is not due to the global warming for which the RME scores better than the fossil diesel but to the other impact categories. In fact, the production of the RME emits more NO_x and more PM than the diesel production. These two pollutants have big influence on human health and air quality. As a consequence, the higher the RME blend is, the lower the Ecoscore will be. This result should not be generalized for all the biodiesel. A biodiesel produced with other feedstock could lead to completely different conclusions.

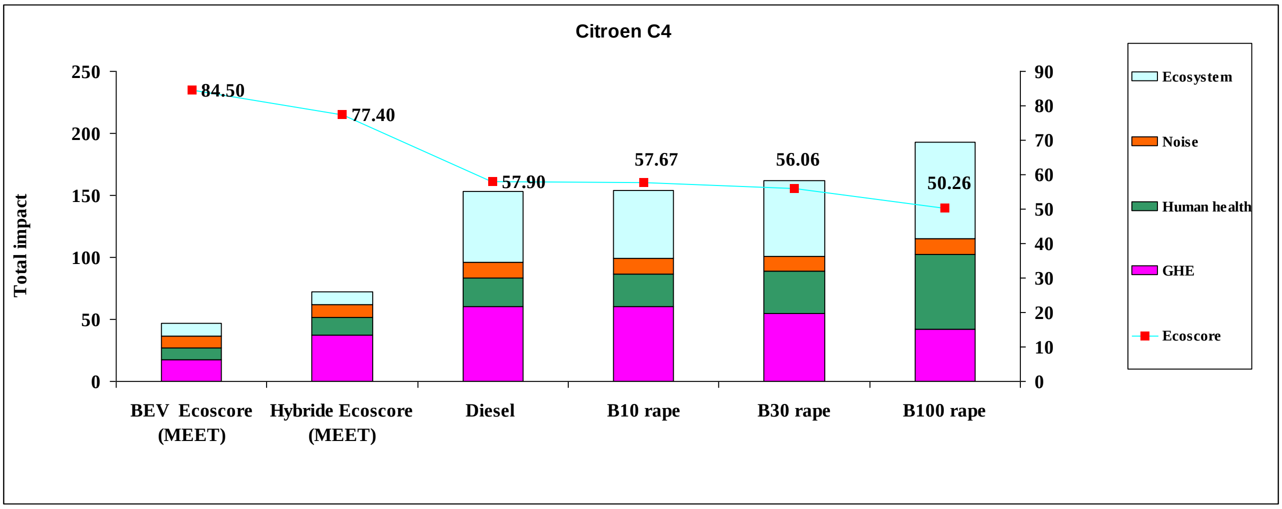


Figure 15: Ecoscore results of the Citroen C4 using different blends of RME

Close to the Ecoscore, the Cumulative Energy Demand (CED) (Hischier et al., 2010) has also been calculated for the different biofuel blends on a Well-to-Wheel basis. It includes the total primary energy from renewable and non-renewable resources involved in a product system. The energy content (the lower heating value) of the assessed product is also included.

The CED of the RME appears to be higher than the diesel one. This is due to the agricultural processes and the fact that the energy content of plants are taken into account in the calculation of the CED. Additionally, one will need more volume of biofuel than fossil fuel to cover the same distance because of the lower energy content of biofuels. However the big share of the CED of biofuels is renewable and their fossil energy demand is lower compared to fossil fuels. For the waste cooking oil methyl ester, only the energy used to collect and treat the waste oil is taken into account. The energy content of the waste oil is allocated to the previous use of the waste oil as cooking oil.

In Figure 9, the CED of high blend (E85) ethanol made with different feedstocks has been assessed. The wheat and sugar cane ethanols have higher CED than the petrol but their fossil CED is lower than the petrol one. In the specific case of sugar cane, the fossil CED is particularly low because of the use electricity from bagasse (dehydrated crashed sugar cane) during the ethanol production. The beet ethanol has the lowest CED. This is due to the fact that the cultivation and fermentation of the beets are less energy intensive.

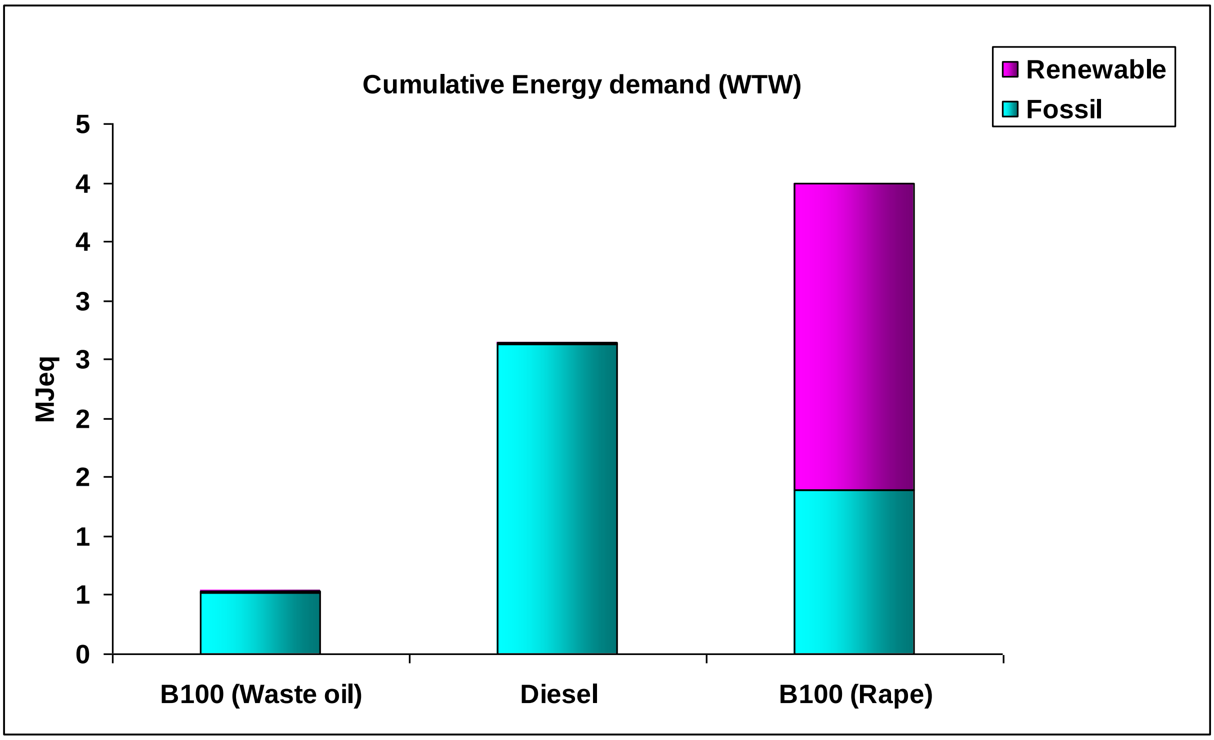


Figure 16: WTW cumulative energy demand of the Citroen C4 using different blends of RME

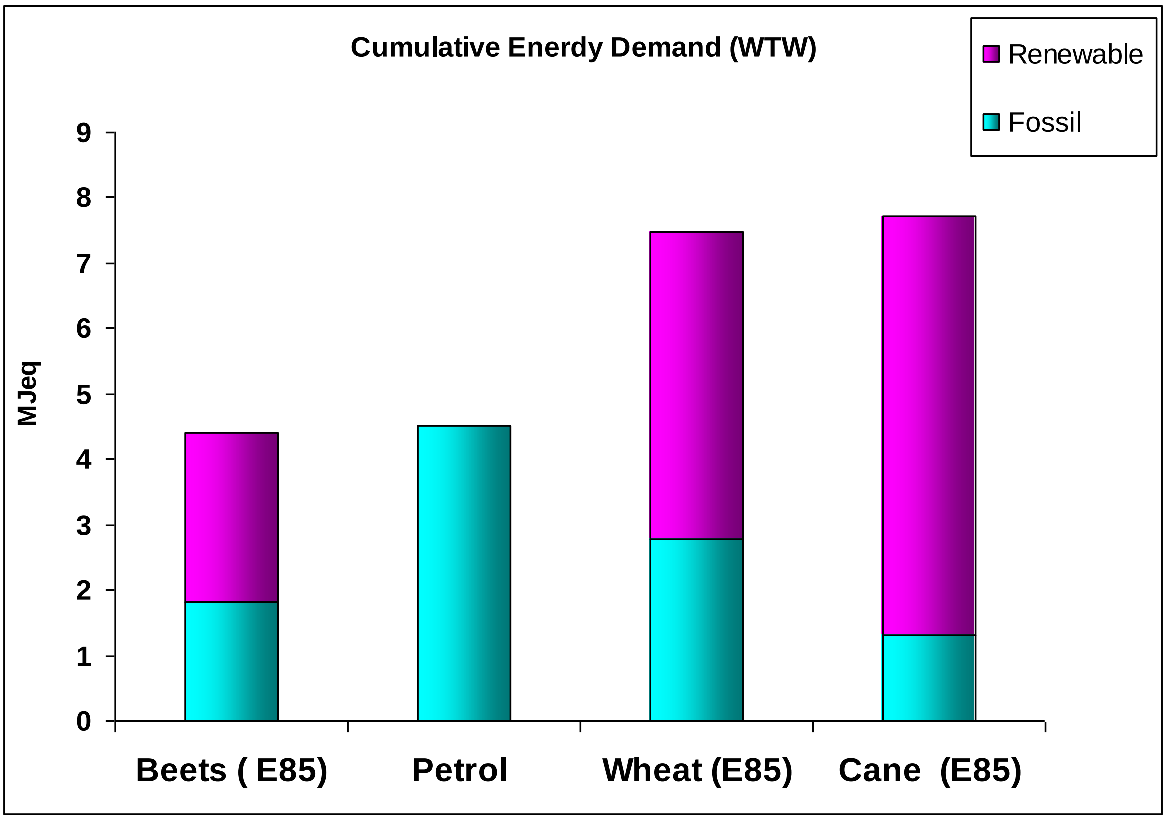


Figure 17: WTW cumulative energy demand of the Saab Biopower using different blends of ethanol

2.5. MICRO-ECONOMIC COSTS

In this micro-economic cost overview a first part is dedicated to the estimation of the cost for end users implied by the acquisition of a vehicle compatible with high biofuel blends compared to its gasoline or diesel equivalent. To do so, vehicle manufacturers were contacted. A second part is dedicated to prediction of the cost for the end users of biofuels blended with fossil fuel at different percentages according to the scenarios of the BIOSES task 1.

2.5.1. Biofuel compatible vehicle cost

The cost for end users implied by the purchase of a vehicle compatible with high biofuel blends compared to its gasoline or diesel equivalent and the cost generated by the adaptation of a conventional vehicle have been estimated by means of interviews with concerned vehicle manufacturers. Results are presented in the table below.

Table VIII: Supplementary purchase cost of a vehicle compatible with high biofuel blends compared to a conventional car and/or the conversion costs of a conventional vehicle (situation 2008)

	Additional purchase cost of biofuel compatible vehicles	**Converting costs**
E85 **Flex-fuel**	GM (Cadillac): 700 € PSA: 0 € Ford ~300 € Renault: 0-200 € Saab: 1000 € Volvo: 500 €	Transformation kit: min. 600 €[3] Placement: min. 150 €
B30	No additional cost	-
B100	No additional cost	-
ED95	ED95 engine (270 bhp) compared to a conventional Scania engine (280 bhp EEV) ~ 13.000 euros[4].	-
Biomethane	Heavy duty CNG engine compared to a diesel equivalent ~ 35.000 €[5]	Converting costs from conventional gasoline car to CNG: 3000 - 6000 €
PPO **(pure plant oil)**	-	Price conversion set[6] Cars/vans: 690-2050 € Trucks: 850-2950 € Tractor: 3300- 3700 €

2.5.2. Biofuel cost – short term projections

On the short term, the biofuel price for end users depends on several parameters such as the price of raw material and fossil fuels, fiscal measures authorized by law, the value of the euro compared to the dollar, the inflation rate.

→ Biodiesel

The price of a given fuel can be calculated by summing the elements presented below. Hereunder, the calculation has been done for pure diesel fuel and for a diesel blend containing 5%vol of biodiesel (market situation in April 2008):

[3] Data from magazine "Autobio n°4: ça roule pour la terre", 4 December 2007, p.86-88.
[4] Personal communication with Beirnaert Mark (Sales Support), Scania Belux, Beers B.V, Belgium N.V./S.A., Luxembourg S.A.
[5] Information from the first study day in the framework of the project Interreg IIIA WLL-Agricométhane in Lille, December 20, 2005.
[6] www.elsbett.com

- Base price:
  - Diesel: 0,53 €/l (Federal Public Service - Department of Finance)
  - Biodiesel: 0,90 €/l (www.eners.ch)
- Distribution costs: 0,15 €/l (Federal Public Service - Department of Finance);
- Excises:
  - Pure diesel (B0): 0,32 €/l
  - Biodiesel blended with diesel (min 5% biodiesel B5): 0,30 €/l (Royal Arrest 29/11/07[7])
- VAT 21%.

⇨ **According to this calculation, the final cost amounts to approximately 1.214 €/l or 33,82 €/GJ for diesel and 1.217 €/l or 34,22 €/GJ[8] for B5**

For higher blending percentages, two scenarios are possible and are detailed below[9].

- SCENARIO FORESEEN BY THE LAW "SENSU STRICTO"

The Royal Arrest of 29 November 2007 stipulates that a diesel blend with a FAME (fatty acid methyl ester) content of at least 5%vol is levied a tax of 0.302 €/l. Therefore, if we consider the law sensu stricto, all biodiesel blends (such as B10, B20, B30, B50 and B100) have to be submitted to the same excise rate of 0.302 €/l.

The values in the table below have been calculated based on this assumption:

Table IX: Simulation of the costs implied by the use of biodiesel at different percentages for end users in conventional cars [10]

	Diesel	B5	B10	B20	B30	B50	B100
Total (€/l)	*1,21*	*1,22*	*1,24*	*1,28*	*1,33*	*1,42*	*1,64*
Total (€/GJ)	34,0	34,2	35,0	36,5	38,1	41,3	49,9

- SCENARIO "BUDGETARY NEUTRALITY FOR THE STATE"

7. Arrêté royal du 29 NOVEMBRE 2007 instaurant un mécanisme de diminution du droit d'accise spécial sur certains carburants (M.B. 05-12-2007-12-05)

8 Heating value B5 = 35,56 MJ/l

9 In the calculations, it is assumed that the biofuels are part of the quota of 380.000 m3 of biodiesel attributed to selected Belgian producers and obtain tax reductions.

10 Source: Data obtained from the Royal Arrest of 29 November 2007 and Federal Public Service (Department Finances). Assumption of UCL for base price of biodiesel

A tax advantage for biodiesel is granted by the Belgian government while keeping neutrality for the state budget. The fiscal administration maintains the excise on diesel blended with biodiesel whereas excises of pure diesel are increased in order to ensure the budgetary neutrality for the State.

In this scenario, it is assumed the State keeps the current logic of increasing the excise rate on fossil fuels with the content of biofuel blended to compensate the fiscal incentive. From the table hereunder, it turns out this scenario could be plausible for a blend B10.

Table X: Simulation of excises on diesel and biodiesel blended with diesel for higher blends maintaining the budgetary neutrality[11]

	Oct 2006	**Nov 2006**	**Mar 2007**	**Oct 2007**						
% biodiesel	0	3,37	4,29	5	7	10	20	30	50	100
Heating value blend (MJ/l)	35,7	35,6	35,58	35,56	35,5	35,41	35,14	34,83	34,3	32,9
Legal excises blended with biodiesel (€/l)	*0,318*	*0,317*	*0,317*	*0,317*	*0,316*	*0,315*	*0,312*	*0,310*	*0,305*	*0,292*
Legal excises blended with biodiesel (€/GJ)	8,91	8,91	8,91	8,91	8,91	8,91	8,89	8,91	8,89	8,88
Legal excises diesel (€/l)	*0,318*	*0,328*	*0,331*	*0,333*	*0,340*	*0,351*	*0,391*	*0,443*	*0,610*	*n.a.*
Legal excises diesel (€/GJ)	8,91	9,22	9,31	9,38	9,58	9,90	11,11	12,72	17,78	n.a.

→ **Bio-ethanol**

The price of a given fuel can be calculated by summing the elements presented below. Hereunder, the calculation has been done for pure gasoline fuel and for a gasoline blend containing 7%vol of bio-ethanol (market situation in April 2008):

- Base price:
  - Gasoline: 0,45 €/l (Federal Public Service - Department Finances)
  - Bio-ethanol: 0,55 €/l (www.eners.ch)
- Distribution costs: 0,15 €/l (Federal Public Service - Department Finances)

[11] Source: Data obtained from Federal Public Service (Department Finances)

- Excises (Royal Arrest 29/11/07):
  - Gasoline (E0): 0,62 €/l
  - Gasoline blend containing min 7%vol bio-ethanol: 0,58 €/l
- VAT 21%.

⇨ **According to these calculations, the cost of gasoline amounts to 1,482 €/l or 46,02 €/GJ and a gasoline blend containing 7%vol bio-ethanol to 1,438 €/l or 46,15 €/GJ[12]**

For blends reaching percentages above 7%$_{vol}$ of bio-ethanol, two scenarios are distinguished.

- SCENARIO FORESEEN BY THE LAW "SENSU STRICTO"

The law of 10 June 2006[13] stipulates that a bio-ethanol blend with a content of **at least** 7% (by volume) is levied a tax of 0.58 €/l. Therefore, if we consider the law sensu stricto, all bio-ethanol blends (such as E10, E20, E30, E85) have to be submitted to the same excise rate of 0.58 €/l. It is important to note that the use of ethanol at some percentages involves a supplementary volumetric consumption of fuel because the energy content per litre of ethanol is 1/3 lower compared to gasoline.

Table XI: Simulation of the costs implied by the use of bio-ethanol at different percentages for end users and conventional cars[14]

	Gasoline	E7	E10	E20	E85
Total (€/l)	*1,48*	*1,44*	*1,44*	*1,45*	*1,53*
Total (€/GJ)	46,5	46,2	46,7	48,8	66,8

- SCENARIO "BUDGETARY NEUTRALITY FOR THE STATE"

In this scenario, the costs for higher blends have been calculated assuming budget neutrality for the state. The simulation of excises presented in the table below could be acceptable for a blend E10, but is not realistic for higher blends such as E85.

[12] Heating value E7 = 31,16 MJ/l
[13] Law of 10 June 2006 regarding biofuels (M.B. 16/06/2006)
[14] Source: Data obtained from the Law of 10 June 2006 and Federal Public Service (Department Finances). Assumption of UCL for base price of bio-ethanol

Table XII: Simulation of excises on gasoline and bio-ethanol blended with gasoline for higher blends maintaining the budgetary neutrality

	Mar-2007	**Oct-2007**					
% bio-ethanol	**0**	**7**	**10**	**20**	**30**	**50**	**85**
Heating value blend (MJ/l)	31,9	31,16	30,84	29,78	28,72	26,6	22,89
Legal excises gasoline blended with bio-ethanol (€/l)	*0,592*	*0,579*	*0,574*	*0,555*	*0,537*	*0,500*	*0,435*
Legal excises gasoline blended with bio-ethanol (€/GJ)	18,56	18,59	18,60	18,64	18,69	18,79	19,02
Legal excises gasoline only (€/l)	*0,592*	*0,623*	*0,637*	*0,694*	*0,767*	*1,000*	*2,90*
Legal excises gasoline only (€/GJ)	18,56	19,99	20,66	23,30	26,70	37,58	126,8

2.5.3. Biofuel cost – long term projections

→ Conventional biofuels

The price of pure diesel/gasoline (B0) or blended with conventional biofuels is calculated based on the following elements:

- Base price

- Diesel and gasoline[15]

In this study, the crude oil price assumptions of the International Energy Agency (2008) have served as base for the projections for fossil fuel base prices. These assumptions should not be interpreted as a prediction of stable energy markets; in reality, prices will certainly deviate widely at times from the assumed trends by the IEA. Crude oil import price assumptions are represented in Figure 18. The average crude oil import price expressed in real terms is assumed to average 100 $ per barrel (2007 as base year) over the period 2008-2015 and then to increase in a broadly linear manner to 122$ in 2030. Nominal prices assume inflation rate of 2,3% per year from 2008. In nominal terms, prices double just over 200$ per barrel in 2030.

15 Calculations UCL based on data from the International Energy Agency (2008)

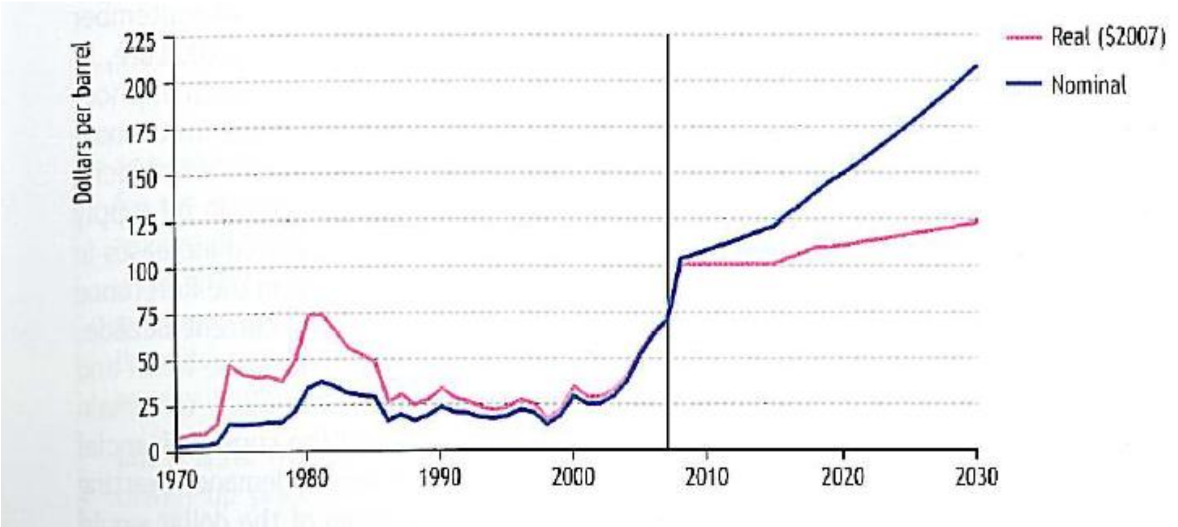


Figure 18 - Average IEA Crude oil import price (annual data)

Assuming a constant exchange rate of 1.3$ for one euro, the following projections in nominal terms have been calculated for diesel and gasoline.

