SenterNovem

Participative LCA on biofuels

Rapport 2GAVE-05.08

Commissioned by

VROM

Summary

Introduction

During the lifecycle of biofuels, emissions arise during biomass feedstock production, transport of the raw material and products, conversion of the feedstock into the biofuel, and use of the fuel in cars. These emissions can have various impacts on environmental themes, such as the greenhouse effect, acidification, eutrofication, toxication, ozon layer depletion and photochemical smog. Also fossil energy carrier and other abiotic resources are consumed. By means of lifecycle assessment (LCA), all these effects can be studied. Whereas there exist a large amount of well-to-wheel energy and greenhouse gas balances of biofuels (Van den Broek et al. 2003), the number of full LCA studies on biofuels on these impacts is very small.

In general, in all LCAs there are many assumptions that cannot be made fully objective. This makes LCA susceptible to comments, even when data selection has been done in an independent and scientific responsible way. Often comments come from stakeholders who do not see the results of the LCA match with their own objectives. Outcomes of an LCA will always benefit some stakeholders more than others. Another important reason for comments is the fact that the whole system of various environmental impacts in a production chain are rather complex and that in many cases it will be difficult for stakeholders to have a feeling with the results and its sensitivity to the main assumptions.

In order to improve the acceptance of the results, SenterNovem commissioned Ecofys to perform a full biofuel LCA with active participation of a diverse group of stakeholders.

The main objective of this study is twofold:

- To communicate the environmental impacts of biomass-based fuels as compared to fossil diesel and gasoline with various stakeholders.
- To actively involve the stakeholders in the whole process of LCA, including the determination of the input parameters.

Participation

The main goal of the project thus was to involve biofuel stakeholders to decide over the goal and scope of the LCA, over parameter input, to learn about the process of lifecycle assessment and to understand its use and limitations. The researchers applied the choices and assumptions agreed upon among the stakeholders so that the final results followed from the joint view of stakeholders and researchers rather than from a researchers viewpoint only.

Stakeholders from the following groups were involved in the project:

- Raw material producers
- Biofuels producers
- Oil industry
- Environmental NGO
- End-users
- Government

These stakeholders were assisted by scientific experts in the areas of lifecycle assessment methodology, agriculture, field/crop N_2O balances, and automotive fuel end-use.

The interaction between stakeholders, experts, and Ecofys was organised in a series of meetings, and through email and internet communication (website). On a range of choices and general assumptions, the stakeholders agreed by consensus or vote majority. A few variations have been made where consensus could not be reached and where the stakeholders felt that alternatives should also be assessed or compared.

The stakeholders found several LCA issues complex. There was recurring discussion on the type of alternative land-use. Practically, the introduction of a biofuel feedstock in the Netherlands would mean the replacement of another agricultural product. The natural feeling was that this would define the alternative land-use. However, that agricultural product would still need to be produced, and, therefore, sooner or later new land will be taken into production elsewhere. The idea that this system expansion could be avoided by directly assuming a fallow land reference situation became gradually accepted.

The system expansion or allocation methods, necessary to deal with multiple products, are fundamental to lifecycle assessment, but the difference in meaning is difficult to understand for relative outsiders. Much time was taken to discuss these concepts.

Some stakeholders would have liked to include biodiversity in the LCA. However, because of a lack of reliable data this was not possible.

Where the main interest and knowledge of stakeholders related to the Dutch territory, LCA assesses the entire supply chain, including effects that may occur in other countries.

Eventually, when the final results were presented, some input parameters became again subject to discussion.

Chains assessed

The stakeholders chose to make the following comparisons:

- Bioethanol from wheat compared to gasoline
- BioETBE from bioethanol from wheat compared to MTBE
- Biodiesel from rapeseed compared to diesel

The bioethanol factory requires a large amount of heat, especially for distillation. In the base case comparison this heat was generated from natural gas. A variation has also been analysed where heat and power for the ethanol factory is generated from straw.

In the baseline biodiesel chain, economic allocation was applied to account for the economic value of the animal feed. A variation has been made that applied system enlargement instead: the rapeseed cake replaces soy based animal feed, which leads to reduced import (and thus production) of soy meal from the United States.

Results and sensitivity

First, it is stressed that the results from the present lifecycle assessment only hold for the cases and choices presented. If chains would be designed differently, the results would be different. E.g. the production of ethanol from agricultural residues can be more energy efficient and with less climate impact.

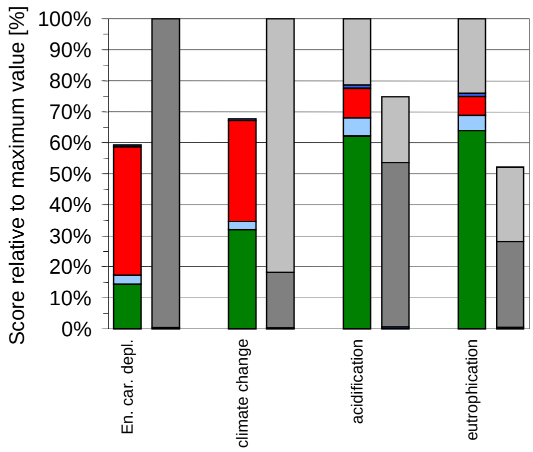


Figure Summary 1. Results of the baseline comparison between bioethanol and gasoline for four environmental themes.

When driving a car on bioethanol instead of gasoline, 40 % less fossil energy is used. There is a small fossil energy requirement in the agricultural step (fertiliser production and tractor use). The largest demand for fossil energy is in the conversion of wheat to ethanol. This is especially caused by the heat required for distillation. Other water/ethanol separation technologies may reduce this heat demand. On the other hand, the energy and climate impact can also be significantly improved by supplying the heat through renewable energy sources, such as the straw that is produced with the wheat and that would otherwise be ploughed back. In the baseline comparison, only 30 % greenhouse gas emission reduction is realised. When the heat and power for the ethanol factory is delivered from combusting straw (via CHP), the reduction can be 65 %.