Table XIII: Projection of base prices (nominal) for diesel and gasoline

	Unit	2010	2015	2020	2025	2030
Base price diesel	*€/l*	*0,68*	*0,76*	*0,93*	*1,10*	*1,30*
	€/GJ	18,94	21,17	25,91	30,64	36,21
Base price gasoline	*€/l*	*0,62*	*0,70*	*0,86*	*1,02*	*1,20*
	€/GJ	19,25	21,74	26,71	31,68	37,27

- Base price for biodiesel and bio-ethanol which is calculated as the sum of the raw material costs, the labour costs, the capital costs, the intermediary costs, the logistics and the by-products costs.

Table XIV: Projection of prices (nominal) for biodiesel and bio-ethanol for 2010, 2020 and 2030[16]

	Unit	2010	2015	2020	2025	2030
Base price bio-ethanol	€/l	*0,67*	*0,68*	*0,67*	*0,67*	*0,67*
	€/GJ	31,46	31,92	31,46	31,46	31,46
Base price biodiesel	€/l	*0,88*	*1,06*	*1,13*	*1,19*	*1,25*
	€/GJ	26,83	32,32	34,45	36,28	38,11

16 Source: FAPRI 2009 U.S., International Energy Agency (2008) & Study of ValBiom (2006)

- Distribution costs:

The future distribution costs have been estimated based on the historical evolution of distribution costs between 1999 and 2009[17] and assuming a linear evolution (linear regression).

Based on this data, projections of diesel and biodiesel costs and gasoline and bio-ethanol costs have been simulated. Only the base price and distribution costs were taken into account, so taxes are excluded.

Table XV: Simulation of diesel and biodiesel costs blended at different percentages by 2010, 2020 and 2030 (excl tax & VAT)

2010	**Diesel**	**B5**	**B10**	**B20**	**B30**	**B50**	**B100**
Total (€/l)	*0,84*	*0,85*	*0,86*	*0,88*	*0,90*	*0,94*	*1,04*
Total (€/GJ)	23,4	23,8	24,2	25,0	25,8	27,4	31,7
2020	**Diesel**	**B5**	**B10**	**B20**	**B30**	**B50**	**B100**
Total (€/l)	*1,14*	*1,15*	*1,16*	*1,18*	*1,20*	*1,23*	*1,33*
Total (€/GJ)	31,9	32,3	32,7	33,5	34,3	36,0	40,5
2030	**Diesel**	**B5**	**B10**	**B20**	**B30**	**B50**	**B100**
Total (€/l)	*1,55*	*1,54*	*1,54*	*1,54*	*1,53*	*1,52*	*1,50*
Total (€/GJ)	43,3	43,4	43,5	43,7	43,9	44,4	45,5

Table XVI: Simulation of gasoline and bio-ethanol costs blended at different percentages by 2010, 2020 and 2030 (excl tax & VAT)

2010	**Gasoline**	**E7**	**E10**	**E20**	**E30**	**E50**	**E85**
Total (€/l)	*0,78*	*0,79*	*0,79*	*0,79*	*0,80*	*0,80*	*0,82*
Total (€/GJ)	24,5	25,2	25,5	26,6	27,7	30,2	35,8
2020	**Gasoline**	**E7**	**E10**	**E20**	**E30**	**E50**	**E85**
Total (€/l)	*1,06*	*1,05*	*1,04*	*1,02*	*1,00*	*0,97*	*0,90*
Total (€/GJ)	33,3	33,6	33,8	34,4	35,0	36,3	39,3
2030	**Gasoline**	**E7**	**E10**	**E20**	**E30**	**E50**	**E85**
Total (€/l)	*1,44*	*1,40*	*1,39*	*1,33*	*1,28*	*1,18*	*0,99*
Total (€/GJ)	45,1	45,0	45,0	44,8	44,6	44,2	43,3

17 Source: Federal Public Service (Department Economy SME, Self Employed and Energy)

→ **Ligno-cellulosic biofuels**

Micro-economic cost estimations have been carried out for ligno-cellulose based biofuels. The simulation is based on the IEA "optimistic" and "pessimistic" production cost assumptions for second generation biofuels (IEA, 2009).

Table XVII: Simulation of nominal ligno-cellulosic bio-ethanol prices (€/GJ and €/l) for the end user for 2010, 2020 and 2030 (excluding taxes)

2010	**Gasoline**	**E7**	**E10**	**E20**	**E85**	**E100**
Optimistic (€/GJ)	24,5	24,6	24,7	24,8	25,9	26,3
Optimistic (€/l)	*0,78*	*0,77*	*0,76*	*0,74*	*0,59*	*0,56*
Pessimistic (€/GJ)	24,5	24,8	24,9	25,2	28,1	29,1
Pessimistic (€/l)	*0,78*	*0,77*	*0,77*	*0,75*	*0,64*	*0,62*
2020	**Gasoline**	**E7**	**E10**	**E20**	**E85**	**E100**
Optimistic (€/GJ)	33,3	33,1	33,0	32,7	30,0	29,1
Optimistic (€/l)	*1,06*	*1,03*	*1,02*	*0,97*	*0,69*	*0,62*
Pessimistic (€/GJ)	33,3	33,2	33,2	33,1	32,2	32,0
Pessimistic (€/l)	*1,06*	*1,03*	*1,02*	*0,99*	*0,74*	*0,68*
2030	**Gasoline**	**E7**	**E10**	**E20**	**E85**	**E100**
Optimistic (€/GJ)	45,1	44,5	44,2	43,3	34,8	32,0
Optimistic (€/l)	*1,44*	*1,39*	*1,36*	*1,29*	*0,80*	*0,68*
Pessimistic (€/GJ)	45,1	44,7	44,5	43,8	37,7	35,8
Pessimistic (€/l)	*1,44*	*1,39*	*1,37*	*1,30*	*0,86*	*0,76*

Table XVIII: Simulation of nominal BTL diesel prices(€/l) for the end user for 2010, 2020 and 2030 (excluding taxes & VAT)

2010	**Diesel**	**BTL5**	**BTL10**	**BTL20**	**BTL30**	**BTL100**
Optimistic (€/GJ)	23,4	23,5	23,6	23,9	24,1	25,9
Optimistic (€/l)	*0,84*	*0,84*	*0,84*	*0,85*	*0,85*	*0,89*
Pessimistic (€/GJ))	23,4	23,7	24,0	24,7	25,4	30,3
Pessimistic (€/l)	*0,84*	*0,85*	*0,86*	*0,88*	*0,90*	*1,04*
2020	**Diesel**	**BTL5**	**BTL10**	**BTL20**	**BTL30**	**BTL100**
Optimistic (€/GJ)	31,8	31,6	31,3	30,9	30,4	27,2
Optimistic (€/l)	*1,14*	*1,13*	*1,12*	*1,10*	*1,08*	*0,94*
Pessimistic (€/GJ)	31,8	31,8	31,8	31,7	31,7	31,5
Pessimistic (€/l)	*1,14*	*1,13*	*1,13*	*1,13*	*1,12*	*1,09*
2030	**Diesel**	**BTL5**	**BTL10**	**BTL20**	**BTL30**	**BTL100**
Optimistic (€/GJ)	43,2	42,5	41,8	40,3	38,9	28,4
Optimistic (€/l)	*1,55*	*1,52*	*1,49*	*1,43*	*1,38*	*0,98*
Pessimistic (€/GJ)	43,2	42,7	42,2	41,2	40,2	32,8
Pessimistic (€/l)	*1,55*	*1,53*	*1,50*	*1,46*	*1,42*	*1,13*

It has to be kept in mind that the price projections mentioned in the tables above are probably quite optimistic, even for the values that IEA indicated as pessimistic.
Estimated fuel cost projections for 2010 are certainly not reached currently, and the technology build-up is happening slower than anticipated in studies performed in the last ten years. So it is very likely that there will be delay in the learning curve and cost reduction of 2nd generation biofuels. It is also likely that feedstock prices for 2nd generation biofuels will increase once demand for ligno-cellulose material increases. This will also dampen the cost reduction curve followed by 2nd generation biofuels. The European Renew project estimated the 2020 cost of Fischer-Tropsch biodiesel between 60 and 100€/GJ, which is more than double the IEA estimations. For cellulose based ethanol the figures are somewhat lower (around 45€/GJ), which is still above fossil fuel price projections.So there is still lots of uncertainty and it is most probable that 2^{nd} generation biofuels will still need policy support to be price competitive, even around 2030.

2.5.4. Life cycle cost calculations (LCC)

→ Introduction

A Life Cycle Cost (LCC) model has been developed to assess the cost-efficiency of alternative and conventional vehicles in the existing Belgian fiscal system. The advantage of using a LCC is that, besides taxation, it covers the three most important financial aspects that determine the car purchase decision, namely purchase price, fuel costs and maintenance costs (Mairesse et al., 2008).

LCC analyses have been widely applied to calculate the retail and LCC of hybrid electric vehicles (Lipman and Delucchi, 2006), to assess the cost-efficiency of alternative fuels and drive trains in Thailand (Goedecke et al., 2007), to examine the economic feasibility of hydrogen as an alternative fuel (Lee et al., 2009), to calculate the cost-efficiency of an electric car versus a gasoline-powered car (Werber et al., 2009) and to make a techno-economic comparison of series hybrid, plug-in hybrid, fuel cell and regular cars (van Vliet et al., 2010).

→ **Methodology**

In the framework of the BIOSES project, a LCC spreadsheet model has been developed to analyze the costs of different vehicles on alternative fuels (including biofuels) 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 kilometres (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 (interest rate of 4%).

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, 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) nearly 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 (cc, kW 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 and fuel):

Depreciation costs

Purchase costs of the reference vehicles (and additional equipment such as a particulate matter (PM) filter) are based on automobile retail websites (Autogids, 2010). Vehicles on alternative fuels (LPG, CNG, biofuels) require additional conversion costs to make them fuel compatible. A LPG and CNG retrofit to the reference vehicle amounts up to respectively 2,000 and 2,500 Euros. Vehicles driving on low blends of biofuels (E5, E10, B5, B10) are still compatible to most existing vehicle engines and require no additional costs. Vehicles able to drive on high blends of biodiesel (B30, B100) don't require added costs, but approval is needed from the vehicle manufacturer. Vehicles to drive on high ethanol blends (E20, E85) need dedicated vehicles with surplus costs between 200 and 1,000 Euros (flexi-fuel vehicles) (see chapter 3.5.2).

Electric Vehicles (EVs), like Citroën C-Zero and Nissan Leaf, have a lithium-ion battery package with a limited driving range of 130 km. It has been assumed that at vehicle use of 7 years and an annual mileage of 15,000 km, no battery replacement will take place.

Vehicles depreciate over time. Loss of value due to depreciation is in the first few years of a vehicle's life a very critical cost parameter. Depreciation rates vary not only along the used fuel or drive train, but also according to the brand image, new model pricing, mileage range, comfort and convenience features and vehicle class (Spitzley et al., 2005). In this analysis, the deprecation cost is only based upon the used fuel and/or drive train and excludes other sources of variation amongst makes and types. As a result, depreciation costs of makes with a high resale value, such as German makes, might be overestimated. The applied depreciation rate after 7 years is 79% for petrol and biofuels, 74% for diesel, 82% for LPG, 83% for CNG and 84% for EV (Van Mierlo et al., 2001).

Insurance

Legally, the civil liability premium is obliged in Belgium. This premium is based on three parameters: living area, age, and bonus-malus which reflect the driving experience and accident rate of the main driver. Here, this premium is calculated for a 37-year-old man, living in Brussels with a bonus-malus of 14 (Ethias, 2007).

Vehicle taxes

The LCC of a car also depends on the vehicle taxation system. Here, the Belgian taxation system is considered which consists of three kinds of taxes:

1) *Acquisition taxes*, comprising a value-added tax (VAT) of 21 % on the net purchase price and a vehicle registration tax (VRT), which is currently based on the power of the vehicle (kW). This VRT is levied once-only upon the registration of the vehicle and is further reduced for LPG and CNG vehicles (minus 298 Euros). EVs get the minimum VRT (61,5 Euros). At the acquisition of a new car, vehicles with low CO_2 levels (resp. lower than 105 g/km; and between 105-115 g/km) receive a reduction of their purchase price (resp. 15%; 3%). EVs even get a special reduction of 30% up to 2012. A reduction of 210 Euros (indexed amount 2010) can be obtained when purchasing a diesel vehicle, standard equipped with a PM-filter and with a CO_2 level lower than 130 g/km (FPS Finance, 2010).
2) *Ownership taxes*, consisting of an annual circulation tax (ACT), currently based on the power of the vehicle (CC). LPG and CNG vehicles pay a compensating ACT, whereas for EVs the ACT is reduced to the minimum (69,7 Euros/year).
3) *User taxes*, referring to the VAT (21%) and excises applied on fuels.

Maintenance costs

Maintenance costs include tire costs, costs for small and large maintenance and costs for annual car inspection (Testaankoop, 2007; GOCA, 2010). Tires are assumed to be replaced when a car has driven 50,000 km and depend on the vehicle type and annual mileage. Costs for small and large maintenance are viewed as costs to keep the vehicle operational including oil replacement, revision of brakes etc. These costs depend on the type and make of the vehicle and drive train. Annual car inspection is obliged for all vehicles aged four years or older. Annual car inspection costs comprise a base price of 27,5 Euros, complemented with an environmental inspection (+ 10,5 Euros for ICE, 3,5 Euros for electric propulsion systems) and an additional inspection for LPG and CNG installations (15 Euros) (GOCA, 2010).

Fuel costs

Fuel prices for reference diesel and petrol vehicles are based on maximum fuel prices in Belgium: in 2010 this was on average 1,24 Euros/l for diesel and 1,50 Euros/l for petrol (Petrolfed, 2010). This includes a VAT of 21% and excise duties (0,39 Euros/l for diesel and 0,61 Euros/l for petrol). Untaxed prices are 0,63 Euros/l for both diesel and petrol. LPG and CNG are exempted from excises. Their fuel prices, including VAT, amount up to 0,54 Euros/l LPG and 0,90 Euros/kg CNG (Petrolfed, 2010). Petrol and diesel blended with an amount of biofuels originating from Belgian biofuel plants (with quotum) get a small excise reduction (0,37 Euros/l for biodiesel blends and 0,57 Euros/l for ethanol blends) (FPS Finance, 2006). Untaxed prices of biofuels depend on many factors (raw materials, capital cost, intermediary processing and logistics), as described in chapter 3.5.3. In this analysis, production prices of 0,55 Euros/l for ethanol and 0,90 Euros/l for biodiesel are assumed, based on the ethanol price on the Rotterdam market and biodiesel prices on the German market. The higher the percentage of biofuel in the blend, the higher total fuel costs/l will be.
Electricity from the grid is not taxed as transport fuel. The exact electricity price depends on many factors, such as separate day and night prices. Here, a variable home-use tariff is used of 0,15 €/kWh (including VAT) (Stroomtarieven, 2010).

Total fuel costs also depend on fuel consumption. Where available, the officially reported fuel consumption, based on the new European driving cycle (NEDC) is used. For other vehicles (e.g. biofuels, EVs), no official figures on energy consumption exists as they are not released on the market yet. In this analysis, fuel consumption of biofuel vehicles is based on the energy density of the fuel and the percentage of biofuel in the blend (Goedecke et al., 2007; H2moves.eu, 2007).

Vehicles on E20 and E85 consume respectively 8 and 35% more than the baseline petrol vehicle, whereas B30 and B100 have a smaller surplus consumption (respectively 3 and 10%) with respect to the baseline diesel vehicle as a result of the higher energy density of biodiesel as compared to ethanol (Chiarimonti and Tondi, 2003). For EVs, energy consumption is based on prototypes, communicated by vehicle manufacturers.

→ **Results**

Figure 19 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 Euros (exclusive car), with a cost per person kilometres travelled that varies from 0,18 Euros (supermini) up to 1,16 Euros (exclusive car).

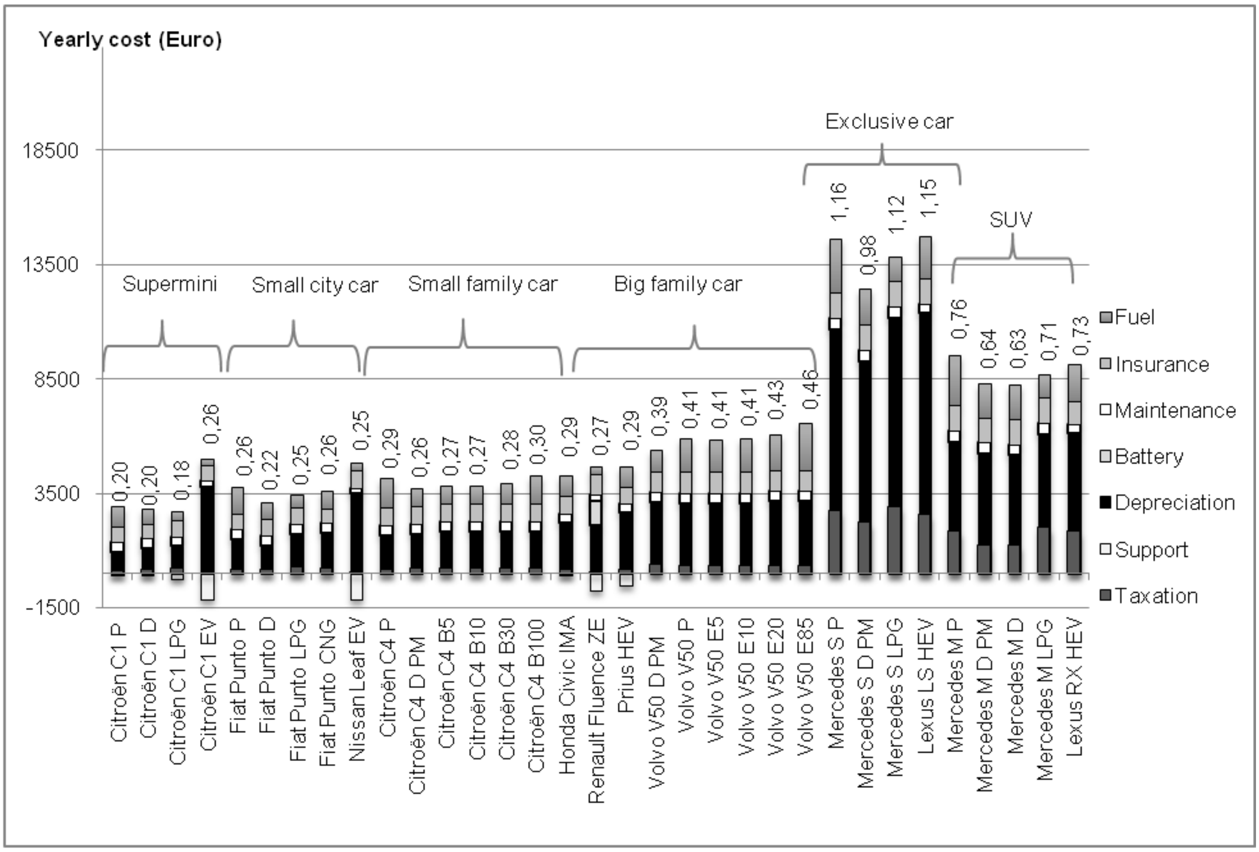


Figure 19: Life cycle costs of conventional and alternative vehicles

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 19 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 P, D). 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 kilometre would be even higher (+ 0,08 Euro/km). The financial attractiveness of EVs can nevertheless increase with battery leasing. For the Renault Fluence, this leasing cost ranges from 100 Euros/month for low mileage users to more than 100 Euros/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 % 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.

→ **Policy implications**

Overall, the LCC analysis illustrates that alternative fuel vehicles and drive trains are at present not beneficial for the end-user from a financial point of view. The fiscal system discourages clean vehicles (e.g. additional ACT for LPG and CNG; fuel taxation of biofuels), whilst incentivizing polluting vehicles (e.g. diesel cars). The existing incentives (exemption of excises for EVs, LPG and CNG; governmental support for low CO_2 emissions and PM-filters) should be complemented with additional policy measures.

A first possibility could consist of a reformation of the current taxation system, based on the environmental performance of vehicles. In the ideal situation, the Ecoscore could be used as a new taxation assessment base, as it takes the total WTW emissions of the vehicle into account. As such, it can add to a technology neutral reformation of the taxation system.

Another possibility could include a fuel tax reformation, in which excise duties for diesel and petrol cars are 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. Ideally, this could be complemented with special fuel tax arrangements for clean vehicles (such as a continuation of the exemption of excises on LPG, CNG and electricity and an adaptation of the excise duties for biofuel vehicles, proportional to the amount of biofuels in the blend).

2.6. BIOFUEL INTRODUCTION SCENARIOS

2.6.1. Defining the scenarios

Based on the technological evolution in vehicle models, the likely biofuel blends on the European markets, and the possible interest of certain end user groups (e.g. public transport, agriculture, etc.), 10 scenarios were defined in the first phase of the project. One was the business-as-usual scenario, basing assumptions on actual policy. Further we developed two scenarios with increased general blending of biodiesel to diesel, ethanol to gasoline and on the longer term BTL to diesel. On top we defined 6 specific high blend scenarios, with a specific focus on certain high biofuel blends: E85, B30, B100, PPO, ED95, bio-methane and a combined scenario of B30, E85 and bio-methane. For a detailed explanation of the different scenarios, we refer to the report "Introduction of biofuels in Belgium - Scenarios for 2010 - 2020 – 2030" [Pelkmans et al, 2008]. For each of the scenarios indicative calculations were performed to check which biofuel share would be reached with these scenarios by 2020 and 2030.

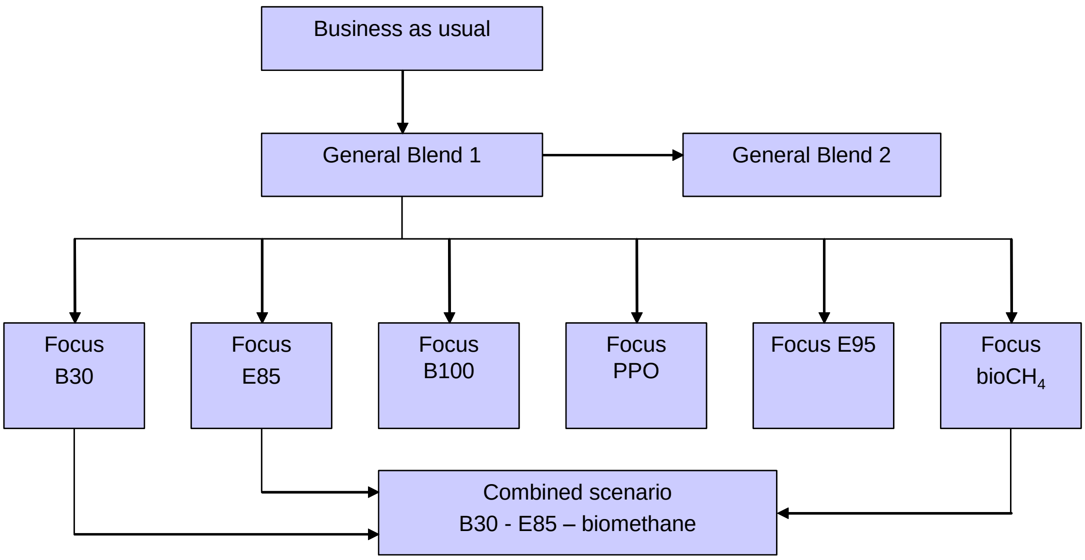


Figure 20: overview of the 10 scenarios considered in BIOSES

In the course of the project it became clear that a distinction needed to be made in the baseline transport scenario in which biofuels are implemented. Future scenarios for road transport can be divided into two main basic paths: a *baseline scenario* and an *energy savings scenario*.

The baseline scenario takes into account the impact of currently (planned and budgeted) policy measures to assess the situation in the future. The energy savings scenario comprises a more enforced/advanced policy and takes into account European medium long period targets (e.g. 20-20-20 targets on energy and climate). Information and assumptions on both scenarios can be found in VMM (2009) where the 'reference case' (MIRA-REF) and the 'Europe case' (MIRA-EUR) are described in more detail. Based on these two scenarios and their projections on technological evolutions and activities, the biofuel scenarios for road transport were developed, focusing on the introduction of biofuels in the transport system. In essence, each scenario can be characterized by information on the following three aspects:

- the transport activity
- technological specifications
- the amount of biofuels (blends).

In Table XIX an overview is presented for all the scenarios used for the final calculations of overall transport energy and emissions. The table provides information on the underlying assumptions for each scenario and provides insights into the differences and similarities between the different scenarios. For the historic 'scenario' information from the 'existing' situation was used, meaning that information on kilometres driven, existing technology and biofuel blends were applied (e.g. based on information from organizations like the "FPS Mobility and Transport" and the "Vehicle Registration Service DIV"), to calculate the energy consumption and emissions.
For the other scenarios Table XIX presents which information source was mainly used for the topics "transport activity", "technology" and "biofuels". MIRA-REF* and MIRA-EUR* are based on the original Reference scenario (MIRA-REF) and Europe scenario (MIRA-EUR) that were developed for Flanders, but these scenarios were updated (marked by *) for the BIOSES project (e.g. introduction of Euro VI heavy duty vehicles and ACEA legislation; update of biofuel blends). Information on the biofuel-blends is presented in separate tables.

In Table XX the volume percentages of biofuels used in MIRA-REF* are provided.

In Table XXI the volume percentages of the MIRA-EUR* are presented. Further, Table XXII provides information about the percentage of second generation biodiesel in the MIRA-EUR* scenario. Blends for FAME (Fatty Acidy Methyl Esters), HVO (Hydrotreated Vegetable Oil) and BTL (Biomass to Liquid) are also presented.

Table XIX. Overview of the different scenarios analyzed in the BIOSES project

Scenarios	**Transport activity**	**Technology**	**Biofuels**
HISTORIC	Existing	Existing	Existing
BAS0	MIRA-REF	MIRA-REF*	No biofuels
BAS5	MIRA-REF	MIRA-REF*	MIRA-REF*
BAS10	MIRA-REF	MIRA-REF*	MIRA-EUR*
BAS10_biogas	MIRA-REF	MIRA-REF* + biogas	MIRA-EUR*
BAS10_flexfuel	MIRA-REF	MIRA-REF* + flexfuel	MIRA-EUR* + E70
BAS10_combi	MIRA-REF	MIRA-REF* + biogas + flexfuel	MIRA-EUR* + E70
ES0	MIRA-EUR	MIRA-EUR*	No biofuels
ES5	MIRA-EUR	MIRA-EUR*	MIRA-REF*
ES10	MIRA-EUR	MIRA-EUR*	MIRA-EUR*
ES10_biogas	MIRA-EUR	MIRA-EUR* + biogas	MIRA-EUR*
ES10_flexfuel	MIRA-EUR	MIRA-EUR* + flexfuel	MIRA-EUR* + E70
ES10_combi	MIRA-EUR	MIRA-EUR* + biogas + flexfuel	MIRA-EUR* + E70

Table XX. Biofuel blends (volume percentages) used in MIRA-REF.*

Vol%	**2006**	**2007**	**2008**	**2010**	**2015-2030**
Biodiesel	0.00	1.39	1.39	4.00	5.00
Bio-ethanol	0.00	1.24	1.24	4.00	5.00

Table XXI. Biofuel blends (volume percentages) used in MIRA-EUR.*

Vol%	**2006**	**2007**	**2008**	**2010**	**2015**	**2020**	**2025**	**2030**
Biodiesel	0.00	1.39	1.39	4.00	7.00	9.00	10.00	12.00
Bio-ethanol	0.00	1.24	1.24	4.00	6.25	9.50	10.00	10.00

Table XXII. Distribution of first and second generation biodiesel in MIRA-EUR.*

Vol%	**2006**	**2007**	**2008**	**2010**	**2015**	**2020**	**2025**	**2030**
FAME	0.00	1.39	1.39	4.00	7.00	7.00	7.00	7.00
HVO	0.00	0.00	0.00	0.00	0.00	1.50	2.00	2.00
BTL	0.00	0.00	0.00	0.00	0.00	0.50	1.00	3.00

In the following sections the most ‘relevant’ scenarios for further analysis will be described more thoroughly. Hereby we focus on the ‘worst case scenario ‘ (baseline without any biofuels), and the energy savings variants since these represent the more advanced scenarios. Methods and assumptions will be described. Information on the other scenarios can be found in the report on Task 4.3, which is available on the BIOSES website.

→ **BAS0: "BASELINE scenario without biofuels".**

In this scenario the prognoses on transport activity and technological specifications are based on the trends from the MIRA-reference scenario (MIRA-REF) in Flanders (VMM, 2009). This scenario presents the impact of currently active policy measures and policy measures that are confirmed to be performed in the future. The MIRA-REF scenario described in VMM (2009) was updated based on current insights and legislation (e.g. introduction of Euro VI heavy duty vehicles and ACEA legislation). Therefore we refer to this scenario as "MIRA-REF*".

Concerning the biofuels, the BAS0 scenario includes no biofuels in the future. This means that until 2008 historic biofuel percentages will be taken into account, but for the future biofuels will be excluded from all the motor fuels. This method assures to study the impact of the biofuels (versus no biofuels).

→ **ES0: "ENERGY SAVINGS scenario without biofuels".**

In this scenario the prognoses on transport activity and technological specifications are based on the trends from MIRA-EUR in Flanders. This Europe-scenario departs from the package of policy measures and policy tools to reach the 20-20-20 goals for energy and climate from the European commission. For the period 2020-2030 we assume that similar emission reduction efforts will be maintained. The MIRA-EUR scenario described in VMM (2009) was updated based on current insights and legislation (e.g. the ACEA legislation). Therefore we refer to this scenario as "MIRA-EUR*".

Concerning the biofuels, the ES0 scenario includes no addition of biofuels in the future.

→ **ES5:"ENERGY SAVINGS scenario with 5% biofuels".**

In this scenario the prognoses on transport activity and technological specifications are the same as in ES0, based on the trends from MIRA-EUR*.

The trend for the use of biofuels is based on the assumptions made in MIRA-REF* that takes also into account the Federal legislation on biofuels of July 2009 (Belgisch Staatsblad, 2009). Hereby we assume that, from 2013, an obligated amount of 5% biodiesel needs to be added to diesel, and 5% of bio-ethanol needs to be added to the petrol (both percentages on a volume basis).

→ **ES10: "ENERGY SAVINGS scenario with 10% biofuels".**

In this scenario the prognoses on transport activity and technological specifications are the same as in ES0, based on the trends from MIRA-EUR*.

Concerning the addition of biofuels, this scenario will include an increased general blending of biofuels in the future compared to the blends in ES5. The blend percentages in the future are based on the assumptions made in the Europe scenario of MIRA (MIRA-EUR) although some adjustments were made based on new insights and legislation (Belgisch Staatsblad, 2009). Until 2010 the biofuel blends will be the same as in ES5, but then this scenario will assume an increased amount of biofuels (also an introduction of second generation biofuels from 2015-2020). In 2025 blend percentages will reach 10 vol%, both for bio-ethanol and biodiesel. In 2030 the percentage of biodiesel will even reach 12 vol% (see Table XXI and Table XXII), part of it through HVO and BTL.

→ **ES10_biogas: "ENERGY SAVINGS scenario with support of natural gas in niche markets, with 10% biofuels".**

In this scenario the prognoses on transport activity are the same as in ES0, based on the trends from MIRA-EUR*. Concerning the technological specifications, the trends from MIRA-EUR* were followed except for the amount of CNG buses and CNG light duty vehicles (LDV). ES10_biogas takes into account an increased amount of CNG vehicles in both buses (De Lijn/TEC/MIVB) and LDV. In Table XXIII the introduction percentages are presented. Both for buses and LDV, the 'extra' amount of CNG vehicles is achieved by lowering the amount of diesel vehicles. Changes were only applied in the amount of vehicles that newly enter the vehicle market. Further we assume that all CNG buses and LDV will run on biogas.

Table XXIII. Introduction of CNG vehicles for buses and LDV in the ES10_biogas scenario. The percentages represent the amount of CNG buses/LDV in the new vehicle fleet of buses/LDV.

	% of new buses on CNG	% of new LDV on CNG
2015	5%	4%
2020	10%	7%
2025	15%	9%
2030	15%	10%

Concerning the amount of other biofuels, the blend percentages from ES10 were used.

→ **ES10_flexfuel: "ENERGY SAVINGS scenario with support of flexfuel vehicles, with 10% biofuels".**

In this scenario the prognoses on transport activity are the same as in ES0, based on the trends from MIRA-EUR*. Concerning the technological specifications, also the trends from MIRA-EUR* were followed, except for the introduction of flexfuel vehicles.

Concerning the introduction of vehicle technologies, this scenario starts from ES10 but takes into account an increased amount of flexfuel cars. The amount of flexfuel vehicles is partly achieved by increasing the amount of flexfuel cars in the new petrol cars and partly by lowering the amount of diesel cars in the new vehicle fleet. Table XXIV presents the percentage of new petrol cars that is considered to be flexfuel in this scenario and the percentage of flexfuel vehicles that is achieved by lowering the amount of diesel cars in the new vehicle fleet.

Table XXIV. Introduction of flexfuel vehicles in the ES10_flexfuel scenario.

	% of the new petrol cars that is flexfuel[a]	**% of the flexfuel vehicles that comes from diesel cars[b]**
2015	5%	0%
2020	50%	5%
2025	100%	7.5%
2030	100%	10%

[a]The first column represents the percentage of flexfuel cars in the new petrol cars.
[b]The second column represents the percentage of flexfuel vehicles that is achieved by lowering the amount of new diesel cars.

Concerning the amount of biofuels in this flexfuel scenario, for biodiesel we use the same blends as used in ES10. The blends of bio-ethanol will however be different as the flexfuel vehicles are able to manage blends up to E85. Therefore the flexfuel-scenario will work with two petrol pumps: one pump with the blend percentage from ES10 and the other one with on average 70 vol% blend where flexfuel vehicles can refuel. In Table XXV we present the % of all petrol cars that will use pump 1 (E85). The rest of the petrol cars will automatically refuel at pump 2 that contains the blend from ES10. Note that we use 70% instead of 85% since we take into account that in practice the E85 pumps will on average 'only' contain 70%vol ethanol.

Table XXV. Relative amount of (all) petrol cars that will refuel on the E85-pump. The rest of the petrol cars will automatically refuel on the pump containing the blends from ES10.

	% of petrol cars that refuel on E85
2015	0%
2020	11.9%
2025	48.3%
2030	73.4%

→ **ES10_combi: ENERGY SAVINGS scenario combining the assumptions from ES10_biogas and ES10_flexfuel".**

This scenario combines the input information from two other scenarios: ES10_biogas and ES10_flexfuel. This combination is possible since both scenarios focus on different vehicle types (buses and LDV in ES10_biogas compared to cars in ES10_flexfuel). This means that the scenario descriptions mentioned at ES10_biogas and ES10_flexfuel can be combined in order to describe the ES10_combi scenario.

Concerning the biofuel blends, the blend percentages from the ES10_flexfuel scenario will be applicable due to the presence of flexfuel vehicles. This means that petrol cars will partly refuel on E85, but other vehicles (both light and heavy duty) will refuel on the 'normal' ES10 blend.

2.6.2. Energy consumption prognoses

Energy consumption is calculated for the whole transport sector (road, rail, inland navigation and off-road vehicles/machinery) for the two 'main' scenarios: the baseline scenario and the energy savings scenario. Details on the non-road calculations can be found in the report on Task 4.3. Results for BAS0 (representing the baseline scenario) and ES0 (representing the energy savings scenario) are presented for all transport modes (see Figure 21 and Figure 22). Results from the historic situation are presented in order to observe 'trends' in energy consumption over time. Results for BAS5, BAS10, ES5 and ES10 will not be discussed in this section on energy consumption since changing the blend percentage of biofuels does not significantly impact the energy consumption. Further, for road transport six extra scenarios were analyzed. Energy consumption results (per fuel type) for the most relevant scenarios are also presented.

Figure 21 and Figure 22 provide insights into the share of road transport in the total picture (for both scenarios) and the evolution over time. Energy consumption values for all the non-road modes (rail, inland navigation and agriculture) are presented in one category: “non-road”. In Figure 21 the total energy consumption for all transport modes is presented for the baseline situation. Except from a small decrease in the energy consumption around the year 2008, energy consumption will tend to increase over time. In contrast to the baseline scenario, energy consumption is expected to decrease after 2015 in the energy savings scenario (see Figure 22). This decrease in energy consumption is partly due to a smaller increase in the amount of road transport kilometres (compared to BAS-scenarios) since road pricing is included in the ES-scenarios. Further, technological improvements such as increased hybridization, will also lead to lower energy consumption factors. The share of heavy duty freight transport in the total energy consumption will increase in the period 2015-2020 since the energy consumption of cars will decrease to a larger extent compared to heavy duty values.

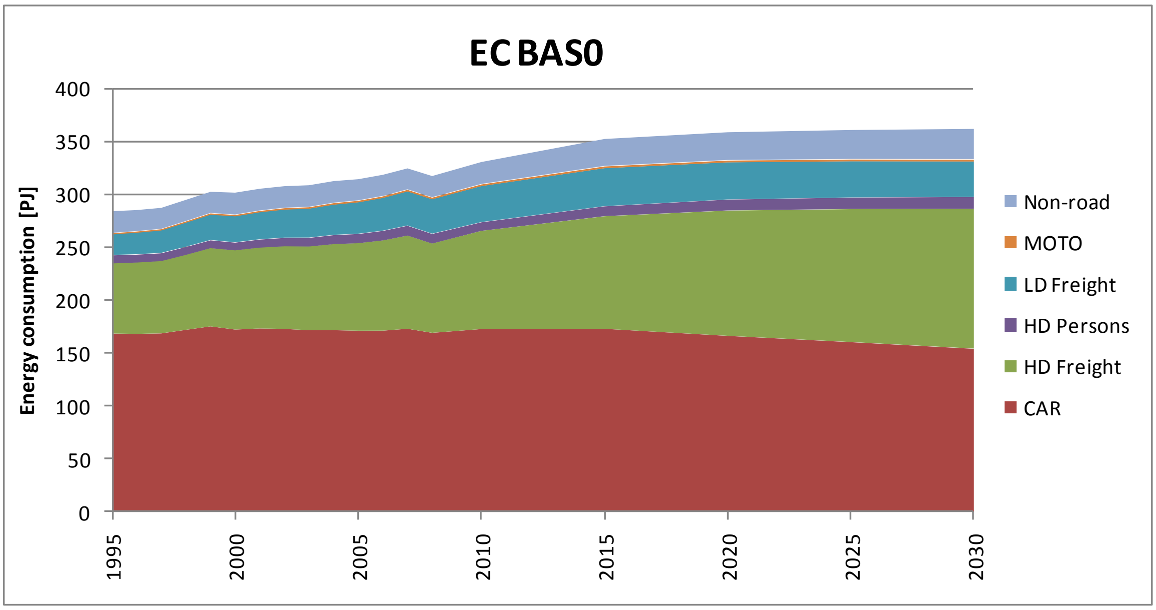


Figure 21. Total energy consumption for all transport modes (BAS0).

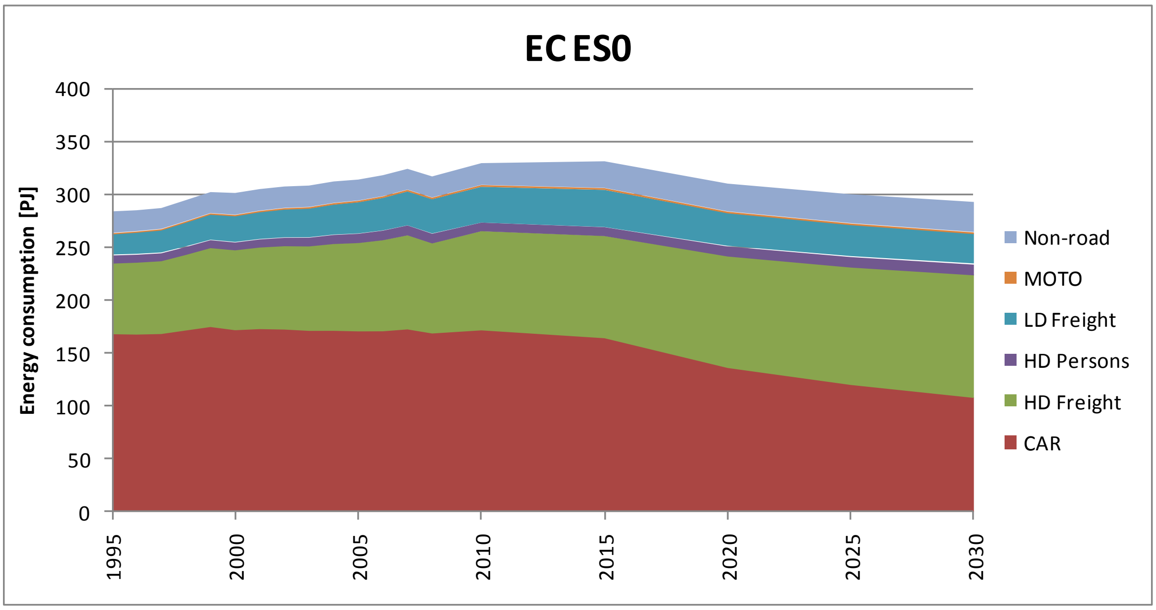


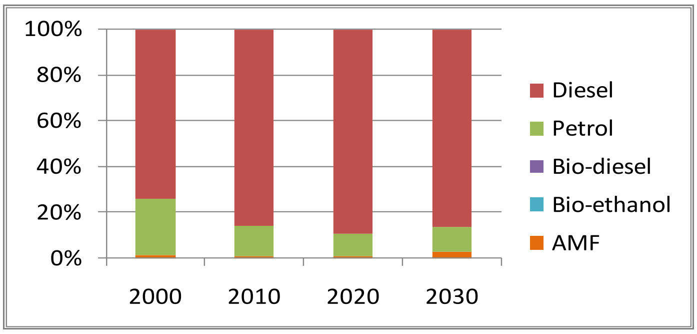
Figure 22. Total energy consumption for all transport modes (ES0).

Figure 23 presents the energy consumption per fuel type for the different scenarios for road transport. These graphs clearly show the variations in the share of biofuels over the different scenarios. The fuel types that are considered are: (fossil) diesel, (fossil) petrol, biodiesel, bio-ethanol and alternative motor fuels (AMF). The AMF-category includes the following fuel types: electric, H2, CNG (including biogas) and LPG. Results for the year 2000 are presented only in BAS0 by means of comparison. In the year 2000 approximately 75% of energy consumption was contributed to diesel, the remaining mainly to petrol fuel.

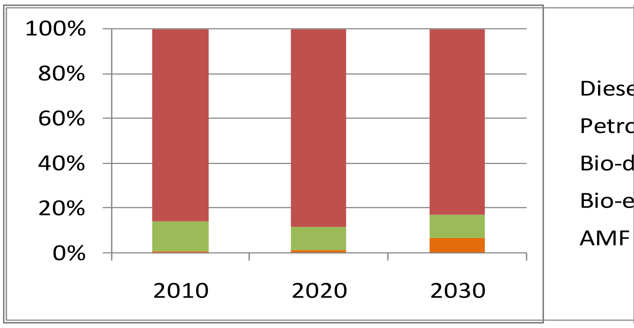
In BAS0 no biofuels are included in the future years. Fossil fuels will therefore stay responsible for more than 95% of the energy consumption in 2030. Fossil diesel will account for more than 80% of the total energy consumption by road transport. As the energy savings scenario includes an increased introduction of alternative fuel technologies such as PHEV (plug-in hybrid electric vehicles) and EV (electric vehicles) compared to the baseline scenario, the share of AMF in the energy consumptions is already significant in ES0. In ES5 we can clearly see a significant and increasing share of biodiesel in the total energy consumption. The share of bio-ethanol stays however very small. In ES10 the share of biodiesel in the total energy figure can be clearly distinguished. In 2030 the relative amount of biodiesel will reach approximately 9% of the total energy consumption. The share of bio-ethanol is still small and will not exceed 1% in 2030.