Compared to gasoline, bioethanol leads to a 30 % reduced impact on climate change. Fertiliser use had a large impact on climate change, through emission of N_2O during both the production and use of N-fertiliser. Also, the conversion process (large energy use) is a large contributor.

Bioethanol performs worse than gasoline in terms of acidification (33% increase) and eutrophication (100 % increase). This is caused by the agricultural emissions of ammonia, NO_x, SO_x, and phosphates. End-use emissions relevant for these impact categories are the same for biofuels and their fossil alternatives.

When comparing BioETBE with MTBE, the reduction in fossil energy use is about 50 %. This is an improved result compared with ethanol replacing gasoline, caused by the more energy intensive production of MTBE compared with gasoline. Similar improvements are found in the other impact categories. In absolute terms, the conversion from ethanol to ETBE requires some extra energy and leads to extra emissions.

In terms of fossil energy use, the biodiesel chain performs about 57 % better than the diesel chain. There are equally large fossil energy uses in feedstock production and the conversion step. In the production of rapeseed feedstock, the larger part (80 %) is in fertiliser production, and the remainder mainly in tractor use. In the conversion to biodiesel, the largest consumer of fossil fuel is the production of methanol from natural gas.

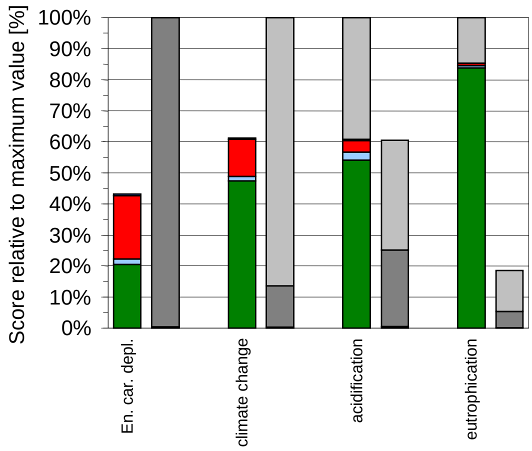


Figure Summary 2. Results of the baseline comparison between biodiesel and diesel for four environmental themes.

Biodiesel has a 40 % lower impact on climate change compared to diesel. The largest contribution comes from fertiliser production and application. Also this chain leads to increased impacts in acidification (67 %) and eutrophication (500 %) compared to diesel.

The sensitivity of the first four impact categories towards the use of fertiliser and towards the feedstock yield per hectare is considerable. Since a lower fertiliser use correlates with a lower product yield, the combined effect is limited.

Improvement options and recommendations

The emission of N_2O from the field is an important contributor to the climate impact of all biofuel chains. This emission is influenced by agricultural methods, more specifically by the amount and type of fertiliser applied, the method of application, timing of harvest, soil type, and the removal of agricultural residues. The ratio of feedstock yields per amount of fertiliser used should be increased to improve the biofuel chains' performances.

The N_2O emissions during fertiliser production could be reduced to almost zero by relatively easy and cost-effective technological measures. These technologies are expected to be applied when legislative or economic driving forces are introduced, such as when N_2O would be included in the European Union Greenhouse Gas Emission Trading Scheme ETS. This is likely to happen on foreseeable terms.

Besides the large influence from fertiliser production, a significant part of the NO_x emissions stem from tractor use. Also these emissions can be expected to decrease through more stringent legislation.

More insight is required in tailpipe and lifecycle evaporative emissions from biofuel blends in vehicles.

It is advised that, based on the positive experience in this project, that strong involvement of stakeholders in lifecycle assessments should be encouraged, in order to bring assumptions in line with the real-world practice, to increase interaction and mutual understanding among stakeholders, and to increase the understanding of the possibilities and limitations of this kind of analyses among stakeholders.

Samenvatting

Introductie

Tijdens de levenscyclus van biobrandstoffen, vinden er emissies plaats bij de productie van de grondstoffen, het transport van de grondstoffen en het eindproduct, bij de conversie van grondstoffen naar biobrandstof, en bij het gebruik van de brandstoffen in een wagen. Deze emissies kunnen verschillende invloed hebben op milieuthema's zoals het broeikaseffect, verzuring, vermesting, vergiftiging (van grond, water, mens), aantasting van de ozonlaag, en smog. Ook worden er fossiele en andere delfstoffen verbruikt. Levenscyclus analyse (life-cycle assessment of LCA) bestudeerd deze effecten. Terwijl er veel studies zijn naar het energiegebruik en de broeikasgasbalans van de productieketens van biobrandstoffen (Van den Broek et al. 2003), is het aantal volledige LCA studies op biobrandstoffen beperkt.

In het algemeen zijn in alle LCA's keuzes aan de orde die niet volledig objectief kunnen worden gemaakt. Hierdoor is LCA onderhevig aan commentaar, zelfs wanneer de data onafhankelijk en wetenschappelijk verantwoord is geselecteerd. Vaak komt er commentaar van belanghebbenden die zien dat de uitkomsten niet overeenkomen met hun belangen. Uitkomsten van LCA zullen altijd voor sommige belanghebbenden positiever zijn dan voor anderen. Een andere reden voor commentaar is het feit dat het hele systeem van milieueffecten in een productieketen nogal complex is, en dat het voor belanghebbenden moeilijk is om gevoel te krijgen voor de relatie tussen de belangrijkste aannames, uitkomsten en gevoeligheden.

SenterNovem heeft aan Ecofys opgedragen om een volledige LCA op biobrandstoffen uit te voeren, en om een diverse groep belanghebbenden hierin actief te laten deelnemen, om zo de uitkomsten van de LCA breder geaccepteerd te krijgen.

Het belangrijkste doel van deze studie is tweeledig:

- Het communiceren van milieu effecten van biobrandstoffen in vergelijking met fossiele diesel en benzine, met een groep belanghebbenden.
- Het actief laten deelnemen van deze belanghebbenden in de gehele levenscyclus analyse, inclusief in het bepalen van de input parameters.