Due to the higher introduction rate of vehicles on biogas in ES10_biogas, the energy consumption by AMF reaches almost 7% in 2030. In ES10_flexfuel and ES10_combi the distribution of energy consumption over fuel types is approximately the same: in 2030 slightly less than 80% of the energy consumption will be caused by fossil fuels. The largest share of this is still caused by fossil diesel. Biofuels (biodiesel and bio-ethanol) are responsible for approximately 14% of the energy consumption.

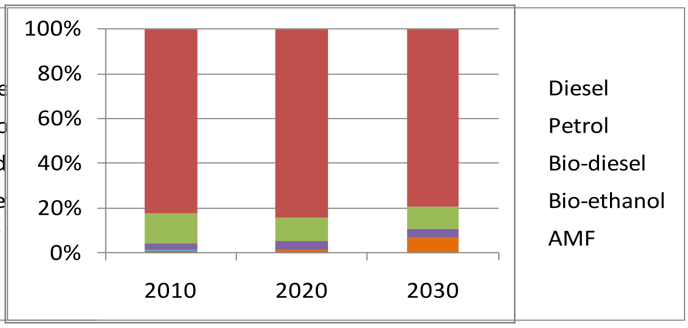
Energy consumption results per vehicle type can be found in the Report on Task 4.3.



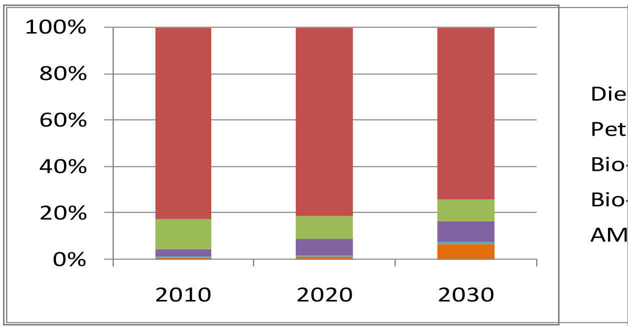
BAS0



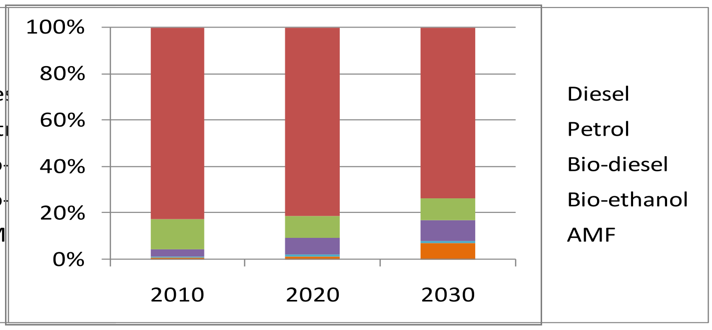
ES0



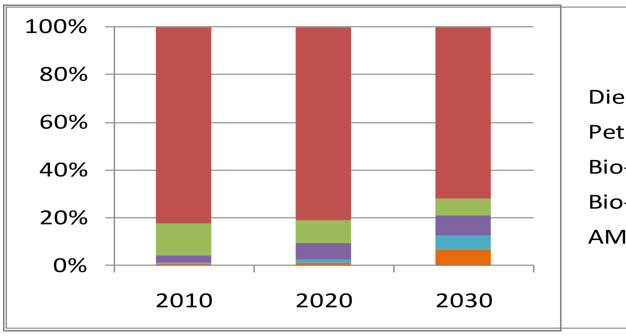
ES5



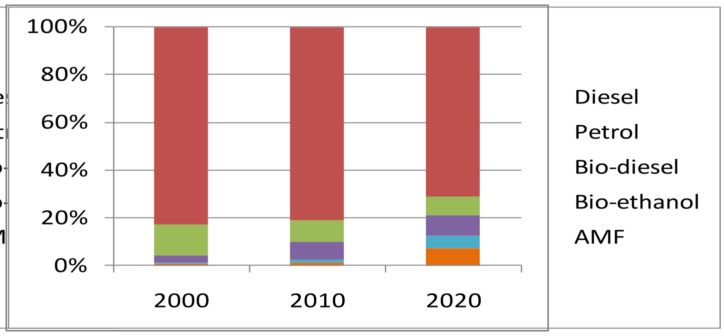
ES10



ES10_biogas



ES10_flexfuel



ES10_combi

Figure 23. Distribution of the energy consumption over fuel types in the different scenarios

2.7. Overall road transport emissions for different scenarios

Emissions for all developed road transport scenarios (see section 2.6.1) were analyzed. Results for the most relevant scenarios and pollutants will be presented in this section, the applied calculation methods are also briefly described. More results can be found in the dedicated report, available on the BIOSES website.

2.7.1. Calculating direct and indirect emissions for road transport

Direct emissions:

VITO's 'E-Motion Road' model was used to assess the impact of different fleet compositions and biofuel blends on the direct emissions from road transport. Hereby the model considers biofuels (biodiesel, bio-ethanol and biogas) to be carbon neutral for transport. More information on this model can be found in the dedicated report on Task 4.3.

Indirect emissions:

Indirect road transport emissions are emissions released during the production and transport of the different energy carriers used for road vehicles. To assess these indirect emissions we updated and extended the indirect emission module of VITO's E-motion model. This module includes the following pollutants: CO_2-eq. (CO_2, CH_4, N_2O), NO_x, PM, NMVOC and SO_2. The basic formula is a multiplication of the energy consumption of road vehicles (MJ per energy carrier) by specific emission factors per energy carrier (g/MJ). We aspired to consider a variation into indirect emission factors over the time period 2010-2030.

For greenhouse gases we applied JEC (2008) as the main reference for most energy carriers. However, for electricity we leaned on VITO's expertise (Lodewijks et al., 2010). For other pollutants we consulted den Boer et al. (2008) for conventional fuels, Boureima et al. (2009) for biofuels and biogas and Lodewijks et al. (2009, 2010) for electricity. Gaps were completed with figures from SUSATRANS (De Vlieger et al., 2005).

Table XXVI presents an overview of the evolution of the emission factors related to the production and transport of the different energy carriers for means of transport. The table also mentions the raw materials energy carriers are made of. For some this is a result of a mix of various materials. The typical mix for biofuels, biogas, electricity and hydrogen in Belgium can be found in the report on Task 4.3 in Annex.

Table XXVI: Evolution of emissions factors related to the production and transport of energy carriers for transport in Belgium.

Energy carrier	Source	Unit	CO_2eq 2010	CO_2eq 2020	CO_2eq 2030	NO_x 2010	NO_x 2020	NO_x 2030	PM 2010	PM 2020	PM 2030	NMVOC 2010	NMVOC 2020	NMVOC 2030	SO_2 2010	SO_2 2020	SO_2 2030
diesel	crude oil	g/MJ	14.5	16.0	17.5	0.021	0.018	0.018	0.002	0.002	0.002	0.088	0.088	0.088	0.053	0.050	0.050
petrol	crude oil	g/MJ	12.9	14.6	16.4	0.026	0.022	0.022	0.003	0.003	0.003	0.211	0.211	0.211	0.063	0.059	0.059
LPG	crude oil	g/MJ	8.1	8.5	8.9	0.020	0.017	0.017	0.002	0.002	0.002	0.057	0.057	0.057	0.030	0.028	0.028
kerosene	crude oil	g/MJ	14.2	16.1	18.1	0.299	0.256	0.256	0.002	0.002	0.002	0.211	0.211	0.211	0.052	0.049	0.049
diesel oil	crude oil	g/MJ	11.5	12.7	13.9	0.017	0.014	0.014	0.002	0.002	0.002	0.088	0.088	0.088	0.043	0.040	0.040
HFO	crude oil	g/MJ	10.1	11.3	12.6	0.017	0.014	0.014	0.002	0.002	0.002	0.088	0.088	0.088	0.043	0.040	0.040
biodiesel	mix	g/MJ	44.6	35.3	32.8	0.143	0.090	0.036	0.033	0.021	0.008	0.018	0.018	0.018	0.080	0.050	0.020
FT-diesel	farmed wood	g/MJ		6.9	6.9	0.101	0.063	0.025	0.021	0.013	0.005	0.027	0.027	0.027	0.043	0.027	0.011
bio-ethanol	mix	g/MJ	40.8	33.9	27.0	0.178	0.111	0.044	0.192	0.120	0.048	0.023	0.023	0.023	0.087	0.054	0.022
CNG	natural gas	g/MJ	12.6	15.0	17.4	0.011	0.011	0.011	0.001	0.001	0.001	0.028	0.028	0.028	0.017	0.017	0.017
biogas	mix	g/MJ	20.5	18.6	16.7	0.022	0.014	0.005	0.005	0.003	0.001	0.005	0.005	0.005	0.012	0.008	0.003
electricity	mix	g/MJ	85.0	97.0	109.0	0.079	0.060	0.045	0.001	0.001	0.003	0.004	0.004	0.004	0.028	0.021	0.019
hydrogen	mix	g/MJ	112.8	139.0	126.1	0.078	0.084	0.090	0.003	0.005	0.007	0.039	0.111	0.183	0.020	0.022	0.023

For conventional fuels and CNG we expected an increase of the emission factors for indirect emissions for greenhouse gases. The epoch of easy accessible and cheap crude oil and natural gas is coming to an end. In addition, it becomes more and more difficult for the production to follow the demand. Therefore, more unconventional and hardly reachable sources of oil have to be exploited, such as crude oil of the polar region, ultra-heavy crude, tar sand (Canada) and synthetic fuels from natural gas and coal.

For biofuels and biogas we expected both greenhouse gases and air pollutants have a potential to decrease due to the use of more efficient and cleaner tractors and transport, a reduced use of synthetic fertilizers and the further optimisation of the production processes of the energy carriers.

For electricity the increase in greenhouse gas emission factors is due to the hypothesis that nuclear power plants are fading out gradually between 2015 and 2025 (Lodewijks, et al., 2009).

2.7.2. Emission results

Direct, indirect and total emissions results are presented for the following scenarios: BAS0, ES0, ES5, ES10, ES10_biogas, ES10_flexfuel and ES10_combi; and the following pollutants: CO_2, NO_x and $PM_{2.5}$.

In Figure 24 until Figure 26 the CO_2 emissions from road transport are presented for the different scenarios on three different time periods: 2010, 2020 and 2030. The indirect emissions of CO_2 do not influence the scenario patterns significantly, direct CO_2 emissions will therefore account for the largest part of the total emissions. In 2010 the highest total emission values of CO_2 occur in BAS0 and ES0. This can be explained by the fact that these scenarios do not include biofuels whereas the other scenarios include at least a small percentage of biofuels (due to the fact CO_2 exhaust emissions are considered to be CO_2 neutral for transport). Results for the future show that direct emissions in the baseline scenarios will first increase in 2020 after which they will decrease in 2030 due technological evolutions in the vehicle fleet that can compensate for the increasing amount of vehicle kilometres. Due to the strong increase of the indirect CO_2 emissions (indirect emissions of fossil fuels will increase strongly over time), total CO_2 emissions will however increase in BAS0 until 2030. The energy savings scenarios, that imply even higher introduction rates for alternative motor fuels and vehicle technologies, will result in much lower CO_2 emissions.

In 2020 and 2030 the highest total CO_2 emissions occur in BAS0 whereas ES10_combi results present the lowest CO_2 emission values. Further, we notice that the biogas scenario has only minor impacts on the CO_2 emissions since only buses and LDV are concerned here. The results for the flexfuel and combi scenario are therefore almost the same. The encouraging of flexfuel cars (that use bioblends up to 85 vol%) will have a significant impact on the reduction of CO_2 emissions.

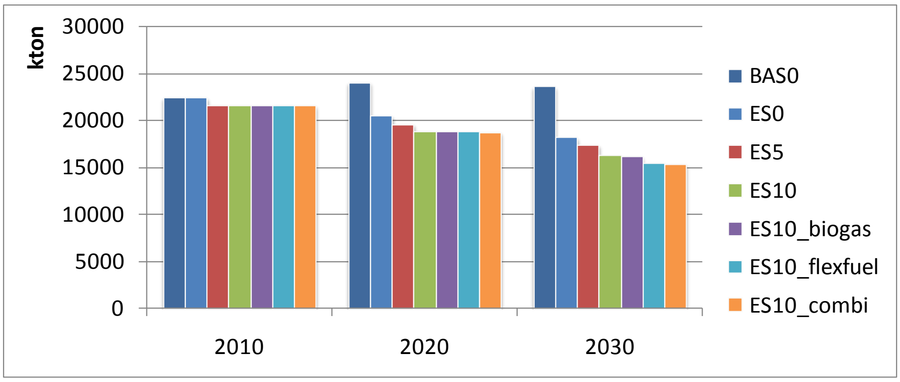


Figure 24. Direct emissions from road transport –results for CO_2.

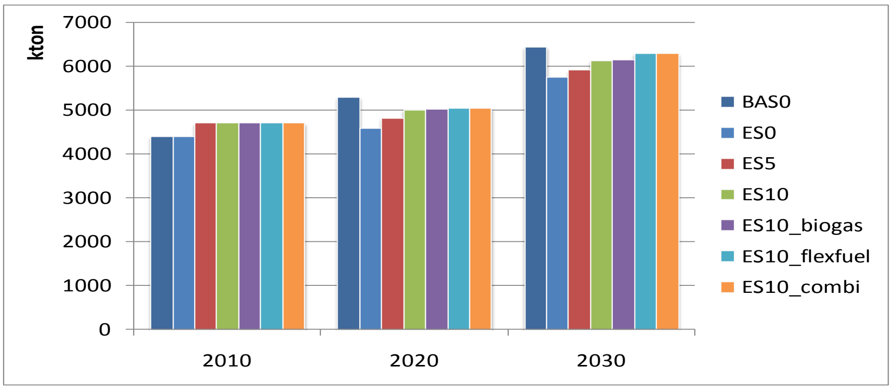


Figure 25. Indirect emissions from road transport –results for CO_2.

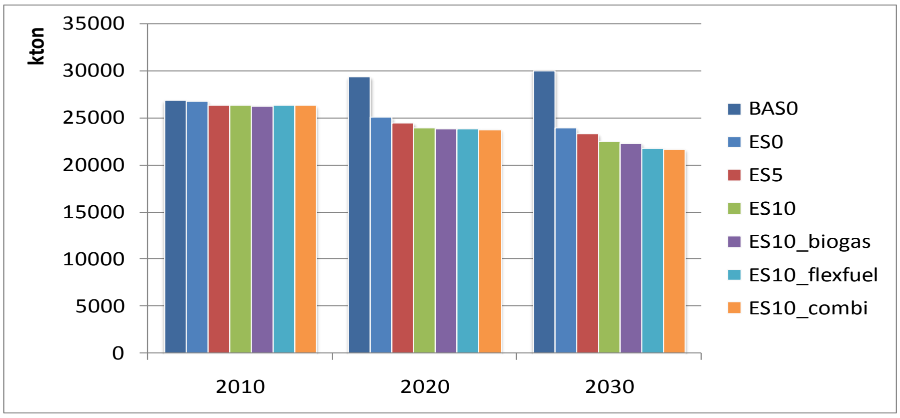


Figure 26. Total emissions from road transport –results for CO_2.

The results for NO_x are presented in Figure 27 until Figure 29. Figure 27 clearly shows the impact of the 'regular' policy measures on the direct emissions of NO_x. Both in the baseline scenarios as in the energy savings scenario significant reductions in NO_x emissions are present. This is mainly due to the replacement of older vehicles by vehicles of a younger generation. Due to more enforced policy measures in the ES-scenarios, NO_x emissions will be slightly lower than the baseline results. Indirect emissions have no significantly impact on the total emission results for NO_x.

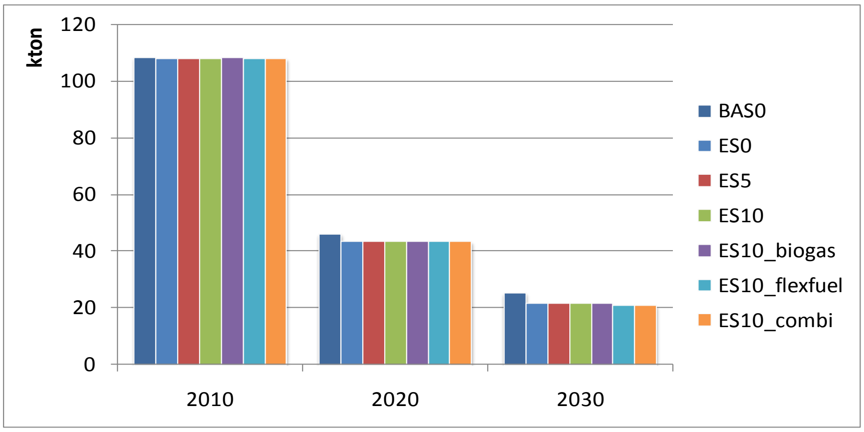


Figure 27. Direct emissions from road transport –results for NO_x.

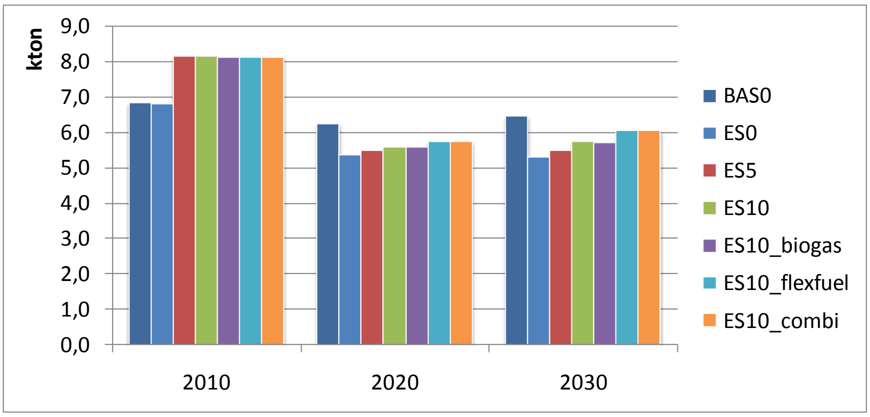


Figure 28. Indirect emissions from road transport –results for NO_x.

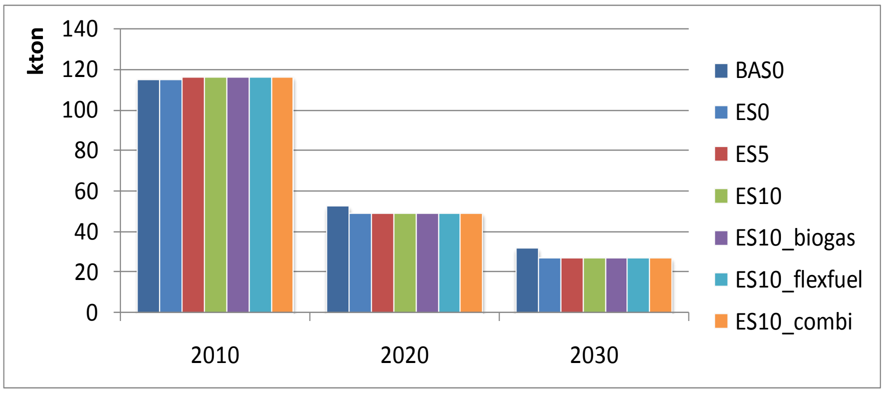


Figure 29. Total emissions from road transport –results for NO_x.

Results for $PM_{2.5}$ (exhaust) are presented in Figure 30 until Figure 32. Direct emissions of $PM_{2.5}$ decrease significantly from 2010 until 2030 for all the scenarios due to technological improvements in the vehicle fleet. Differences between the baseline and the energy savings scenarios are small. In the indirect emission results, the highest values are present in the ES10_flexfuel and ES10_combi scenario. Moreover, these indirect emissions are in the same order of magnitude as the direct emissions, resulting in the highest total $PM_{2.5}$ emissions in these two scenarios.

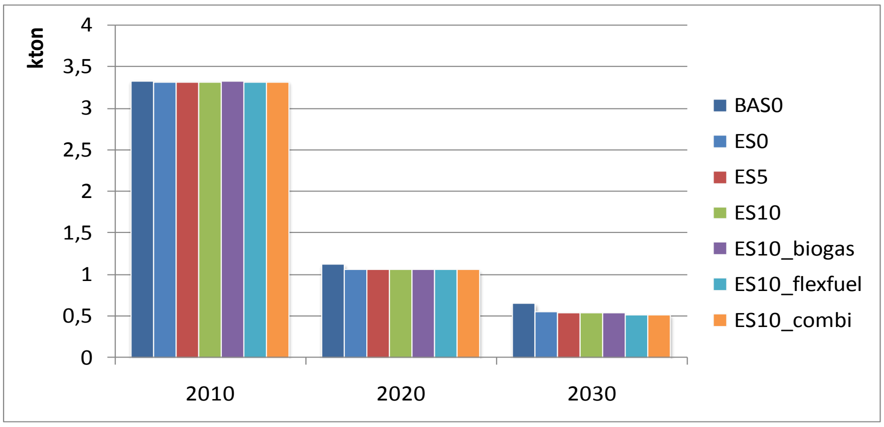


Figure 30. Direct emissions from road transport –results for $PM_{2.5}$.

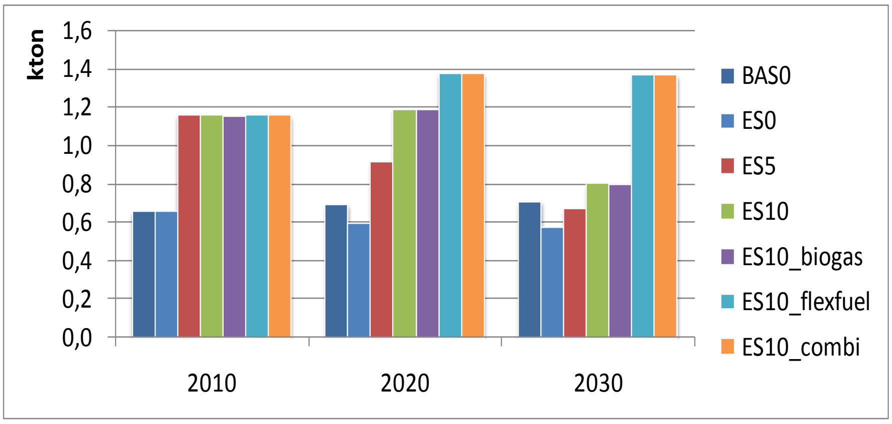


Figure 31. Indirect emissions from road transport –results for $PM_{2.5}$.

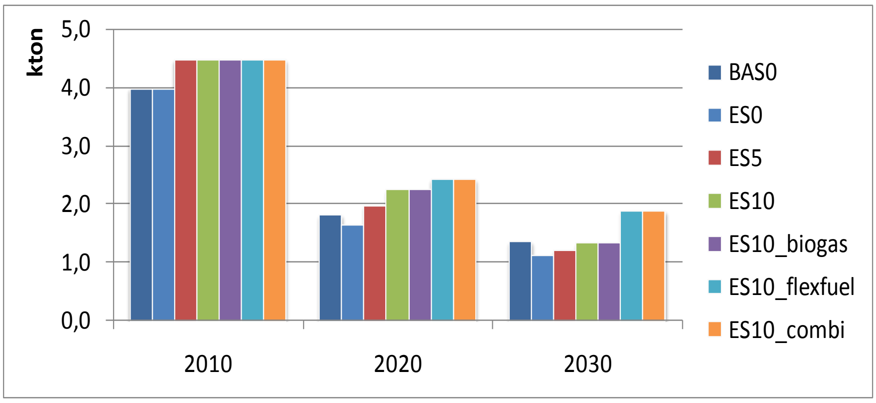


Figure 32. Total emissions from road transport –results for $PM_{2.5}$.

2.8. MACRO-ECONOMIC MECHANISMS

2.8.1. Introduction

In order to design appropriate policies, it is important to capture the dynamics that determine the biofuel market. In the framework of the BIOSES project, a system dynamics model has been developed to gain insight in the long-term dynamic behaviour of biodiesel over time.

2.8.2. Methodology

The system dynamics approach, founded by J.W. Forrester in 1958, is a good method to understand the behaviour of a complex system over time. The basis of the method is that the structure of any system is as important in determining its behaviour as its constituting elements. The biofuel market is modelled as an "open" system since it is influenced by external and exogenous events and driving forces and not by its endogenous past behaviour ("closed" system). The difficulty in modelling this "open" system lays in the inclusion or exclusion of elements and interactions. On the one hand, all important or potentially important elements should be included in order to have an adequate model of the real-world. On the other hand, it is impossible and undesirable to model the whole world. So, it is important to investigate which elements are part of the system (endogenous variables) and which elements (could) seriously impact the system, but are not influenced by the system (exogenous variables). All other elements will be left out.
System Dynamics deals with internal (positive or negative) feedback loops, stocks and flows, time delays and nonlinearities. These elements help describing the dynamic, long term, non-linear behaviour of aggregated social systems (Pruyt, 2007).

The SD modelling process consists of 6 steps (see Figure 33).

The *first step* is the problem definition which explains the aim of the model and the time horizon for simulation. The *second step* covers the system conceptualization in which the mental model is set up and feedback loops are analyzed. As such, it will provide decision makers a better understanding of the relationships between the different elements of the system, in order to design and control for a desirable future. The *third step* is the modelling step in which equations are written down. The *fourth step* is the simulation step. The model which has been built in the framework of the BIOSES project is rather designed to generate interesting insights and more understanding. The model cannot be used to generate numerically precise forecasts or exact measures of sensitivity to parameter changes. The main goal of the simulations is to illustrate the resulting mode of behaviour. *Step 5* is the policy analysis which finally leads to the policy implementation *(step 6).*

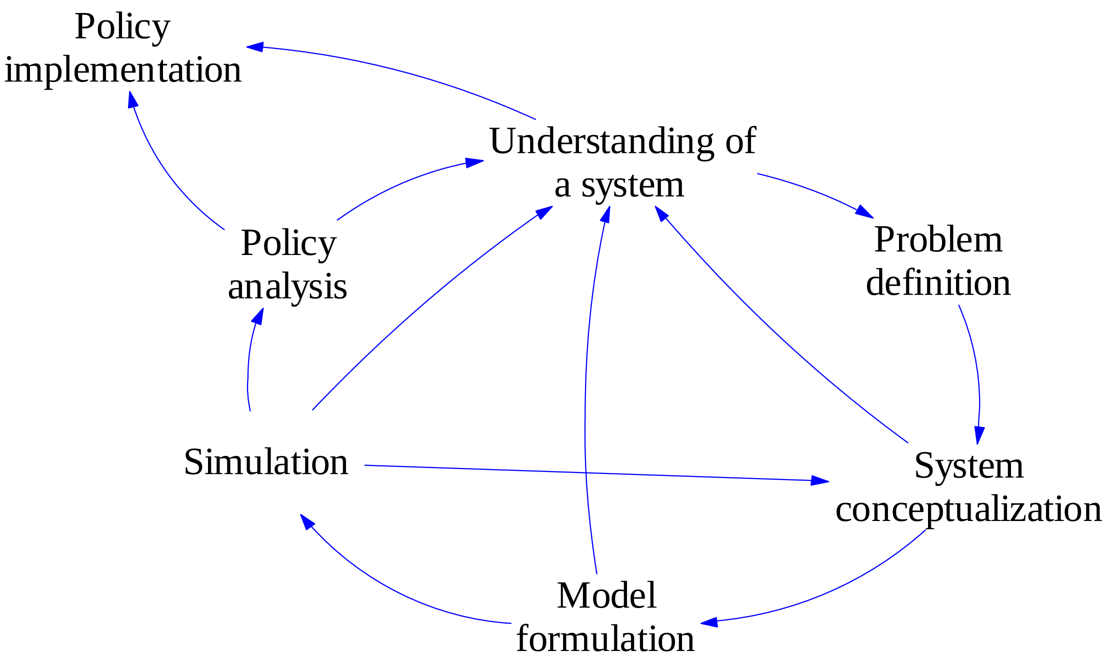


Figure 33: System Dynamics modelling process

Step 1: Problem definition

The purpose of the SD model in the framework of BIOSES is exploratory, namely to gain insight in the long-term dynamic behaviour of biodiesel over time. Insights in dynamic behaviour can be obtained, but validated forecasts or predictions cannot be generated. The model's border is the geographical border restricted to Belgium. The model also has a restriction in time (20 years), in accordance with the time frame of the BIOSES project.

Step 2: System conceptualization

In this step, the mental representation of the biodiesel market is given and a causal loop diagram with feedback loops elaborated. Several causal-loop diagrams with respect to the rapeseed market, biodiesel production, by-products and biodiesel consumption have been constructed. As an example, Figure 34 illustrates the causal-loop diagram of the rapeseed market. The arrows between the variables (production, consumption and arable land) are denoting the causal influences. Positive polarities (+) are indicating whether the effect changes in the same direction as the cause whereas the negative polarity (-) indicates the inverse. An example of a positive polarity is the positive effect of "area in use for rapeseed" on the "rapeseed production". A negative polarity is for example the relation between the production and the consumption of rapeseed. There will be more consumption at a low rapeseed price and vice versa (law of demand). A feedback loop is called positive or reinforcing if the number of "-" signs in the feedback loop is even generating exponential escalating behaviour. A negative loop will rather generate a balancing effect. Positive as well as negative feedback loops act simultaneously, with different strengths at different times.

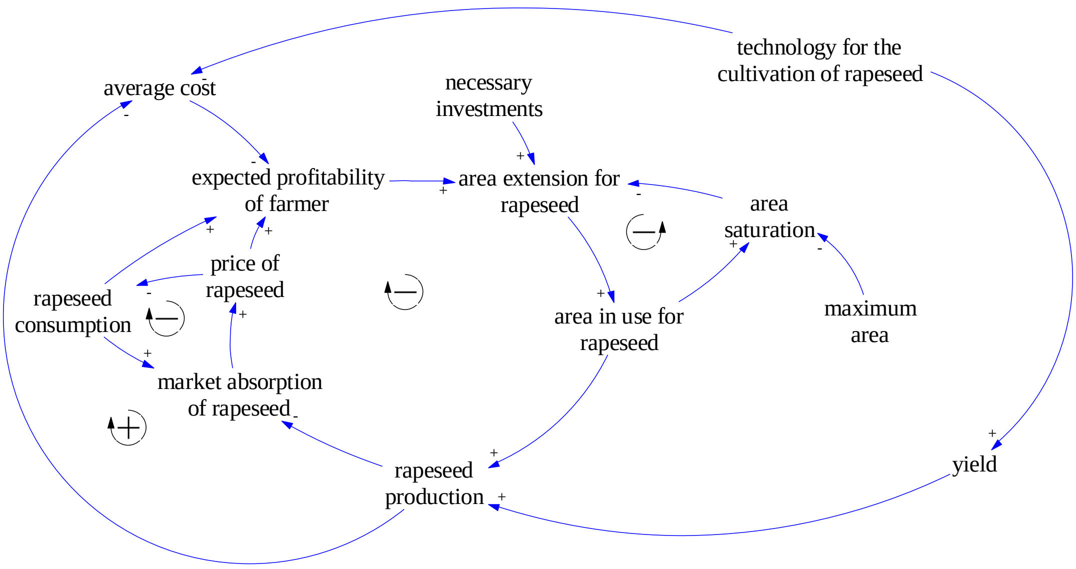


Figure 34: Causal loop diagram of the rapeseed market

Step 3: Model formulation

In this step, the entire causal-loop diagram of the biodiesel market is translated into a Forrester diagram which consists of stock and flow diagrams. A stock is the term for any variable that accumulates or depletes over time whereas the flow is the rate of change in a stock. The area of rapeseed is for example a stock, which can accumulate by means of an extension of the area whereas it can deplete by means of shrinking the area (outflow).

Extension and shrinkage of area will however depend on profit of the feedstock producer and the available stock, etc. The equations determining the correlations between the variables are written down in this step.

Step 4: Simulations

Here, several simulations are elaborated based on the formalized model (Figure 35) and the identified functions. Simulations can be performed by changing parameter values of variables that are subjected to uncertainties in the upcoming years. In this case, several assumptions with respect to diesel price, diesel demand and the fuel purchase behaviour of consumers (are consumers willing to pay more for the environmental friendlier aspects of biofuel as compared to conventional diesel or not) were made and the dynamic effects on the entire biodiesel market were reported.

Step 5: Policy analysis

The simulations performed in step 4 clearly pointed out that the proportion of prices (biodiesel versus conventional diesel) plays a very important role in the adoption of biodiesel in the end-user market. Moreover, it also revealed that the production of biodiesel needs a critical mass before it can become successful. Several dynamics on the short and longer term have been noticed: on the short term, a shock in biodiesel demand leads to a positive shock in rapeseed price, which consequently affects biodiesel prices; on the longer term, scale advantages will gain more weight.

Policy measures on the short term should focus on reducing these price increases of rapeseed for not hindering biodiesel production. This can include subsidies for farmers or the introduction of maximum prices. Today, the fuel price difference between biodiesel and conventional diesel is still too large, so biodiesel is currently not very attractive for the end-user (see chapter 2.5.4). A quota system or an obligation system might in this respect become an attractive option to enhance biodiesel consumption.

An additional simulation exercise on a possible quota system (2% and increasing with 0,75% to 2010 and with 1,05% to 2020) forecasts an increasing demand, very sharp rising costs and the need for area extension which stops after approximately 10 years due to limited area availability in Belgium. If however, the simulation exercise would be extended towards Europe, taking into consideration that on European level the availability of arable land is 129 times greater than arable land in Belgium (109 Mha versus 0,84 Mha) and the fact that European diesel demand is “only” 27 times greater than diesel demand in Belgium (192 Mtons versus 7,21 Mtons), the availability of arable land will be a less restrictive factor.

2.8.3. Shortcomings of the model

The current model does not take into consideration possible uncertainties that may arise with respect to risk aversion of producers, consumers and farmers; weather and climate uncertainties; uncertainties with respect to the investment climate, etc. Other possible links with the petroleum sector, food sector, etc. are also left out. Lastly, the model was restricted to Belgium which might not adequately represent reality. A European model could probably more accurately predict the dynamics of the biodiesel market over time.

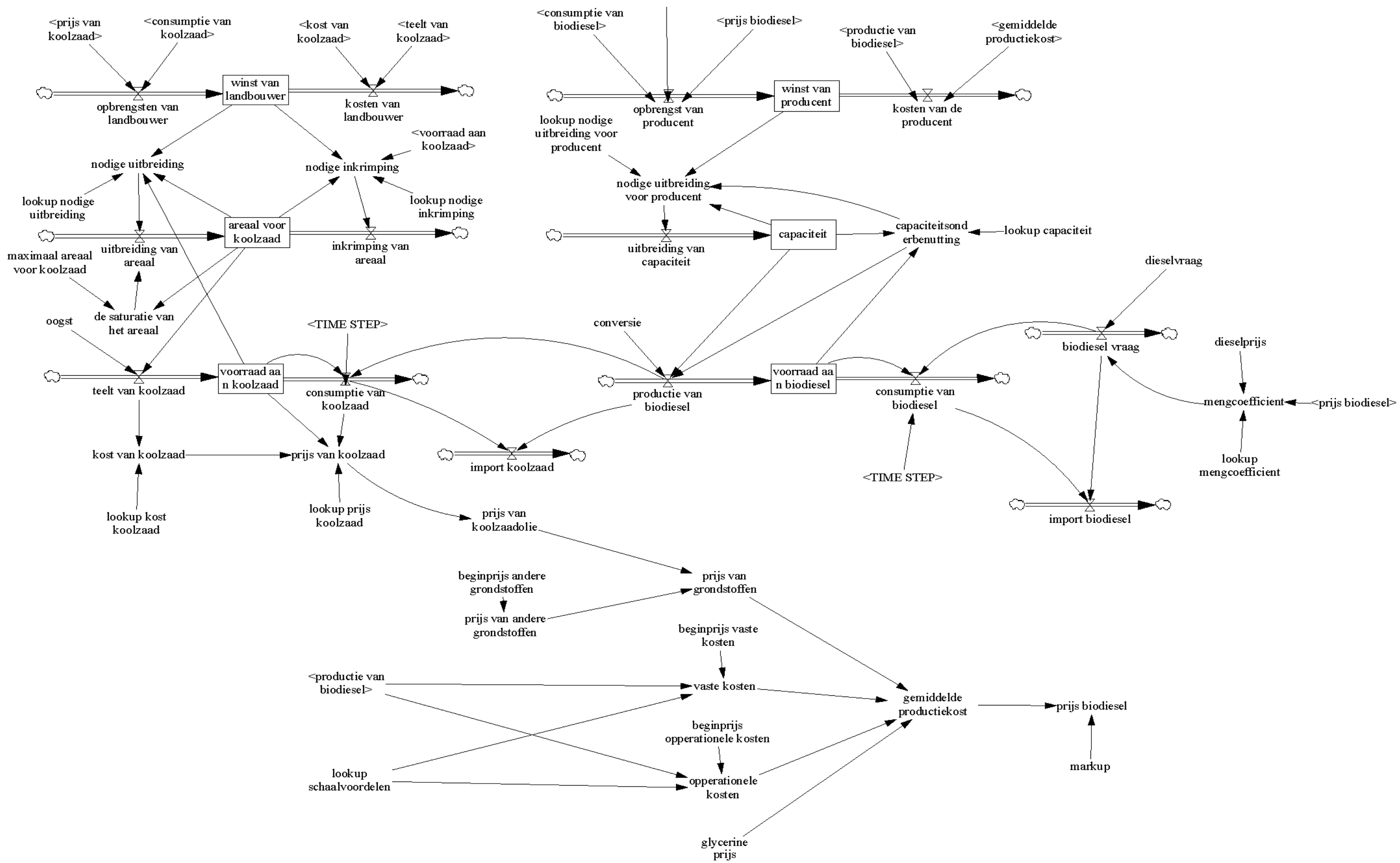


Figure 35: Model formulation

2.9. STAKEHOLDER POSITIONS AND BARRIERS (MAMCA ANALYSIS)

2.9.1. Introduction

Despite the actions of many EU countries, the market penetration of biofuels on national levels has been problematic. An assessment report of the European Commission in 2007 (EC, 2007) highlighted that only 50% of the EU 2005 target was reached and that the EU 2010 target of 5.75% biofuels would probably not be met either. Many articles have been focusing on the implementation of the biofuel directives on a European (PREMIA, 2006), national (Bomb et al., 2007) and city level (Silvestrini et al., 2010) and on the associated implementation problems (Di Lucia and Nilsson, 2007) and pointed out that the commitment of several sectors (government, car makers, fuel companies etc.) and a common vision and strategy are indispensable factors for a successful market uptake of biofuels. Biofuel sectors often cope with many concerns related to economic, environmental, legal and technical issues which should be addressed to get a successful market penetration of biofuels. So far, the stakeholders' point of view has been questioned by means of face-to-face interviews (Di Lucia and Nilsson, 2007; Bomb et al., 2007), but a common approach that integrates the stakeholder visions into the evaluation process of biofuel options is currently lacking.

In this task, a methodology is proposed that addresses the above mentioned problem. This multi-actor multi-criteria analysis (MAMCA) (Macharis, 2000) enables the evaluation of several alternatives, while explicitly taking the point of view of the involved stakeholders into account. As such, an insight is gained in the stakeholder support for different biofuel options and adequate measures can be identified to facilitate their implementation.

In the framework of the BIOSES project, the MAMCA approach aims to gain understanding in the stakeholders' point of view for several biofuel options that the Belgian government has at its disposal for the implementation of the RED (2009/28/EC) and its 10% target.

2.9.2. Methodology

The MAMCA methodology consists of 7 steps (see Figure 36).

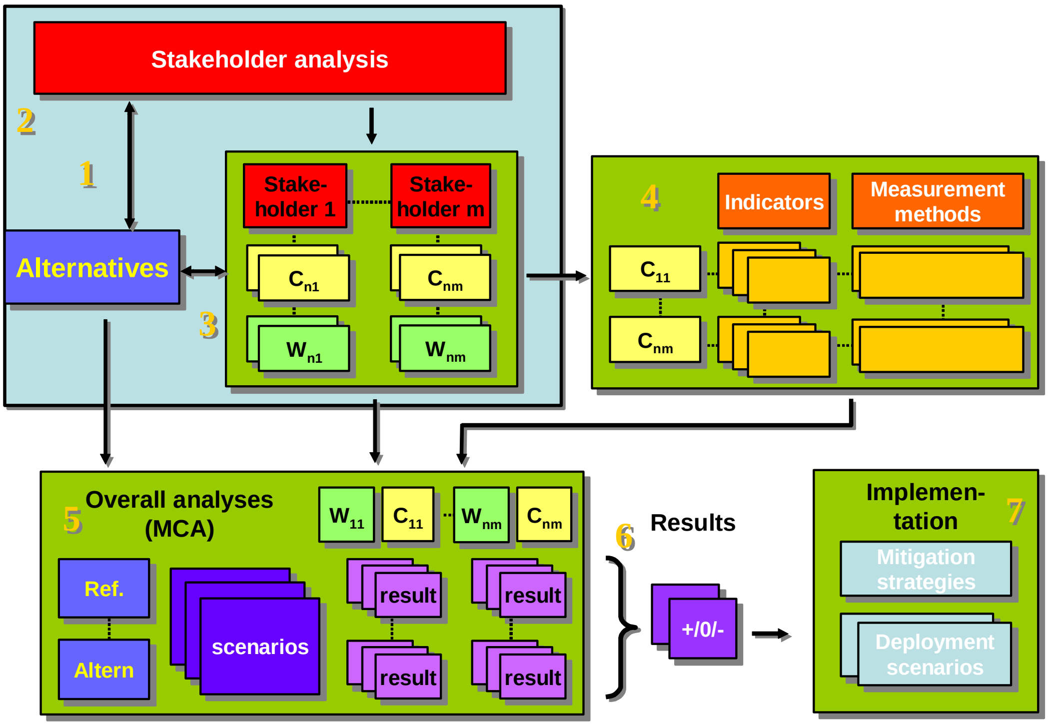


Figure 36: The 7 steps of the MAMCA methodology (Macharis, 2000)

The first step is the definition of the problem and the identification of the alternatives. These alternatives can represent different policy options or actions to be taken.

Next, in step 2, the various relevant stakeholders, as well as their key objectives, are identified.

In step 3, these objectives are translated into criteria and then given a relative importance (weights). The choice and definition of evaluation criteria are based on the identified stakeholder objectives and the purposes of the alternatives considered. Subsequently, for each criterion, one or more indicators are constructed that can be used to measure to what extent an alternative contributes to each individual criterion (step 4). Indicators can be direct quantitative indicators (like money spent, reductions in CO2 emissions achieved) or it can be qualitatively scored on an ordinal indicator (e.g. high/medium/low). Moreover, the measurement method for each indicator is also made explicit (e.g. willingness to pay, quantitative scores based on macroscopic computer simulation). This permits measuring each alternative performance in terms of its contribution to the objectives of specific stakeholder groups. Steps 1 to 4 can be considered as mainly analytical, and they precede the 'overall analysis', which takes into account the objectives of all stakeholder groups simultaneously and is more synthetic in nature.

The fifth step is the construction of the evaluation matrix, aggregating each alternative contribution to the objectives of all stakeholders.

After that, in step 6, the multi-criteria analysis yields a ranking of the various alternatives and shows their weak and strong points. The MAMCA provides a comparison of different strategic alternatives and supports the decision maker in its final decision by pointing out for each stakeholder which elements have a clearly positive or negative impact on the sustainability of the considered alternatives. Afterwards, the stability of the ranking can be assessed through sensitivity analyses.