Participatie

Het belangrijkste doel van het project is dus om belanghebbenden te betrekken in beslissingen over doel en reikwijdte, inputparameters, om hen te laten leren over het proces van levenscyclusanalyse en haar nut en beperkingen te begrijpen. De onderzoekers hebben keuzes en aannames gebruikt waarover de belanghebbenden het eens waren, zodat de uiteindelijke uitkomsten het gevolg zijn van de gezamenlijke inzichten van belanghebbenden en onderzoekers, en niet alleen van de onderzoekers.

Belanghebbenden uit de volgende groepen namen deel in het project:
- Grondstofproducenten (akkerbouw)
- Biobrandstofproducenten
- Olie industrie
- Milieu organisatie
- Eindgebruikers
- Overheid

Deze belanghebbenden werden bijgestaan door wetenschappelijke experts op het gebied van levenscyclus analyse, landbouw, lachgas emissies uit veld en gewas, en finaal gebruik van brandstoffen in auto's.

De interactie tussen belanghebbenden, experts, en Ecofys was georganiseerd in een reeks bijeenkomsten, en verder door middel van email en internet communicatie (website). Over een reeks van keuzes en algemene aannames, werd beslist door middel van een meerderheid van stemmen. Enkele variaties zijn gemaakt op punten waar geen consensus kon worden bereikt en waar de belanghebbenden vonden dat de alternatieve mogelijkheid ook moest worden onderzocht.

De belanghebbenden vonden een aantal LCA onderdelen ingewikkeld. Er was terugkerende discussie over de keuze voor alternatief landgebruik. In de praktijk zou de introductie van een grondstof voor biobrandstoffen in Nederland leiden tot verdrijving van een andere grondstof, welke dus het landgebruik in de alternatieve (oorspronkelijke) situatie zou bepalen. Echter, dit landbouwproduct zou ook in de nieuwe situatie moeten worden geproduceerd, waardoor vroeg of laat elders braakland in productie zou worden genomen. Het idee dat deze systeemuitbreiding kon worden vermeden, door het direct aannemen dat grondstof productie plaats vindt op van oorsprong braakland, werd gaandeweg geaccepteerd.

Systeemuitbreiding en allocatie methoden om met processen om te gaan die meerdere producten produceren, zijn fundamenteel binnen LCA, maar het verschil in betekenis is moeilijk te doorgronden voor relatieve buitenstaanders. Er is ruim de tijd genomen om deze concepten te bespreken.

Sommige belanghebbenden hadden graag biodiversiteit meegenomen in de analyse. Dit was niet mogelijk vanwege een gebrek aan betrouwbare data.

Terwijl de interesse van de meeste belangstellenden uitgaat naar het effect binnen Nederland, kijkt LCA naar de gehele keten, inclusief effecten die buiten Nederland optreden.

Uiteindelijk, bij presentatie van de eindresultaten, werd de discussie over sommige input parameters weer geopend.

Onderzochte ketens

De belanghebbenden kozen ervoor om de volgende ketens te onderzoeken:

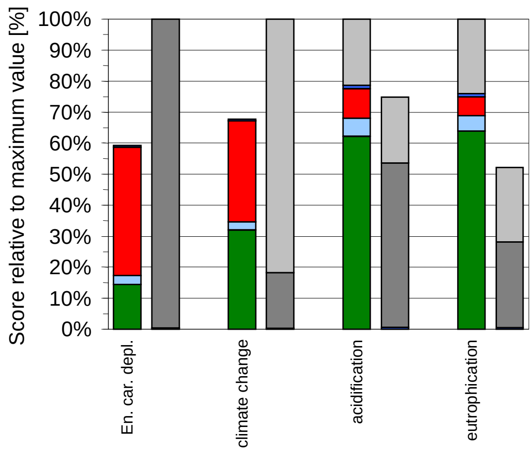
- Bioethanol uit tarwe vergeleken met benzine
- BioETBE uit bioethanol uit graan vergeleken met MTBE
- Biodiesel uit koolzaad vergeleken met diesel

De bioethanol fabriek heeft een grote hoeveelheid warmte nodig, vooral voor distillatie. In de basisvergelijking werd aangenomen dat deze warmte uit aardgas wordt geproduceerd. Een variatie is ook bestudeerd waarin warmte en kracht voor de ethanolfabriek uit stro wordt opgewekt.

In de basisvergelijking, werd een deel van de milieueffecten toegerekend aan gecoproduceerd diervoeder. Een variatie is gemaakt waarbij dit diervoeder binnen de keten blijft, maar leidt tot vermindering van soja diervoeder import uit de VS, en dus tot vermindering van landbouwactiviteit daar.

Resultaten en gevoeligheden

Ten eerste moet worden benadrukt dat de resultaten uit de huidige LCA alleen geldig zijn voor de onderzochte ketens met gemaakte keuzes. Als ketens anders zouden zijn ontworpen, dan zouden de resultaten ook anders zijn. Bijvoorbeeld, de productie van ethanol uit landbouwafval kan minder energie kosten en leiden tot minder klimaateffect.



Figuur Samenvatting 1. Resultaten van de basis vergelijking tussen bioethanol en benzine voor vier milieuthema's.

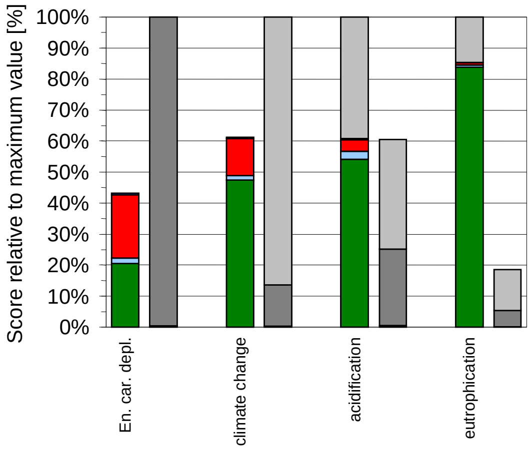
Om met een auto op bioethanol te rijden in plaats van op benzine, is 40 % minder fossiele energie nodig. Er is nog altijd een vraag naar fossiele energie in de landbouw stap (in kunstmest productie en tractor gebruik). De grootste vraag naar fossiele energie zit in de conversie stap van tarwe naar ethanol. Dit komt vooral door de warmte nodig voor distillatie. Andere water/ethanol scheidingstechnologieën kunnen deze warmte vraag misschien terugdringen. Aan de andere kant, het effect op energie en klimaat kan ook behoorlijk worden verbeterd door de warmte uit hernieuwbare bron te leveren,, zoals uit het stro dat is gecoproduceerd met het tarwe en dat anders zou worden teruggeploegd. In de basis vergelijking wordt slechts 30 % emissiereductie gerealiseerd. Wanneer warmte en kracht uit stro worden geleverd, kan de reductie 65 % zijn.

In vergelijking met benzine, leidt het gebruik van bioethanol tot een 30 % kleiner effect op klimaatverandering. Het gebruik van kunstmest heeft een groot effect op klimaat, vanwege de emissie van N_2O (lachgas, een sterk broeikasgas) tijdens de productie en door toepassing van stikstof kunstmest. Ook de ethanolfabriek, door het energiegebruik draagt veel bij aan klimaatverandering.

Bioethanol presteert slechter dan benzine op het gebied van verzuring en vermesting van het milieu. Dit wordt veroorz3aakt door landbouwkundige emissies van ammonia, NO_x, SO_x, en fosfaten. Eindgebruiksemissies die belangrijk zijn in deze effect categorieën zijn gelijk voor biobrandstoffen en de fossiele alternatieven.

Wanneer we bioETBE vergelijken met MTBE, is de beperking in fossiel energiegebruik ongeveer 50 %. Dit is een verbeterd resultaat in vergelijking met het vervangen van benzine door ethanol. Dit wordt veroorzaakt doordat de productie van MTBE energie-intensiever is dan de productie van benzine. Ook in andere effectcategorieën treedt een relatieve verbetering op. In absolute zin, kost het omzetten van ethanol naar ETBE wat extra energie en leidt tot extra emissies.

Biodiesel ketens gebruiken 57 % minder fossiele energie dan fossiele diesel ketens. Het energiegebruik is gelijkelijk verdeeld over grondstofproductie en conversie. In de productie van koolzaad grondstof, het grootste deel (80 %) zit in het produceren van de kunstmest, en de rest vooral in tractorgebruik. Bij het omzetten naar biodiesel, zit het grootste fossiele energiegebruik in de productie van methanol uit aardgas.



Figuur Samenvatting 2. Results of the baseline comparison between biodiesel and diesel for four environmental themes.

Biodiesel heeft een 40 % kleiner effect op klimaatverandering in vergelijking met diesel. Het grootste deel komt uit kunstmest productie en toepassing. Ook deze keten geeft een toename in verzuring (67 %) en vermesting (500 %) in vergelijking met diesel.

De gevoeligheid van de eerste vier effectcategorieën voor variatie in kunstmest gebruik en grondstof opbrengst per hectare is aanzienlijk. Maar omdat een lagere kunstmestgift relateert aan een lagere opbrengst per hectare, is het gecombineerde effect beperkt.

Verbeteropties en aanbevelingen

Emissie van N_2O vanaf de akker levert een belangrijke bijdrage aan het klimaat effect van iedere biobrandstof keten. Deze emissie wordt beïnvloed door landbouwkundige methode, vooral door de hoeveelheid en type van toegepaste kunstmest, de manier waarop de toepassing plaatsvindt, timing van de oogst, bodemsoort, en het al dan niet verwijderen van gewasresten. De verhouding van gewasopbrengst per hoeveelheid kunstmest zou moeten worden verhoogd om de prestatie van biobrandstofketens te verbeteren.

De N_2O emissies tijdens kunstmest productie kunnen tot bijna nul worden gereduceerd door toepassing van relatief makkelijke en goedkope technologieën. Deze technologieën worden verwacht zodra er wettelijke of economische drijfveren worden geïntroduceerd, zoals wanneer N_2O in het emissie handelssysteem ETS van de Europese Unie zou worden opgenomen. Dit wordt op afzienbare termijn verwacht.

Naast de grote invloed uit kunstmest productie, komt er een significant deel van NO_x emissies uit het gebruik van de tractor. Ook deze emissies kunnen naar beneden gaan als gevolg van strengere wetgeving.

Er is meer inzicht nodig in de eindgebruiks- en verdampingsemissies als gevolg van het toepassen van mengsels van biobrandstoffen en fossiele brandstoffen.

Gebaseerd op de positieve ervaringen in het huidige project, verdiend het aanbeveling om belanghebbenden intensief te betrekken in levenscyclus analyses. Op deze manier kunnen aannamen in lijn worden gebracht met de echte praktijk, kan de interactie en het wederzijds begrip tussen belanghebbenden worden vergroot, en kunnen zij de beperkingen en mogelijkheden van LCA beter begrijpen.

Content

1 Introduction

1.1 Background

During the lifecycle of biofuels, emissions arise during biomass feedstock production, transport of the raw material and products, conversion of the feedstock into the biofuel, and use of the fuel in cars. These emissions can have various impacts on environmental themes, such as the greenhouse effect, acidification, eutrofication, toxication, ozon layer depletion, photochemical smog, land use, and biodiversity. Also fossil energy carrier and other abiotic resources are consumed. Whereas there exist a large amount of well-to-wheel energy and greenhouse gas balances of biofuels (Van den Broek et al. 2003), the number of full LCA studies on biofuels on these impacts is very small.