The last stage of the methodology includes the actual implementation of the policy measure (step 7).

Once the decision is made, steps have to be taken to implement the chosen alternative by creating deployment schemes.

→ **Step 1: Defining the problem and the alternatives**

The first stage of the methodology consists of identifying the possible alternatives submitted for evaluation. Taking into account (1) the current and future Belgian fuel mix, (2) the technological evolution of vehicle models, (3) the likely biofuel blends on European markets and (4) the possible interest of certain end user groups, the Belgian government disposes of 4 realistic biofuel options that can add to the 10% target. Additionally, a reference fossil fuel option is added to the evaluation process providing a benchmark against which the other policy options can be compared. Overall, the following alternatives are evaluated:

1. Fossil fuels, with no biofuels applied in the transport fuel system.
2. Biodiesel (FAME & HVO), blended up to a level of 10% (B10) to all diesel fuel. In this analysis, biodiesel will be produced from rapeseed coming from Europe (70%), soya from the US (20%) and used oil from Belgium (10%).
3. Ethanol, blended to all gasoline fuel (E10) and in addition the introduction of FFVs (using E85) to obtain a higher ethanol share on the market. Here, ethanol is assumed to be produced from wheat out of Europe (70%), sugar beets from Belgium (20%) and sugarcane from Brazil (10%). On the longer term, this ethanol can be derived from ligno-cellulose (2nd generation technology).
4. Bio-methane, applied in a number of niche markets such as buses, vans or trucks operating in city traffic. Biogas is assumed to be produced on a Belgian level, consisting of 30% sewage sludge, 10% manure and 60% corn.

5. BTL (2nd generation technology), blended to all diesel fuel. Here, BTL will be produced from Belgian waste wood (30%), European farmed wood (40%) and Belgian grass (30%).

→ Step 2: Stakeholder analysis

Stakeholders are people who have an interest, financial or otherwise, in the consequences of any decision taken. Here, the stakeholders were identified according to the biofuel supply chain. These stakeholder groups were validated at a dedicated BIOSES workshop for biofuel representatives (Turcksin & Macharis, 2009). The identified stakeholder groups are the agricultural sector, biofuel converters, fuel distributors, end users, car manufacturers, government and NGOs & North-South organizations.

→ Step 3a: Defining criteria

An in-depth understanding of each stakeholder group's criteria is critical in order to appropriately assess the different alternatives. The choice and definition of the criteria is primarily based on the identified stakeholder objectives and the purposes of the considered alternatives. With this information, a hierarchical decision tree can be set up. In this analysis, the evaluation criteria are first tracked by the literature.
Next, during a stakeholder workshop (Turcksin & Macharis, 2009), representatives from each stakeholder group had the opportunity to evaluate and validate the pre-defined criteria. Figure 37 renders the final decision tree, in which the different stakeholder groups and their multiple criteria are highlighted. Throughout this decision tree, it can be observed that biofuels refer to many concerns at the same time - economic, environmental, legal and technical aspects - in which each stakeholder group has its own stake.

→ Step 3b: Allocation of weights to the criteria

In order to let the stakeholders express their preference for the different criteria, weights are allocated. There exist several methods for determining the weights: direct rating, point allocation, trade-off, pair wise comparisons, etc. The latter procedure, developed by Saaty (1980), proves to be very interesting in this case. That is why the decision making software Expert Choice based on Saaty's analytical hierarchy process (AHP), was used.

It was found that the economic criteria get the highest preference from feedstock producers, biofuel producers, fuel distributors and vehicle manufacturers. The highest priorities for end users are related to technical and performance issues such as safety (-perception) and compatibility. The Belgian government, NGOs and North-South organizations are rather concerned about environmental issues like reducing GHG emissions, improving air quality and lowering the ecological impact of the production chain. The only legal aspect that gets a high priority is the compliance of Belgian legislation with European targets (government).

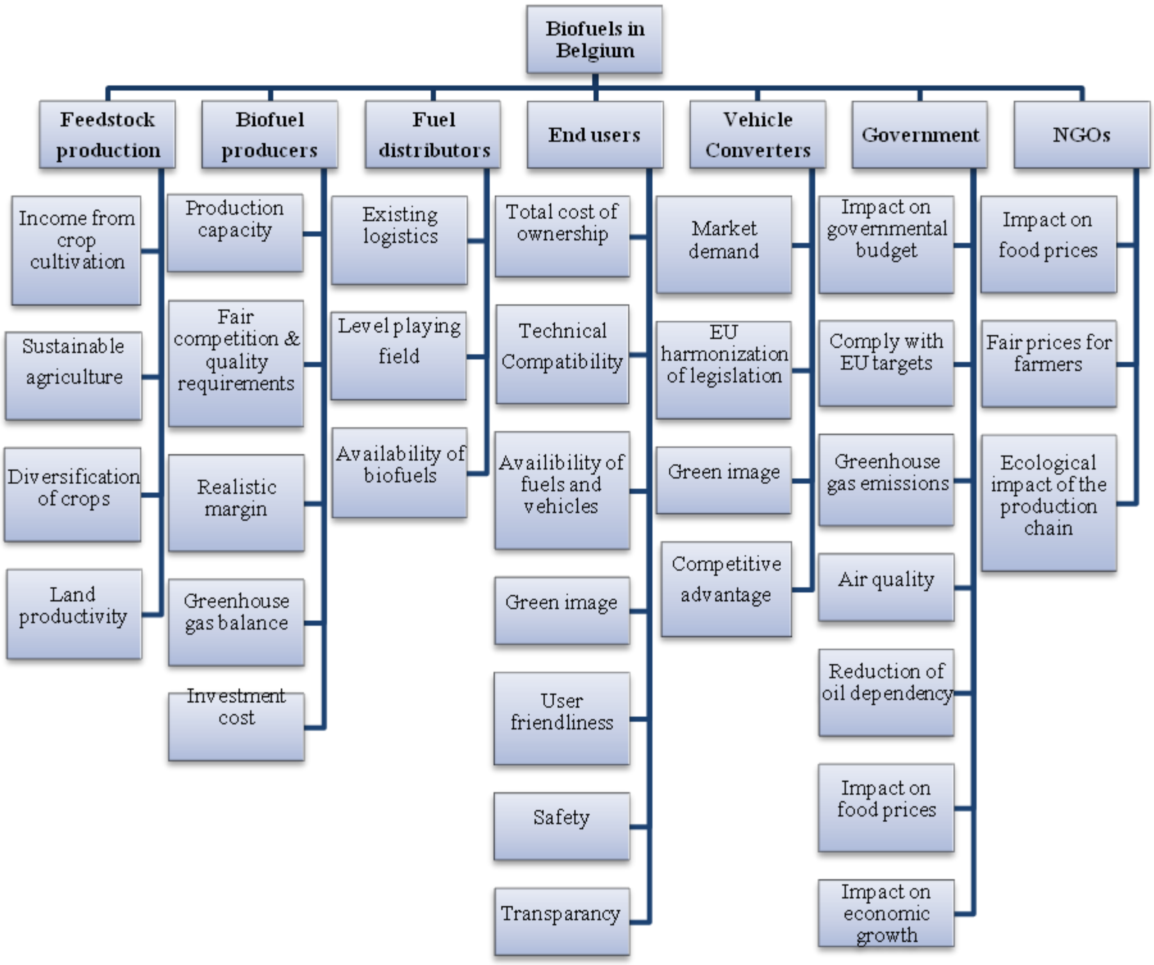


Figure 37: Final decision tree showing different stakeholder groups and their multiple criteria

→ Step 4: Criteria, indicators and measurement methods

In this step, the previously identified stakeholder criteria are 'operationalized' by constructing indicators that can be used to measure whether, or to what extent, an alternative contributes to each individual criterion. Indicators are usually, but not always, quantitative in nature. This enables pair wise comparisons of the alternatives with respect to the specific criteria. In this analysis, the pair wise comparisons of the alternatives with respect to the criteria of all stakeholder groups have been made by the BIOSES project team (Vrije Universiteit Brussel, VITO and Université Catholique de Louvain). By letting experts assign the performance values, a scientific and solid foundation in the evaluation process of alternatives is provided.

→ Step 5: Overall analysis and ranking

In order to assess the different alternatives, the software tool Expert Choice was used (ExpertChoice, 2000), based on Saaty's AHP method. This software combines the weight allocation, performed by the stakeholders and the performance valuation of the alternatives, assigned by the experts.

→ Step 6: Results of the MAMCA

The MAMCA developed in the previous step leads to an insight in the support that the various stakeholder groups attach to the proposed biofuel options, given their specified criteria. Figure 38 to Figure 41 show the outcomes for respectively the feedstock producers, biofuel producers, fuel distributors, vehicle manufacturers, end users, government and NGOs and North-South organizations.

For *feedstock producers* (Figure 38, left), income from crop cultivation (gross margin per hectare) and diversification of crops to different markets (food, fuel, animal feed) are the most important criteria to be obtained. Ethanol is ranked high with respect to these criteria and is therefore the most preferred option for them, followed by the production of biogas, which contributes the most to the other two goals; sustainable agriculture (measured by the use of pesticides, water and eutrophication in GJ/fuel) and land productivity (in GJ per hectare).

For *biofuel producers* in the Belgian market (Figure 38, right), there is no extra room for extending the possibilities of ethanol and biodiesel. Existing production facilities are underused and market access is difficult ('production capacity'). The increasing trend towards 'dieselification' in Belgium also creates a less favourable position for gasoline replacing fuels like ethanol.

Taking into account the high expected diesel demand and its easy market accessibility, BTL is the best option for additional biofuel production. Moreover, this fuel will be less confronted with cheap feedstock from international markets (‘fair competition’) and provides the best results with respect to the ‘GHG balance’, measured by the typical GHG emission savings from the RED (2009/28/EC). As this fuel is still in a research and development phase, it is expected that BTL will be less favourable with respect to ‘realistic margin’ and ‘investment cost’.

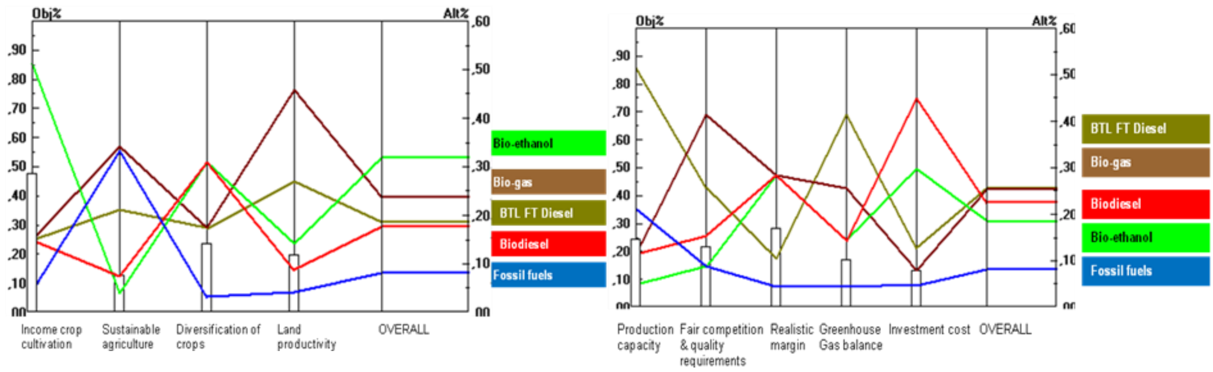


Figure 38: MAMCA results for Feedstock producers (left) and Biofuel producers (right)

For *fuel distributors* (Figure 39, left), fossil fuels are preferred over biofuels when it comes to the use of the existing infrastructure and the existence of a level playing field. Conversely, fossil fuels are ranked very low with respect to the security of supply and the sustainability (‘availability of sustainable resource’) of this fuel. Because of the large importance that fuel distributors attach to this criterion (see the large rectangular bar for this objective), ethanol and BTL are ranked as most supported options.

Fossil fuels are most preferred by *vehicle manufacturers* (Figure 39, right) because of the easy accessibility to the vehicle market and the low (additional) investment and development costs. Nevertheless, focussing on fossil fuels will not be effective in attaining a ‘green image’. Biogas is the best placed to obtain a green label, but this gaseous fuel is clearly not an option in view of the other goals.

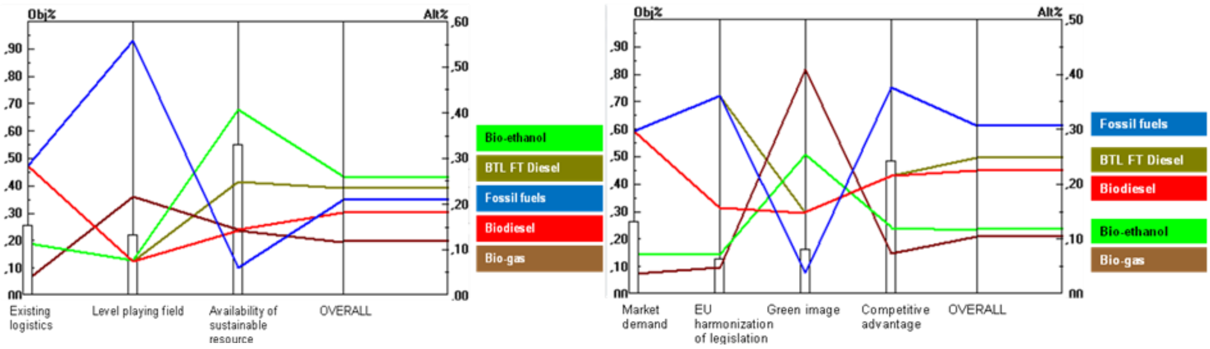


Figure 39: MAMCA results for Fuel distributors (left) and Vehicle manufacturers (right)

For *end users* (Figure 40, left), fossil fuels and biodiesel (through B10) are the favoured options given that these fuels have no or hardly any impact on the total cost of ownership of the vehicle (see also section 2.5.4 on the Life Cycle Cost), technical compatibility, availability of vehicles and fuels, user friendliness (measured by the fuel energy content) and safety (measured by the flash point and perception of safety). Fossil fuels are of greater importance than biodiesel with respect to the knowledge of the fuel and technology ('transparency'). On the other hand, to reach the objective 'green image', there is a complete different prioritization of the biofuel options than for the other goals. Here, biogas and ethanol are the most effective ones.

Biogas is the most supported option for the *government* (Figure 40, right) as it positively contributes to ecological criteria such as 'GHG balance' and 'local air quality'. Compared to the other biofuel alternatives, it also has a small impact on 'governmental budget' and 'food prices' and it adds to the 'reduction of oil dependency' and to the creation of employment ('economic growth'). It however scores less on the 'compliance with EU standards', as its potential to reach the 10% renewable energy target by 2020 will be modest and limited to certain niche markets. Biodiesel has a high score on this criterion as its contribution to the 10% target could be substantial, given the high diesel share in Belgium.

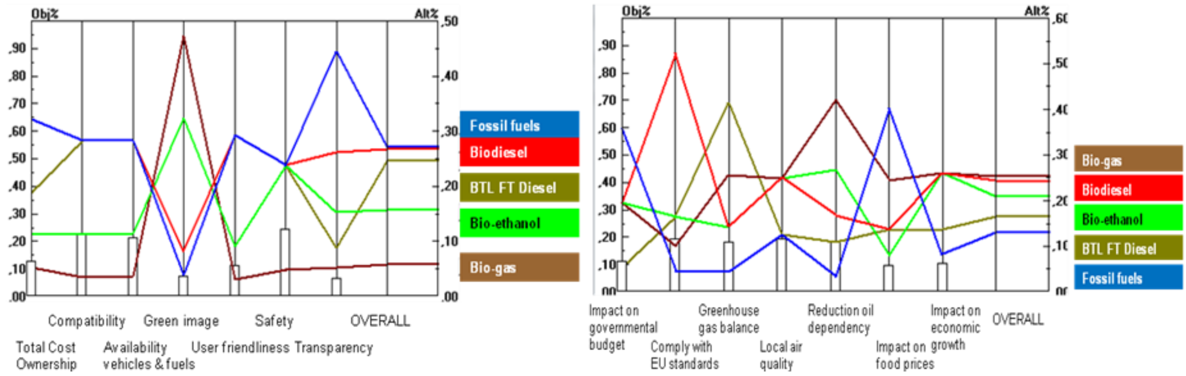


Figure 40: MAMCA results for End users (left) and Government (right)

For *NGOs and North-South organizations* (Figure 41), ethanol and biogas are the most important biofuel options as they contribute to the most important criterion 'ecological impact of the production chain', which is measured by ecosystem quality, water use and GHG savings (in GJ/fuel).

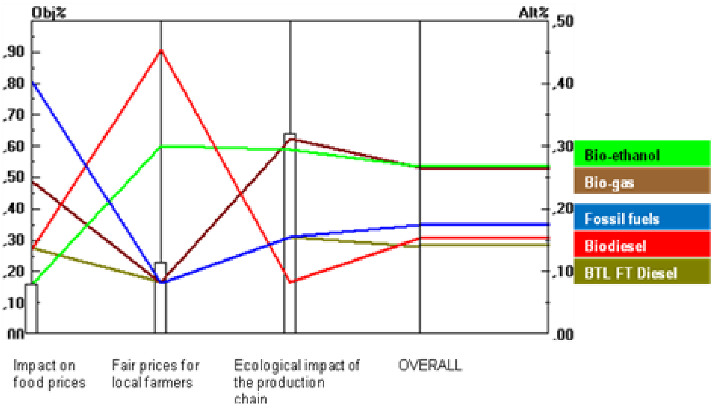


Figure 41: MAMCA results for NGOs and North-South organizations

→ Step 7: Implementation

This is the final step of the MAMCA, after the policy maker has decided on which alternative(s) to implement. The information on each stakeholder's position, gathered from the previous steps, helps tremendously in identifying implementation pathways and additional policy measures to facilitate the choice of the chosen alternative(s).

2.9.3. Policy implications

With insights from the MAMCA, additional policy measures can be established to tackle the barriers and disadvantages which could emerge once policy makers decide on which biofuel option(s) to implement and for which stakeholders.

For *feedstock producers*, support for crop cultivation might be required to obtain a realistic income from energy crops and to become commercially viable with respect to (inter) national competitors.

To ensure a realistic margin for *biofuel producers*, incentives such as *direct subsidies*, proportional to the amount of biofuels produced could be possible, if in line with European competition rules (Pelkmans et al., 2009).

Additionally, in order to enhance sustainable biofuel production, *incentives* can be given only to manufacturers reaching high GHG reductions for their biofuels, or processing feedstock for non-food use (PREMIA, 2006).

For *fuel distributors,* a sufficient *tax reduction* to cover the extra biofuel costs is necessary to encourage them in introducing a larger share of biofuels in their total sales. Moreover, high blends (e.g. E85), to be offered by private pumps for captive fleets and/or public pumps, require not only *dedicated support* (for infrastructure adaptations etc.) and an adaptation of the *fuel quality standards* for high biofuel blends by the CEN, but also a close collaboration with *vehicle manufacturers* to deliver biofuel compatible vehicles. Saab, Volvo, Ford, PSA-group, GM and Renault are ready to offer FFVs (for E85) on the Belgian market, but require a uniform *European fuel standard* and access to the market. To increase market demand, an *authorization to sell high blends* for fuel distributors is required together with dedicated incentives for FFVs such as fuel tax reductions or user advantages to enhance their attractiveness.

For *end users*, the total cost of ownership demonstrated that the purchase and use of biofuel compatible cars is still more expensive than conventional fossil fuel vehicles (see also section 2.5.4 on the Life Cycle Cost). *Fuel tax reduction* would be a possible instrument to counterbalance the higher production cost and ensure the price competitiveness of biofuels (Bomb et al., 2007). To enhance the attractiveness of high blends, *user advantages* such as free parking or reduction of circulation taxes could be issued. Additionally, the compatibility, availability and user friendliness of these vehicles and fuels should be ensured. Systems to encourage the availability of high blends could include subsidies for filling stations and mandates to fuel distributors to offer at least one renewable fuel. Demonstration and research projects could also enlarge the visibility and illustrate the user friendliness of high biofuel blends. Other possibilities include *procurement methods* such as public green procurement (increasing the number of clean vehicles to be included in public sector fleets), common procurement (a large number of users purchasing clean vehicles to achieve economies of scale and reduce costs) or leadership by example (use by other vehicle users, governmental fleets or public transport fleets) (PREMIA, 2006; Pelkmans et al., 2009).

The MAMCA also illustrated the *lack of transparency* with respect to the knowledge and information on biofuels. Awareness building campaigns, together with the creation of objective websites, brochures and a biomass observatory could contribute to a better knowledge and understanding.

For *government* and NGOs and North-South organizations, the MAMCA showed that the sustainability of biofuel production should be ensured. The RED (2009/28/EC) already contains *sustainability criteria* such as the fact that biofuels should not be made from raw materials obtained especially from land with recognized high biodiversity value, from forests, from areas designated for nature protection, from highly bio-diverse grassland etc. (Art. 17 of 2009/28/EC). European Member States had time until the end of 2010 to implement these sustainability requirements into national law. For *NGOs and North-South organizations*, additional sustainability requirements might be vital as indirect land use changes and social effects are not covered yet by the RED (IST, 2009).

CHAPTER 3 POLICY SUPPORT

3.1. INTRODUCTION

The BIOSES project has been active from January 2007 until January 2011. This has been a very intensive period on the policy side in terms of biofuels.

On European level, the Renewable Energy Directive was prepared, and finally approved by the European parliament in December 2008. It was published in May 2009 as directive 2009/29/EC. With all discussions about the sustainability of biofuels compared to fossil fuels - whereby the introduction of biofuels was often linked with the unprecedented increase of food prices in the same period - , the period 2007-2008 was a rather uncertain period for the biofuel sector.

Moreover, the biofuel quota system which was introduced in Belgium in 2006, did not result in the anticipated biofuel volumes defined in the quota system. This brought the young biofuel sector in Belgium in a rather difficult economic position. From mid-2009 the Belgian government introduced an obligation system to blend at least 4% by volume biodiesel with diesel, and at least 4% by volume bio-ethanol with gasoline. This, together with the publishing of the Renewable Energy Directive in May 2009, brought some stability to the biofuel market.