Within the BIGFIT Prelude (Van den Broek et al. 2002) project a simplified LCA of wood-based FT diesel as compared to fossil diesel was undertaken. It was found that the wood-based FT chain scored better on most environmental impacts. It was clear, however, that the results were very much dependent on a limited set of assumptions, such as:

- The amount of fertiliser used during energy crop cultivation and the conversion factors for determination of leaching and N_2O emission of this fertiliser;
- The reference base for direct emissions of fossil based diesel;
- The emissions of ships for international transport of wood;
- The energetic efficiency of the BIGFiT conversion steps;
- The estimation of all main assumptions for the year 2020.

Changes in these variables, that are often difficult to determine in a fully objective way, cause significant changes in the outcomes of the LCA.

The limited scope of this simplified LCA lead to a few open questions:

- How can environmental impacts of the whole chain, but mainly of energy crops cultivation, be minimised?
- What would be the environmental performance of the biofuel chain when some input data would be changed?
- What is the opinion of a range of experts and of environmental stakeholders on the most important input data used?

In general, in all LCA's there are many assumptions that cannot be made fully objective. This makes LCA susceptible to comments, even when data selection has been done in an independent and scientific responsible way. Often comments come from stakeholders who do not see the results of the LCA match with their own objectives. Outcomes of an LCA will always benefit some stakeholders more than others. Another important reason for comments is the fact that the whole system of various environmental impacts in a production chain are rather complex and that in many cases it will be difficult for stakeholders to have a feeling with the results and its sensitivity to the main assumptions.

In order to improve the acceptance of the results, SenterNovem commissioned Ecofys to perform a full biofuel LCA with active participation of the stakeholders.

1.2 Research objective

The main objective of this study is twofold:

- To communicate the environmental impacts of biomass-based fuels as compared to fossil diesel and gasoline with various stakeholders by performing a participative LCA of these options.
- To actively involve the stakeholders in the whole process of LCA execution, including the determination of the input parameters.

In this project, a group of experts watched over the quality of the data input used. The result is an information exchange, in which the stakeholder will be better informed on the environmental performance of the considered biomass chains and in which stakeholders will be informed in detail on the points of view of other stakeholders regarding the respective biomass chains. Although full consensus may be difficult to reach, convergence of opinions on the environmental performance of various biofuels is expected.

Thus, besides reporting assumptions, research method and results, this study mainly aims to increase the interaction / discussions between stakeholders, to increase their knowledge on the (in)posibilities of lifecycle assessment, to increase their understanding of the results and sensitivity towards assumptions, and to report the way the participation took place.

1.3 Approach

On beforehand, four biofuels that could be assessed were preselected by Ecofys and SenterNovem:

- Bioethanol from wheat
- Biodiesel from rapeseed
- Bioethanol from woody biomass
- Fischer-Tropsch diesel from woody biomass

Because of the limitation of the budget and time a demarcation must be made of the given cases. The stakeholders were asked to choose one of the following combinations of biofuels chains:

- Two short term biofuel options:
  - Biodiesel from rapeseed compared to diesel;
  - Bioethanol from wheat compared to gasoline;
- Two long term options:
  - Fischer-Tropsch diesel woody biomass compared to diesel;
  - Bioethanol from woody biomass compared to gasoline;
- Two gasoline replacement options:
  - Bioethanol from wheat compared to gasoline in the short term;

  - Bioethanol from woody biomass compared to gasoline in the long term;
- Two diesel replacement options:
  - Biodiesel from rapeseed compared to diesel in the short term;
  - Fischer-Tropsch diesel from woody biomass compared to diesel in the long term.

In the first stage of the project a selection of one of the four combinations is made by the stakeholders.

In various meetings the goal and scope of the study, the composition of fuel chains from well-to-wheel, and scientific methods were discussed by the stakeholders. They asked for advice from experts in the field of LCA, agriculture, N_2O emissions from fields, and end-use. The stakeholders made the major decisions. Ecofys prepared the items to be discussed, compiled the advices, made the calculations according to choices of the stakeholders, and finally reported the results.

1.4 Reading guide

Because of the two-fold nature of this study, the report deals with LCA inputs and results on the one hand, and with interaction, discussions and explanations on the other hand.

Chapter 2 describes the interaction with the stakeholders through meetings, mailings and a website.

Chapter 3 to 6 deal with the LCA itself, from the definition of the chains, via assumptions and applied methods to the results.

The Annexes contain more details on the stakeholder involvement (minutes of workshops) and on LCA input (advices from experts, basic assumptions).

2 Stakeholder participation

Stakeholders were involved in the assessment, to decide over goals and scope, over parameter input, to learn about the process of lifecycle assessment and to understand its use and limitations. The interaction with stakeholders was organised in a series of meetings, and through email and internet communication.

This section was written by Ir. Jorg Raven and Ir. Eric van den Heuvel of SenterNovem.

2.1 Original goals

One of the goals of the project was to involve stakeholders of the biofuel chain in the process of making choices for points of departure and assumptions. Transparancy as well as the quality of the research results were to benefit from this approach. The stakeholders themselves were to obtain insight in the complexities of performing a lifecycle assessment (LCA) and were to get detailed information about the motives and preferences of the other parties involved. Also, they were to obtain awareness of the limited applicability of the results of the lca by participating in the process.

The researchers applied the choices and assumptions agreed upon with the stakeholders so that the final results followed from the joint view of stakeholders and researchers rather than on the choices and points of view of the researchers alone.

2.2 Organisation

For a good participation of stakeholders in the LCA process, a condition is that the distribution of the different participants is well-balanced, so that (most of) the interests involved in the biofuels topic are covered. The coverage of stakeholders in this LCA is displayed in Figure 2-1, indicated by the thick lines around the boxes. The stakeholders were assisted in the discussions and decision-making by experts. These experts in the fields of lifecycle assessment, agriculture, N_2O emissions from fields, and automotive end-use were involved to complement the knowledge level of the researchers and to be able to directly answer questions of stakeholders and advise on complex matters in their field of expertise. In Annex F the names of the participating organisations are listed along with their attendance at the 5 meetings that were held.

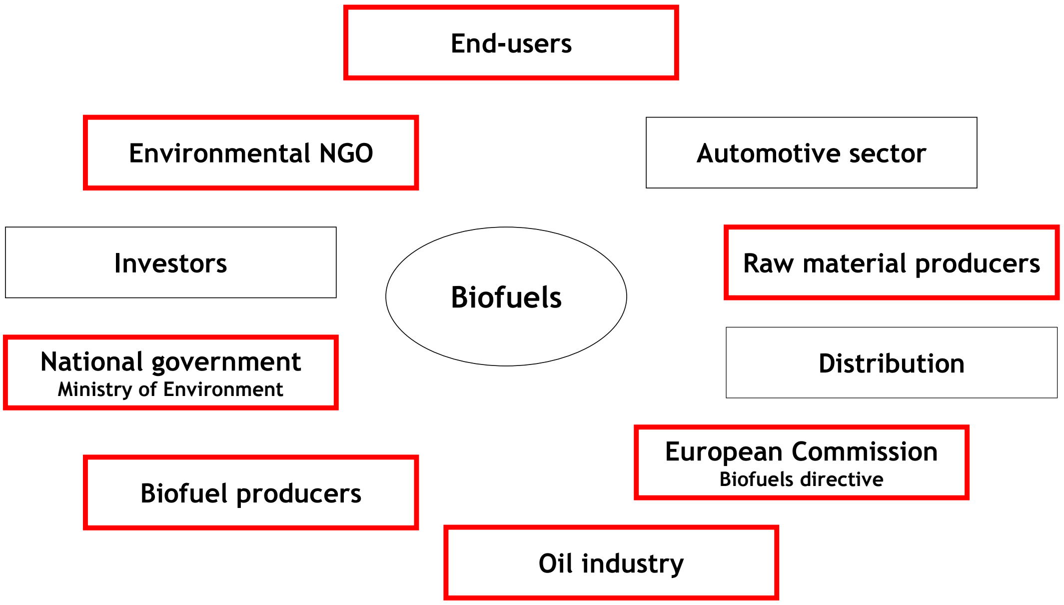


Figure 2-1. Coverage in this LCA of stakeholders around the biofuel topic is indicated by thick-bordered boxes.

The subject of the five workshops is given below (more details about the contents of the workshops can be found in the minutes in Annex A):

WS1: Choice of biofuels chains, goal and scope definition.
WS2: Decisions on method, and generic well to wheel layout
WS3: Parameter details
WS4: Draft results (LCA quick scan)
WS5: Final results

The group of stakeholders agreed that a decision about a choice or assumption can be made by:

a. Reaching consensus
b. If there is no consensus, then by voting (directly or after a meeting, by e-mail)
c. If sufficiently important, then incorporate more variations to be dealt with in the study. The number of variations should be kept small to avoid an impracticable "tree of choices".

Experts did not vote, but when asked by the stakeholders, they gave advice. They guarded the basic methodology and data quality of the LCA work.

During the project the stakeholders were given access to a virtual office, hosted by the VIEWLS website (www.viewls.org). The virtual office enabled the stakeholders, experts and researchers to view the minutes, contact information on other stakeholders, preliminary results and presentations.

2.3 Process and stakeholder input

The actual participation of the stakeholders as a group was limited to 5 afternoon workshops. In each workshop the researchers presented and clarified the choices that had to be made in the workshop. Then each choice was discussed and, if necessary, explained by experts and recorded. A full list of the choices made can be seen in Table 2-1. The minutes of those meetings can be consulted in Annex A.

Table 2-1. List of choices and motives of the stakeholders.

Choice	Outcome	Motives	Workshop
1. Chains to be compared	Biodiesel and bioethanol on the short term will be compared with diesel and gasoline respectively. There is the wish to incorporate ETBE compared to MTBE.	Short-term fuel options are closest to introduction. ETBE is likely option for ethanol application.	1
	Reference for growing feedstock is green fallow/ set aside land	See Section 4.1.4.	
2. End use and functional unit	Complete chain including end-use will be assessed. Comparison on basis of km driven.	Transparent functional unit including end-use	1
	Diesel-engine vehicles will be a weighed average of light and heavy duty. Otto-engine vehicles will be light duty only. biofuel application will be blends	Case most likely at market introduction	
3. Time horizon	Short-term, 3 years horizon, vehicle performance averaged for current fleet.	Beyond 3 years, many variables change (i.e. fuel standards, emissions standards)	1
4. Geography	Maximum possible feedstock production in the Netherlands.	Feedstock production can go up in Netherlands.	2
	Biofuels target is 4.2% by energy	In-between 2005 and 2010 target.	
	Bioethanol: feedstock is wheat from Western Europe. Biodiesel: feedstock is rapeseed; ½ from Western Europe, ¼ from Eastern Europe and ¼ from World[1].	Biomass availability depends on market	
	Import commodity for biodiesel from EE and World is bio-oil	Long-distance transport	
5. Allocation method for multi-product processes	Method chosen is economic allocation for all chains. In the sensitivity analysis the method of system enlargement will also be used for one chain (rapeseed cake displaced by soy meal).	Practical consideration to opt for economic allocation; system enlargement to show consequences of other method	2
6. Impact assessment categories	All possible categories will be assessed, relevance of the results will be expressed on a relative basis.	Stakeholders wish to see all impacts.	2
7. Feedstock production	As the type of agriculture, Ecofys assumed the practice as is reported in the KWIN.	Other types of agriculture have no data available in the chosen geographical area's other than the Netherlands.	Not plenary discussed
	Soil type is assumed to be mineral.	Advice from Alterra.	
8. Transport	From world: large sea vessel (150 ktonne), Eastern Europe: barge (1.2 ktonne) Each transport step carries freight on the return way.	Perceived as the most likely scenario	Not plenary discussed

[1] in this study, Western Europe is represented by United Kingdom, the Netherlands, Germany and France. Eastern Europe is represented as Poland. For the World, an average of these 5 countries has been taken (see Annex E.1).