The directive included the obligation of European member states to prepare a National Renewable Energy Action Plan (NREAP), which needed to be submitted to the European Commission by June 2010. The plan includes an action plan to reach the 10% target for renewable energy in transport. The BIOSES project has contributed actively to the Belgian NREAP through regular consultation with policy administrations in terms of (1) projections of diesel and gasoline consumption in a baseline and an energy saving scenario, (2) providing realistic biofuel introduction scenarios which were applied in the NREAP, and (3) consulting, involving and informing biofuel stakeholders, of which several representatives were part of the BIOSES follow-up committee, on the potential framework of biofuel introduction in Belgium.

In this chapter we will make a distinction between short term recommendations in a 2020 roadmap, related to the Belgian NREAP, and a longer term policy roadmap, where we will also emphasize the interaction with other transport policy options of energy saving and electric mobility.

3.2. ROADMAP UNTIL 2020

3.2.1. Link with the Belgian National Renewable Energy Action Plan

The European Directive for the promotion of energy from renewable sources 2009/28/EC (RED) fixes a mandatory 10 % target for renewable energy in transport by 2020. The Belgian National Renewable Energy Action Plan (NREAP) sets yearly indicative targets for renewable energy consumption in transport in view of reaching the national 2020 objective. Figure 42 shows these yearly indicative targets as well as the expected contribution of each technology. The yearly indicative targets regarding the contribution of biofuels are represented in Table XXVII and Table XXVIII and translate into an *8% share of biofuels* in the total renewable energy consumption in transport in 2020.

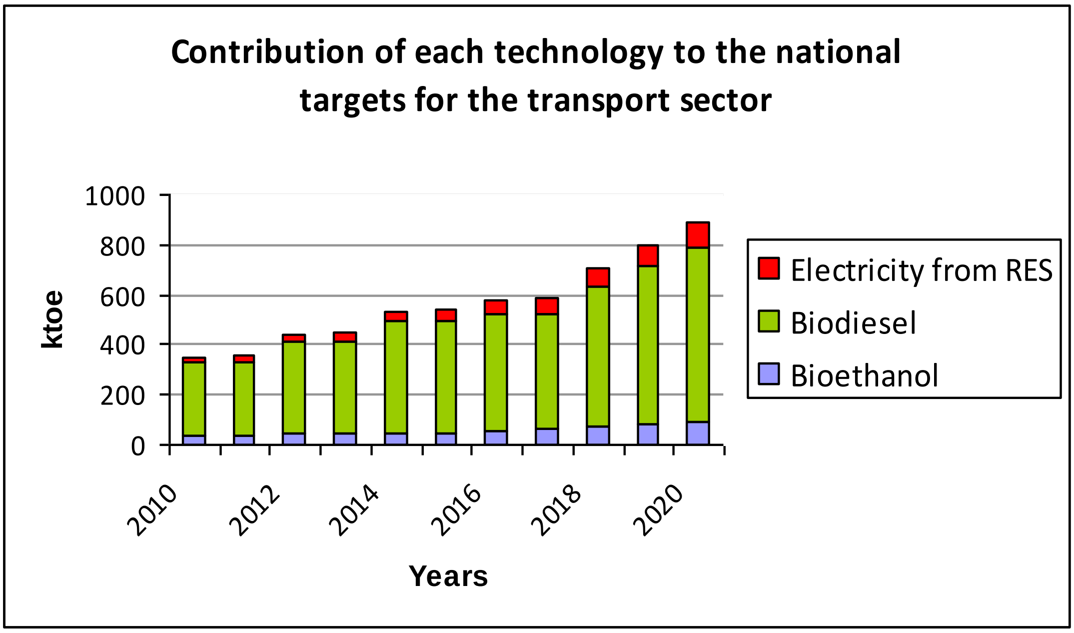


Figure 42: National targets for the transport sector defined in the NREAP and contribution of each technology[18]

The BIOSES project has contributed actively to the elaboration of the Belgian NREAP, through regular consultation with policy administrations and by providing projections on future energy consumption trends. The NREAP fixes objectives but does not specify which technologies will enter in play to reach the biofuel targets.

18 In this figure, a multiplication factor has already been applied to take into account the double counting of biofuels produced from waste, residues and ligno-cellulosic material and of renewable electricity

The BIOSES project has analysed the technologies necessary in reaching the national objectives in a roadmap for biofuels (task 3.2) and discussed on this topic with policy makers at the occasion of a dedicated workshop (Final BIOSES workshop 15 December 2010). The main elements resulting of this work are presented below. Mind that in the roadmap, it is assumed that biodiesel targets can be reached through any biofuel replacing diesel fuel, so not only FAME.

The national objective will be reached through:

1. General blending of FAME and bio-ethanol

General blending of conventional biofuels is expected to play a major role in reaching the 2020 national objectives. It is anticipated E10 and B7 will be on the market as standardized fuels by 2020 at the latest. As indicative figure, Table XXVII shows the general blending requirement if the NREAP targets for biodiesel were to be reached through general blending of FAME in diesel exclusively.
Similarly Table XXVIII shows the percentages bio-ethanol that would need to be blended in total road gasoline sales to fulfil the target fixed by the Renewable Action Plan, assuming the national target for bio-ethanol is reached through general blending of bio-ethanol in gasoline exclusively. As shown in the tables below, general blending up to E10 and B7 alone is not sufficient to reach the national 2020 targets.

Table XXVII: FAME blending requirement to reach the national targets for biodiesel (NREAP) through general blending (ktoe)

	2005	2010	2011	2012	2013	2014
Biodiesel targets of the REAP	90	292	293	369	371	447
Including biodiesel from Article 21(2)[19]		*0*	*0*	*0*	*0*	*0*
Diesel evolution, incl biodiesel[20]	7302	7762	7806	7843	7887	7930
General blending (%vol)	1,3%	4,1%	4,1%	5,1%	5,1%	6,2%
	2015	**2016**	**2017**	**2018**	**2019**	**2020**
Biodiesel targets of the REAP	449	466	461	557	628	698
Including biodiesel from Article 21(2)	*0*	*44*	*44*	*101*	*114*	*127*
Diesel evolution, incl biodiesel	7967	7872	7784	7689	7594	7500
General blending (%vol)	6,2%	6,5%	6,5%	7,9%	9,1%	10,2%

[19] Article 21(2) of the RED specifies that the contribution of biofuels produced from waste, residues and ligno-cellulosic material will count double towards the target. A multiplication factor has already been applied to all targets for biofuels described under Article 21(2) in this document.
[20] Source: BIOSES estimations

Table XXVIII: Bio-ethanol blending requirement to reach the national targets (NREAP) through general blending (ktoe)

	2005	2010	2011	2012	2013	2014
Bio-ethanol targets of the NREAP	12	37	36	43	42	49
Gasoline evolution, incl ethanol[21]	1527	1419	1369	1318	1268	1217
Ethanol low blending in gasoline (%vol)	1,2%	4,0%	4,0%	5,0%	5,0%	6,2%
	2015	2016	2017	2018	2019	2020
Bio-ethanol targets of the NREAP	47	55	65	76	84	91
Gasoline evolution, incl ethanol	1168	1142	1117	1091	1065	1039
Ethanol low blending in gasoline (%vol)	6,2%	7,4%	8,8%	10,7%	12,0%	13,4%

2. Unlimited general blending of renewable paraffinic fuel in diesel fuel

Renewable paraffinic fuels, such as hydro-treated vegetable oils (HVO) or FT-Diesel (a.k.a. BTL), can be blended in diesel fuel at an unlimited percentage using conventional vehicle technology. Blending of renewable paraffinic fuels could be introduced as complement to FAME to reach blending percentages which exceed 7%vol. HVO, a fuel reaching early commercial stage in Europe, could be introduced in a first phase, before BTL becomes commercially available (Figure 43). With the high focus on diesel fuels in Europe, biodiesel from vegetable oils (FAME, HVO) will face an important demand in Europe up to 2020.

Most European member states – even strong agricultural countries like France - are anticipating import of biodiesel, vegetable oil or oil seeds to fulfil their demand for biodiesel. This may create additional stress on worldwide vegetable oil markets. Demand for FAME (reaching 7%vol) and HVO (reaching ~2%vol) should therefore be stabilized around 2020. Further growth should be ensured through cellulose based diesel fuel: FT-Diesel should be progressively introduced starting 2018.

[21] Source BIOSES estimations

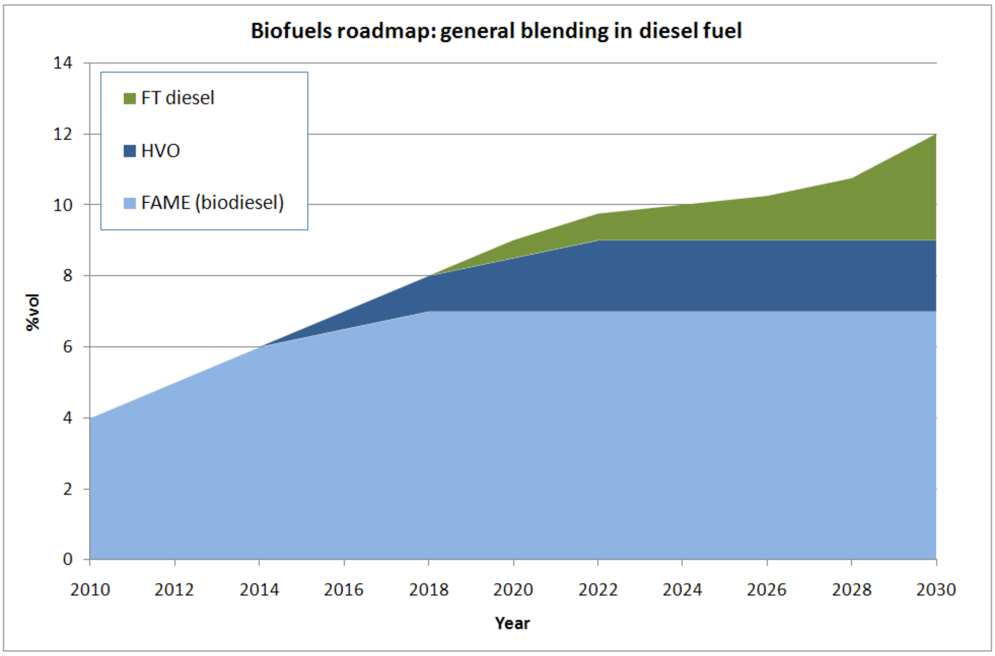


Figure 43: Biofuel roadmap for general blending in diesel fuel

3. High blends

For bio-ethanol, Table XXVIII reveals that the introduction of high blends is essential in reaching the national bio-ethanol target. Options are E85 (creating the need for flexfuel vehicles), ED95 (changing part of the heavy duty diesel fleet) or E20 as a more general blending (which also requires some fuel flexibility). While E20 introduction probably creates the same challenges of fuel compatibility as E85, while the impact of E85 is much higher, we focussed here on strategies to introduce E85 and possibly ED95.

- *E85*

There should be a clear focus on introducing flexfuel vehicles (FFVs) in the gasoline vehicle market. Preferably this should happen in a coordinated way at European level. We anticipate that a realistic target could be that the share of flexfuel vehicles (FFVs) should reach 5% in 2015 and 50% in 2020. If promoted, FFVs can partly replace diesel cars, for use in fleets.

Roadmap for the introduction of E85 and flex-fuel vehicles
Demonstrations of E85 as a fuel in combination with flexfuel vehicles in fleets to be started on short term
Availability of E85 in public fuel stations (as pump for E5 will become available). Mind that in order to have sufficient amounts of FFVs driving around at that time, FFV models should be promoted earlier (even if they drive on gasoline in the beginning).

(Pelkmans, 2008) calculated a support scenario for E85 implying a share of E85 in public and private fuel stations reaching less than 1% of gasoline sales in 2015 and 5% in 2020. As indicative figure, through this scenario ethanol use through E85 could amount to over 35 ktoe (50.000 m³) in 2020. This means that in addition to the 10% general ethanol blending in gasoline (which can lead up to 65 ktoe in 2020), the introduction of E85 according to the scenario above E10 would be sufficient to reach the target fixed by the NREAP.
Bio-ethanol can also be produced from ligno-cellulose in the future, so the roll-out of FFVs is also important on the longer term.

- *ED95*

In (Pelkmans, 2008) a support scenario for ED95 was analysed which anticipates that ED95 use for buses will focus on public transport companies, with exclusion of subcontractors, reaching 2% in 2015 and increasing to 4% in 2020. For trucks, the share in fuel consumption is rather limited: an ED95 share of 0.5% in 2015 and of 1% in 2020 is assumed. As indicative figure, the contribution of bio-ethanol used as ED95 (if introduced according to the quantities of the scenario above), could represent a substantial amount, possibly in the order of 30 ktoe (45.000 m³) in 2020. In other words, this scenario would be sufficient to supplement the 10% general blending to all gasoline, and reach the bio-ethanol target in the REAP for 2020. An additional advantage of this strategy would be that ethanol is replacing diesel in this case and would diminish diesel imports.

Biodiesel blends

For biodiesel, the necessity of introducing high blends is less straightforward than for bio-ethanol due to the possibility of increased general blending (exceeding 7%vol) in diesel fuel by the introduction of renewable paraffinic fuels (HVO, BTL). Biodiesel high blends (B30 or B100) could however contribute significant volumes (as illustrated below) and in a long term vision, support could be given to the development of such blends in niche markets.

- *B30*

In (Pelkmans, 2008) a support scenario for B30 was analysed which assumes that B30 use for passenger cars could reach 2% of diesel sales in 2015 and 4% in 2020. For diesel buses, a share of 5% in 2015 and 15% in 2020 of B30 use is assumed. For trucks, mainly regional transport is envisaged (exclusion of international transport) and B30 use could reach up to 4% in 2015 and 8% in 2020. Regarding vans, which are more used for regional distribution, an evolution of 5% in 2015 and 15% in 2020 is considered. Mind that these figures are very ambitious, certainly because its market has not started yet. As indicative figure, the contribution of biodiesel used as B30 to the national targets will still stay below 2% of overall diesel consumption. So the introduction of B30 (according to the scenario above) and general blending of FAME in diesel fuel (B7) alone is not sufficient to reach the targets of the NREAP.

- *B100*

(Pelkmans, 2008) calculated a support scenario for B100 in which a B100 share of 2% in 2015 and 8% in 2020 in the total bus energy consumption is assumed. For trucks, mainly regional transport is envisaged (exclusion of international transport): an evolution of 1% in 2015 and 4% in 2020 is considered. As for B30, mind that these figures are very ambitious, because its market has not started yet. The indicative contribution of B100 will also stay below 2% of overall diesel consumption, and to some extend it also focuses on the same niche markets (so the contributions of B30 and B100 cannot be cumulated). So neither will the introduction of B100 (according to the scenario above) and the general blending of FAME in diesel fuel (B7) alone be sufficient to reach the targets of the NREAP.

Biomethane

Biomethane – produced from upgraded biogas - constitutes a technology with great environmental advantages, which has proven state of performance in other European countries and which is already commercially available. This fuel is therefore favoured by several stakeholder groups in the MAMCA analysis. Biomethane is usually derived from waste streams, and in that case it can be counted double towards the 10% target. It can be used in unlimited blends with natural gas in dedicated natural gas vehicles.

Although the contribution of biomethane has not been planned in the national Belgian NREAP published in 2010, and its potential contribution in 2020 is rather limited (Pelkmans, 2008), it is recommended that biomethane is actively supported in niche markets, as it can be an important option after 2020.

3.2.2. Policy recommendations on the short to medium term

The Belgian Renewable Action Plan (REAP) sets indicative yearly biofuel consumption targets in view of reaching the 2020 objective. To fulfil the targets fixed by the NREAP, policy around energy consumption in transport should be a combination of:

1. Increased general blending

The MAMCA analysis reveals the challenge regarding market introduction of biofuels requiring adapted infrastructures. Indeed, the introduction of new fuel infrastructures requires important investments, coordination between fuel suppliers and the automobile sector and promotional activities to change mentalities in the larger public. In a first phase, general blending will therefore play a major role in reaching the national targets. In this view, the current blending obligation of $4\%_{vol}$ should be progressively increased according to quality standard publications.

2. Promote the use of biofuels with good greenhouse gas performance

The revised Fuel Quality Directive 2009/30/EC (revising Dir 98/70/EC and 2003/17/EC) requires fuel suppliers to reduce the life cycle greenhouse gas emissions per unit of energy from fuel and energy supplied of 6 % by 31 December 2020 compared to 2010. Biofuel blending is one of the major instruments for the sector to reach this. With the current biofuel targets, actual share of biofuels will be around 8% (= without double counting), and when these biofuels reach on average 50 to 60% greenhouse gas saving compared to fossil fuel, overall greenhouse gas reduction for fuel suppliers will be around 4.5%. So in terms of the Fuel Quality Directive target, a shift to biofuels with higher greenhouse gas savings is required. The current targets have no link with the GHG performance of biofuels. It is therefore essential to support well performing biofuels in terms of greenhouse gas emission savings. For example, in 2015 Germany will shift from biofuel blending targets (~RED) to GHG reduction targets (~FQD).

3. Support for innovative solutions

Although the contribution of advanced biofuels to national targets is expected to reach significant volumes only on the longer term (after 2020, see chapter 3.3), the promotion of such innovative solutions is crucial from now on. Support to innovative biofuels should focus on supporting research projects as well as pilot, demonstration and first industrial deployment of technologies (reference plants). Priority should be given to value chains leveraging on industrial synergies with existing facilities as they might offer the best economic and industrial framework to manage the high risk / high cost of deploying promising new technologies. Also, focus should be on biofuels performing (in terms of energy and GHG) at least as well as existing ones (European Biofuels Technology Platform, 2010).

4. Promotion for market development of higher blends

The MAMCA analysis reveals the challenge regarding market introduction of biofuels requiring adapted infrastructures.
For vehicle manufacturers the bio-ethanol scenario and the biogas scenario score much lower than the rest due to low market demand, low EU harmonization of legislation and a low competitive advantage.
For fuel distributors, bio-ethanol and biogas show a low score regarding existing logistics. For end-users, bio-ethanol and biogas again show very poor figures. Indeed, the introduction of new fuel infrastructures requires important investments, coordination between fuel suppliers and the automobile sector and promotional activities to change mentalities in the larger public.
Despite their difficult market introduction regarding vehicles manufacturer and end users, the biogas and bio-ethanol scenarios have been favoured by several other stakeholder groups such as feedstock producers, NGOs, biofuels producers (only for biogas), fuel distributors (only for bio-ethanol) and finally by the government (especially for biogas).

Support should be given to the development of these options (E85, ED95, bio-methane and possibly B30, B100 or PPO), at least in niche markets as the development of high blends is crucial in reaching national objectives (especially for bio-ethanol). In the case of E85, this fuel should be distributed in public fuel stations from the moment E5 has been phased out.

The MAMCA results should be put to profit by anticipating the apprehension of certain stakeholders groups with regard to high blends through the implementation of adequate policy measures to promote the use of dedicated vehicles and to create a significant network of adapted filling stations. This can be done through several different measures which are detailed below.

a. *Support to adapted vehicles:*

- Reduction of the purchase price

A possibility would be to include alternative fuel vehicles (FFVs for example) in the list of vehicles which are granted an "eco-reduction" by the Federal Government;

- Public procurement or joint procurements

Public procurements (increasing the number of alternative fuel vehicles to be included in public sector fleets) and joint procurements (a large number of users purchasing clean vehicles to achieve economies of scale and reduce costs) have also proven to be very useful tools to introduce alternative fuel vehicles on the market and to reduce their price.

- Tax advantages

Tax advantages on the ownership tax or circulation tax and fiscal advantages to company cars constitute another possibility to favour the use of alternative fuel vehicles.

- Other advantages

Other advantages can be granted to the owners of alternative vehicles such as parking privileges and special access to Low Emission Zones/Congestion Zones (decisions on local level) as is the case in Sweden.

b. *Support to appropriate refuelling infrastructure*

Possible support actions are:

- Mandate for fuel distributors to offer at least one alternative fuel (as done in Sweden);
- Subsidies for the installation of private pumps for captive fleets distributing higher blends;

- Subsidies for fuel distributors distributing higher blends / pure blends via public pumps.

c. *Financial support for the high blend*

Due to the higher production costs of biofuels (in comparison with fossil fuels) and the lower energy content of ethanol, high blends of biofuels (per km, not necessarily per litre) are currently not competitive with fossil fuels and specific financial support will have to be given to such biofuels, at least on the short term.
Fixed quotas of bio-ethanol (250 000 m^3) and biodiesel (380 000 m^3) are currently tax exempted under the Law of 10 June 2006. This results in a tax reduction of gasoline containing at least 7% ethanol in volume and of diesel containing at least 5% FAME in volume. Tax exempted biofuel quotas will disappear after 2013. For then on the tax incentives could be transferred to promote high blends in particular, by introducing a reduction of taxes proportional to the biofuel content.

5. Sustainability measures

Sustainability is revealed to constitute a major issue for biofuel introduction and acceptance amongst stakeholders by the MAMCA analysis. For instance, the main concern in relation to the biodiesel scenario is related to sustainability. The biodiesel scenario scores low regarding availability of sustainable resources for the fuel distributors and regarding sustainable agriculture for the feedstock suppliers. For NGOs, the biodiesel scenario scores low due to potential competition with food and due to the ecological impact on the production chain. Vegetable oil demand should therefore be stabilized by 2020 and progressively replaced by ligno-cellulosic based biofuels or advanced biodiesel (FT-Diesel or BTL). BTL is currently in a demonstration phase and is not yet commercially available.

The sound implementation of the sustainability criteria of the Renewable Energy Directive 2009/28/EC (RED) reveals to be crucial for successful market introduction of biofuels in Belgium. There is an urgent *need for more coherence across Member States* in the implementation of these sustainability criteria. The practical implementation of the sustainability requirements in legislations should be based on relevant, transparent and science-based data and tools. *Sustainability-related tools and data* should be a priority for public funded R&D. Moreover, *models, monitoring and impact assessment tools* to help assess the implementation of enacted legislation and to prepare public (policy) and private (investment) decisions should be developed.