Table 2-1 c'd. List of choices and motives of the stakeholders

9. Conversion	Standard facility size for biodiesel is assumed to be 150 ktonne/year and for bioethanol 200 Ml/year. The process type for biodiesel is assumed to be standard; for bioethanol the semi-wet process is chosen. Auxiliaries; electricity is taken from grid. Heavy fuel oil for heating the oil press (biodiesel). Natural gas for generating the heat required for ethanol production.	Representative for current practice.	2
10. Co-products	Wheat and rapeseed straw: 1/3 left in field (ploughed into soil), 1/3 applied as bed-material for cattle, 1/3 applied for local electricity generation in CHP unit.	Depends on geographical location of feedstock production, therefore a mix is chosen.	2
	Cake from both biodiesel and bioethanol production is applied as fodder for cattle.	Cake is assumed to have value	
	Glycerine from biodiesel production is sold to pharmaceutical market	Glycerine market assumed large enough for next 3 years	
	Lignin residue from ethanol production will not be combusted to produce heat and electricity. However, a variation will be analysed where straw is used for CHP.		
	CO_2 from ethanol production is not considered as a co-product	Considered too far from real implementation	
11. End-use	Maximum allowable blends will be used in part of the fuel (biodiesel in diesel: 5% by volume, bioethanol in gasoline: 5% by volume, bioETBE in gasoline: 15% by volume)	More attractive to apply 5% ethanol in part of the gasoline, than 3.5% in all gasoline.	2

Upon choosing the impact assessment categories (choice 6), some stakeholders mentioned that the impact on land-use and biodiversity[2] should also be assessed because those themes could be put under pressure with increasing biofuel consumption. Normally these categories are not included in LCAs, however it is decided that the impact on land-use will be assessed by means of the direct land-use that can be allocated to the biofuel.

Regarding the fossil fuel chains it was mentioned that it is very important to use real world data and gain insight in allocation within refineries in order to make an equal comparison between fossil and bio-based chains. Ideally, the same (type of) choices, assumptions and methods should be applied to both chains.

Workshop 4 was mostly dedicated to discussion of the results of the quick scan, or preliminary results, as workshop 5 was used for the presentation of the final results.

[2] The impact on biodiversity has not been assessed, because of lack of reliable data. Stakeholders mentioned the importance of this category, e.g. the disorientation of whales caused by oil drilling and shipping noise, and the impacts from monoculture feedstock production plots.

3 Chains compared

The stakeholders choose to make the following comparisons:

- ***Bioethanol from wheat, with gasoline***
- ***BioETBE from bioethanol from wheat, with MTBE***
- ***Biodiesel from rapeseed, with diesel***

In this chapter the chains from feedstock production, via distribution up to end-use are described, as well as some major variations applied.

3.1 Bioethanol compared with gasoline

The first comparison is between bioethanol and fossil fuel derived gasoline, see Figure 3-1 (**A**). One kilometer driven by a car on ethanol (as E5 [3]) will be compared by one kilometre driven by a car on gasoline.

The feedstock for the bioethanol is winter wheat produced in Western Europe. Therefore, parameters for yield and fertiliser application are assumed to be an average of the Netherlands, Germany, France and the UK. The use of pesticides and equipment energy is taken the same for each country. Per truck, the harvested wheat is transported to an ethanol factory. Of the co-produced straw, a two third part finds an application as bed material and feedstock for electricity generation. This implies an economic value and, therefore, the straw bears part of the environmental burden of the chain. The methodology chapter will describe how co-products are dealt with in this LCA. The remainder of the straw is left in the field and ploughed in the soil, which influences soil emissions.

The ethanol factory co-produces animal feed (distillers dried grains with solubles - DDGS), which has an economic value. The factory requires a large amount of heat, especially for distillation. In the base case comparison this heat is generated from natural gas, which contributes significantly to the chain's overall use of fossil fuels and overall greenhouse gas balance. In variation **A1** the heat is generated from straw. This requires straw from the field to be dried, baled and transported. The combined heat and power facility produces more electricity than is needed, so that the remaining part has to be sold to the grid.

The bioethanol product is distributed to fuel storage depots and stations by truck. The end-user is an average Dutch passenger car in 2008.

The reference fuel gasoline is produced in Western-European refineries.

[3] In order to visualise the differences between biofuels and fossil fuels, we use the "neat fuel comparison basis" (Van den Broek et al. 2003). In other words, we concentrate only on that part of the blend where the difference is made with the introduction of biofuels.

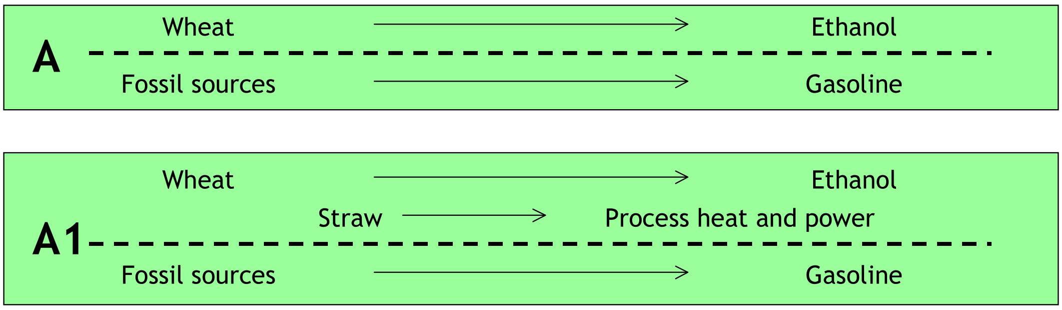


Figure 3-1. Well-to-wheel chain for bioethanol compared with one for gasoline. A represents the base case comparison, where in A1 heat for the ethanol factory is generated from straw.

3.2 bioETBE compared with MTBE

The second comparison is between biomass derived ETBE (ethyl tertiary butyl ether) and MTBE (methyl tertiary butyl ether), see Figure 3-2 (**B**). For this chain, bioethanol is converted to bioETBE by synthesis with isobutylene. MTBE is produced from methanol by synthesis with isobutylene. For the same energetic amount of ether, slightly different amounts of isobutylene are required. The methanol for MTBE is produced from natural gas.