There is a need for *further research* to develop *models and monitoring tools to better understand and assess the issues around indirect land use change* (European Biofuels Technology Platform, 2010).

Finally, for the ethical and social aspects related to the consumption and production of biofuels, measures need to be taken to deliver objective and straightforward information about biofuels. The complexity of biofuel issues is not yet fully understood by the public and there are still too many misconceptions and simplistic analyses. Enhancing the image of biofuels within the general public is essential to increase the biofuel consumption to reach national targets, especially when it comes to the high blending. *Awareness campaigns* are needed to generate a better comprehension of biofuel related issues.

3.3. LONG TERM ROADMAP (2030)

3.3.1. Link with other policies & longer term vision

Biofuels are part of an overall strategy to reduce the environmental impact of transport and reduce the dependency of the transport sector on crude oil (which is now >95%). In the overall strategy, the following pillars are identified, which should be developed in parallel:

1. energy saving and clean technologies in transport;
2. introduce renewable energy in transport through
    a. electric mobility;
    b. sustainable biofuels.

In the long term, it is clear that a balance will appear between electricity and liquid (or gaseous) fuels (both fossil and bio). This is also anticipated in the worldwide scenarios of the International Energy Agency (IEA). IEA made projections for worldwide energy use up to 2050, in a baseline scenario and a ‘BLUE Map’ scenario (Figure 44) which strives for a reduction of 50% in energy related greenhouse gas emissions. Conclusions of these scenarios by 2050 indicate a major reduction (~35%) is needed of overall energy use in transport compared to the baseline scenario; the remaining energy consumption will be constituted of about half by fossil based fuels (most of it diesel and jet fuel for long distance traffic) and the other half will be renewable based, with biofuels, electricity and potentially also hydrogen.

In the BLUE Map scenario, IEA projects that biofuels will make up around 25% of the remaining energy use in transport by 2050. Most will probably be advanced biofuels, based on cellulose.

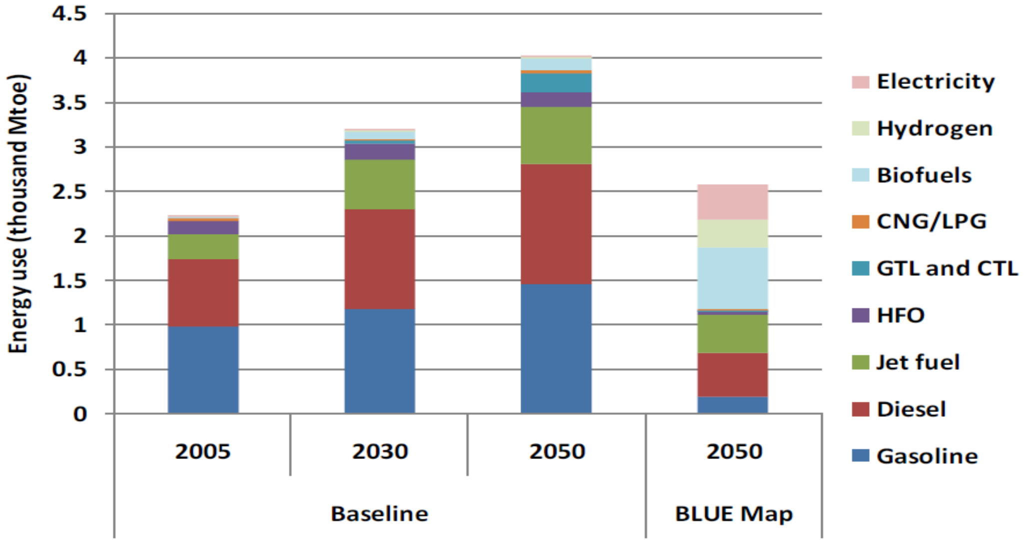


Figure 44: IEA transport scenarios towards 2050 (IEA ETP 2008)

Basis Blue Map: 50% reduction in global energy-related GHG from 2005 to 2050

→ **Energy savings in transport**

Energy saving in transport has the most direct impact on reducing greenhouse gas and all other emissions, as well as reducing consumption of fossil fuels in transport. Policies focused on energy saving may stop the anticipated growth of energy consumption in transport, stabilize energy use between 2010 and 2015, and reduce it afterwards. In an "energy saving" scenario, it was calculated that energy use in transport could be *13% lower in 2020* compared to a baseline scenario (see chapter 2.6.2, Figure 21 and Figure 22). In the longer term, this could amount up to *20% in 2030*. Most of the reduction can be achieved for passenger cars. Energy consumption by heavy duty freight can be stabilized. In any case heavy duty vehicles will reach a growing share in overall transport energy consumption. Biofuels are the main option for this sector to shift from fossil fuels.

Policies which could be implemented to enhance energy efficiency:

- favouring low-CO2 emitting vehicles (tax differentiation) towards the target of 95 g CO2/km (average of new sold vehicles) by 2020,
- further efficiency improvements in the vehicle drivetrain,

- hybridisation,
- energy saving tyres, aerodynamics,
- more efficient airco systems,
- promote fuel efficient driving behaviour,
- modal shift (to public transport, cycling, ...),
- mobility plans (incl. road pricing).

→ **Electric mobility**

Electric mobility presents several advantages. The absence of tailpipe emissions is a clear benefit in terms of local air quality. The overall efficiency of the electricity pathway is generally higher than the efficiency attributable to a pathway combining fuels and combustion engines, and electricity can be produced from all kinds of sources, including various renewable pathways. The major drawback of electric mobility is the immaturity of the (sales) market and the high costs of technology.

Policy support is still required to develop electric mobility. The main focus for electric vehicles will be on *local traffic* (delivery vans, public transport) and on the segment of *passenger cars*. Long distance traffic (trucks, coaches, airplanes, maritime) strongly relies on a high density (liquid) fuel and it will be difficult to create a major role for electricity in these sectors. Train traffic, which can be based on electricity, constitutes an exception. A sales figure of 10% pure electric or plug-in hybrid vehicles is considered to be an ambitious but still realistic target within the next 10 years. This would represent sales of around 50.000 electric vehicles in 2020 in Belgium. Prospects of electric technology are mostly on the longer term (beyond 2020).

Nevertheless policy support is necessary from today to reach long term targets. The following policy support should be considered:

- support for the development of electric and hybrid vehicles and their components;
- incentives (incl. fiscal) for buying these vehicles (e.g. through demonstration in niche markets, purchase subsidies, example role of the government, ...);
- building charge infrastructure and gaining experience with recharge technologies and strategies;
- mapping the potential role of these technologies in the future transport sector;
- analysis of the potential impact on the electricity grid and electricity production, in order to reach an optimal integration.

The following figures show the anticipated sales of different vehicle technologies in the car segment for 2010-2020-2030 in three scenarios: (1) a baseline scenario, relying on existing policy, (2) an Energy Saving scenario, relying on proactive policy and (3) a visionary scenario with very high support for electric mobility [MIRA-S, 2009]. The current distribution of 75% diesel cars and 25% gasoline cars is clear in all three figures. For 2020 we see the gradual introduction of a substantial amount of hybrid vehicles, even in the baseline scenario. The main difference in the scenarios lays in the introduction of plug-in hybrid (PHEVs) and pure electric vehicles (EVs). While in the baseline scenario sales of PHEVs and EVs is limited to 4% of car sales in 2020, this goes up to 10% for the Energy Saving scenario and 15% in the Visionary scenario.
For 2030 the differences are even bigger: in the baseline scenario PHEVs and EVs would have a 30% share in vehicle sales, going up to 50% in the Europe scenario and even 90% in the visionary scenario. Mind that most are plug-in hybrids, which still rely partly on fuel.

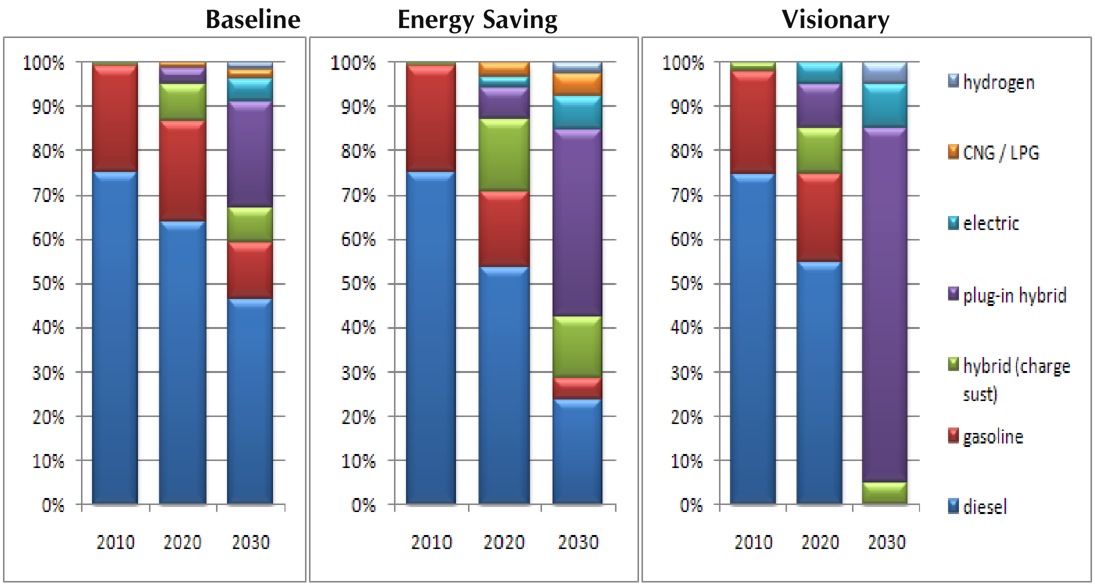


Figure 45: Technologies in car sales in different scenarios. Source: MIRA, 2009

When calculating what these scenarios would mean in terms of transport energy consumption, these electric cars would reach the shares of overall transport energy consumption represented in Table XXIX. While the visionary scenario is by definition rather extreme, the second (energy saving) scenario is ambitious, but not unrealistic. Therefore we suggest setting this as target.

Table XXIX: EV energy consumption, as compared to overall transport energy consumption

	Baseline	Energy Saving	Visionary
2020	0.2%	0.6%	2%
2030	2%	6%	14%

3.3.2. Role of cellulose based biofuels on the longer term

Advanced biofuels will enter the market in the coming decade. They are produced from a wider range of feedstock than current biofuels, including ligno-cellulosic feedstocks from residual/ waste biomass, dedicated energy crops as well as new concepts (e.g. algae, etc) through conversion techniques which are still in development. The production of advanced biofuels makes use of a large part of the biomass through conversion of ligno-cellulosic material.
At the current state of technology, the main options for advanced biofuels seem to be FT-Diesel (BTL) in diesel vehicle technology, cellulosic ethanol in gasoline vehicle technology and bio-SNG in compressed natural gas (CNG) vehicle technology. There are of course other options which are currently studied such as bio-DME in diesel vehicle technology as well as bio-methanol and bio-butanol in gasoline vehicle technology, or even bio-hydrogen in fuel cell vehicles.

Availability of sustainable feedstock at competitive prices is a major challenge for biofuels in the long run. Diversification of feedstock is therefore a major issue for future biofuel development. Biofuel production costs are largely dependent on feedstock prices and instability in the prices of agricultural commodities makes it important to support and develop technologies allowing for feedstock flexibility. Figure 46 shows an indicative roadmap from the European REFUEL project, indicating how advanced biofuels could enter the market.

This roadmap was developed in 2007, with very optimistic views on the development of cellulose based biofuels. Market development for these kinds of fuels is however going slower than anticipated at that time. Nevertheless the principles in the figure are still valid:

1. Start-up of the biofuel market with conventional food-crop based biofuels (biodiesel, ethanol). Demand for these fuels will saturate in the coming decade.

2. Ligno-cellulose based biofuels will enter the market in the coming decade. The market will start based on residues like straw or corn cobs & stalks. Afterwards dedicated ligno-cellulosic crops (wood, grass) will also come into play.

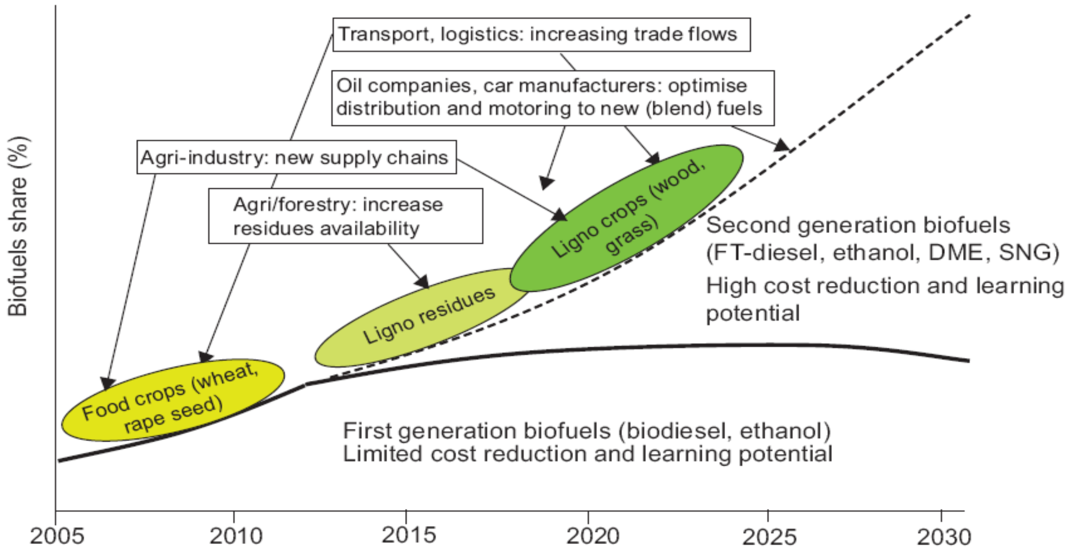


Figure 46: Indicative roadmap for second generation biofuels. Source: REFUEL (2007)

3.3.3. Policy recommendations

The following conclusions can be drawn from the previous chapters:

- while in the next 10 years current biofuels (based on agricultural crops) are still the basis, further growth afterwards will have to come from other feedstocks, like waste & residues, ligno-cellulose and possibly algae (long term),
- on the long term there can be synergy between electric mobility and biofuels:
    - biofuels can have an important role in the future transport system, specifically in heavy duty & long-distance transport,
    - specific focus for electric vehicles is needed for local traffic, passenger cars or public transport,
- when shifting to ligno-cellulose as a resource, this opens a lot of biomass potential on a global scale, but sustainability safeguards are clearly needed to avoid overexploitation at the local level,
- when using biomass it is important to look at synergies, e.g. co-production of bio-chemicals & materials, fuels, electricity, heat & other products (principle of bio-cascading and biorefinery concept),

- the main options for advanced ligno-cellulose based biofuels up to 2030 seem to be synthetic biodiesel (BTL) in diesel vehicle technology, ligno-cellulosic ethanol in gasoline vehicle technology and bio-SNG in compressed natural gas (CNG) vehicle technology. This means that for the long run, ethanol compatible vehicles and natural gas vehicles should be supported. Synthetic biodiesel does not pose problems with diesel technology.
- energy efficiency and energy saving in transport is key, in terms of limited resources of fossil resources, biomass & materials (batteries).

Based on the scenario calculations we suggest the following middle and long term policy targets:

Table XXX: suggested policy targets for the Belgian transport system

	Energy saving in transport	**Sales of electric cars (EV & PHEV)**	**Sustainable biofuels**
2020	13% compared to baseline	10% of car sales	8.5%* of transport energy use
2030	20% compared to baseline	50% of car sales	15% of transport energy use (1/3 based on cellulose & waste)

* 10% target of RED through double-counting waste & cellulose-based biofuels & electric mobility

Policy has an important role in the following fields:

- sufficient mobilization of biomass in a sustainable way
  - collection of residues,
  - new energy crops for farming sector ?
  - worldwide trade => support developing countries (also in agriculture); safeguard social, economic & environmental sustainability
- support energy efficient conversion technologies
  - further improvement of current installations
  - technologies using new feedstocks ("2nd generation")
  - integration / co-generation of fuels, electricity, heat and products
- efficient implementation of sustainability requirements (administrative burden, avoid administrative burden for smallholders),
- support market deployment (blending obligations, adapted fuel tax, fuel stations),
- reward high GHG performance of biofuels,
- support biofuel compatible vehicles (e.g. FFVs), preferably in a European frame.

CHAPTER 4 DISSEMINATION AND VALORISATION

Interaction with stakeholders and policy makers and dissemination have been key within the BIOSES project, as the project period (2007-2010) has been a very intensive period on the policy side in terms of biofuels. The BIOSES project has actively contributed to the Belgian NREAP through regular consultation with policy administrations, in terms of (1) projections of diesel and gasoline consumption in a baseline and an energy saving scenario, (2) providing realistic biofuel introduction scenarios which were applied in the NREAP, and (3) consulting, involving and informing biofuel stakeholders, of which several representatives were part of the BIOSES follow-up committee, on the potential framework of biofuel introduction in Belgium.

4.1. BIOSES WORKSHOPS

On *4 June 2009*, the BIOSES consortium organized a workshop at VUB in Brussels, entitled "Support options for biofuels on Belgian level". The programme of the workshop was in two parts: (1) discussion on biofuel policy options, (2) Start of a MAMCA exercise for stakeholder consultation.

On *15 December 2010* the consortium organized the final workshop at BELSPO in Brussels, entitled "A roadmap for biofuels in Belgium". 30 people attended the workshop, with coverage of most involved stakeholder groups and policy departments. Also people from outside the BIOSES consortium gave presentations. The workshop was organized in two parts: (1) Policy measures, (2) Biofuel impacts.

The presentations of both workshops are publicly available on http://wwwa.vito.be/bioses/events.htm.

4.2. ACTIVE PARTICIPATION IN BIOFUEL POLICY RELATED WORKSHOPS AND WORKING GROUPS

UCL (project partner) was the main organizer of the *3rd and 4th Table Ronde Biocarburants*, respectively on 10 June 2008 in Bois-de-Villers and 10 March 2010 in Namur.

BIOSES results and policy recommendations were used as input, while content and discussions of these roundtables were also directly relevant for the work within the BIOSES project.

All presentations are available on the Valbiom website: http://www.valbiom.be/index.php?url=fr/biocarburants/table-ronde-biocarburants/ http://www.valbiom.be/index.php?url=fr/4eme-table-ronde-biocarburants/

Discussion forum Biofuels, Flemish Parliament, Brussels, 1 April 2009. Project partner VITO was coordinator of a study for the Flemish Parliament on biofuels, in which biofuel sustainability, policy options and stakeholder positions were the main topics.

ENOVER workshop “Belgian perspectives for renewable energy in transport”, Brussels, 22 January 2010. Presentation by Ina De Vlieger based on BIOSES work (scenarios). Presentation by Jean-Marc Jossart “Biofuels in the national action plan”. The workshop served as preparation for the Belgian NREAP.

Targeted discussions with SPF Economy on the biofuel role in the Belgian NREAP (1^{st} half 2010).

Presentation at the final workshop of the European project ELOBIO (“effective and low-disturbing biofuel policies”), Brussels, 25 March 2010. VITO was partner in this project, responsible for inventory of biofuel policies.

Participation in the Biofuels Roadmap Workshop of IEA (International Energy Agency), Paris, 15-16 April 2010.

Discussion with administrations and biofuel producers on the Royal Arrest regarding the transposition of RED sustainability criteria for biofuels and bioliquids (14 January, 23 June, 26 October 2010).

Participation in the Belgian mirror group of CEN TC383 on “Sustainably produced biomass for energy applications – principles, criteria, indicators and verifiers for biofuels and bioliquids”.

Targeted discussions with the Belgian Petroleum Federation (BPF) on biofuel introduction scenarios and on the MAMCA study. Presentation of biofuel policy options to the General Information meeting of the Belgian Petroleum Federation, Antwerp, 2 December 2010.

Participation in the conference "Fuels of the future 2009", Berlin, 30 November-1 December 2009. Germany is a European leader the transposition of the RED and was the only country, end 2009, to have implemented the biofuel sustainability criteria.
The sessions "Political framework conditions for biofuels" and "Safeguarding sustainable biofuel production" as well as the parallel forums "Biofuels already established on the market" and "Renewable energies in the transport sector of the future" were directly relevant for the work within the BIOSES project.

Participation in the World Bioenergy Conference 2010, Jönkoping, 25 May – 27 May 2010. Parallel conferences "Policy – How to make it all happen", "Biofuels – new innovations and leading global examples" and "How to build a market for biofuels" have served as input for the works within the BIOSES project.

Participation in the Follow-up Committee of the TEXBIAG project.

CHAPTER 5 PUBLICATIONS

5.1. PEER-REVIEWED PUBLICATIONS

Van Mierlo J., Sergeant N., Timmermans J.-M., Wynen V., Turcksin L., Macharis C., 2007. Cost Efficiency of Clean and Efficient Vehicle Technologies (Belgian Situation). Transportation Research Part D: Transport & Environment, 2007.

Bram S., De Ruyck J. and Lavric D., 2009. Using Biomass: a System Perturbation Analysis, Applied Energy, Volume 86, Issue 2, February 2009, Pages 194-201, Elsevier.

Turcksin, L., Macharis, C., Lebeau, K., Boureima, F., Van Mierlo, J., Bram, S. De Ruyck, J., Jossart, J.-M., Gorissen, L., Pelkmans, L., 2011. A multi-actor multi-criteria framework to assess the stakeholder support for different biofuel options: the case of Belgium. Energy Policy 39, 200-214.

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5.2. PRESENTATION AT CONFERENCES AND PUBLICATION IN PROCEEDINGS

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ANNEXES

ANNEX 1: COPY OF THE PUBLICATIONS

ANNEX 2: MINUTES OF THE FOLLOW-UP COMMITTEE MEETINGS

Annex 1 : available on our website
http://www.belspo.be/belspo/ssd/science/pr_energy_en.stm

Annex 2 : available on request to project coordinator