The comparison is done in a 2008 passenger car fuelled by gasoline.

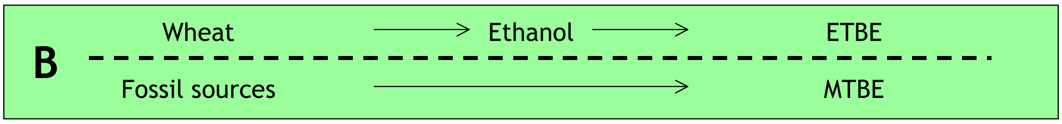


Figure 3-2. Well-to-wheel chain for bioETBE compared with one for MTBE.

3.3 Biodiesel

The third comparison is between biodiesel and fossil fuel derived diesel, see Figure 3-3 (**C**). The feedstock for biodiesel is rapeseed oil. Half of this feedstock is assumed to come from Western Europe, one quarter from Eastern Europe and one quarter from "the rest of the world". In this LCA, the difference between feedstock production in Western Europe (average between Netherlands, Germany, France and the United Kingdom) and Eastern Europe (Poland) resides in the yield per hectare and the application of fertiliser. The use of pesticides and energy for equipment (per tonne feedstock) for the different countries is kept at one value.

The feedstock rapeseed in all countries is transported to the oil press by truck. From the oil press to the biodiesel factory there is generally no distance, except when explicitly stated. The feedstock oil from the "rest of the world" is transported by ocean ship to a biodiesel factory in Western Europe. In the oil press animal feed is co-produced, in the biodiesel factory, glycerine is co-produced. In the base case economic allocation (see Chapter 1) is applied to account for the economic value of the animal feed. In comparison C1, system enlargement is applied instead: the rapeseed cake replaces soy based animal feed, which leads to reduced import (and thus production) of soy meal from the United States.

The distribution of the final product is the same as for other chains. The (bio)diesel is used in a weighted average of passenger cars and heavy duty vehicles in 2008.

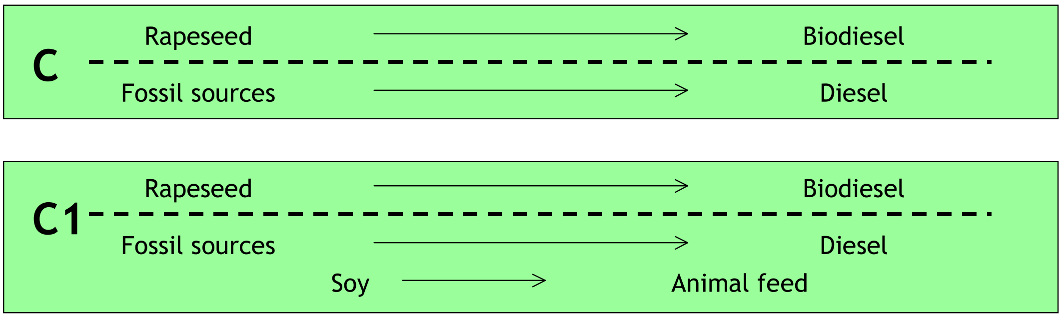


Figure 3-3. **Well-to-wheel chain for biodiesel compared with one for diesel.** C **represents the base case comparison with economic allocation to the co-products. In** C1 **system enlargement is applied: the rapeseed cake replaces soy based animal feed from the USA.**

4 Major assumptions

This chapter deals with the following major technical and economical items:
- ***Feedstock production.***
- ***Greenhouse gas emissions from fertiliser production.***
- ***Brief description of the biofuel factories.***
- ***End-use efficiency and emissions.***

More detailed assumptions and parameters for the LCA are given in Annex D.

4.1 Feedstock production

A significant part of the well-to-wheel emissions reside in the feedstock production, more specifically in the production and application of fertiliser and in the application of pesticides. The actual agricultural emissions are discussed in this section, Section 4.2 will deal with fertiliser production.

4.1.1 Greenhouse gases from fertiliser application

Farming is the primary source of greenhouse gas emissions associated with biofuels production because of emissions of nitrous oxide (N_2O). These emissions are not very large in mass terms but the very high greenhouse effect of this gas (about 300 times more than CO_2 on mass basis) makes their impact significant. N_2O emissions from farming are dominated by two sources: nitrogen fertiliser production and fertiliser application on the field (Edwards et al. 2004).

The IPCC (Intergovernmental Panel on Climate Change) applies a generic method to calculate the N_2O emissions from agriculture. Part of the applied N fertiliser directly volatiles to ammonia, which leads to emission of N_2O. Another part yields direct soil N_2O emissions. For this soil emission, the IPCC gives an uncertainty range.

In the present LCA, it is assumed that part of the residues is left in the field, which partly leads to extra soil N_2O emissions. The IPCC method cannot distinguish between crops (as it is applicable to country level). Therefore, an N balance was designed for this LCA, based on the method of Velthof and Kuikman (2000), which explicitly accounts for emissions from crop residues, and including the main IPCC N_2O emission factors. This method is described in detail in Annex E.4.

The exact amount of fertiliser and the resulting yield are to a large extent determined by farm economics. In the present LCA an average yield and fertiliser application has been assumed from data on the selected countries (See Annex E.1). A sensitivity analysis will be done to assess the influence of the effect of yield / fertiliser combinations on the overall chain environmental performance.

4.1.2 Other emissions from fertiliser application

In the case of phosphorus fertiliser it was assumed that 9 % of the P surplus leaches to groundwater in the form of phosphates (Van Zeijts et al. 1996).

4.1.3 Application of pesticides

As with the application of fertiliser, the application of pesticides is the result of an economic consideration by the farmer. The application of pesticides leads to direct emissions to soil, air and water. The impact of pesticides on toxicity of sweet and marine water and sediments is known for most of the applied pesticides. For the few pesticides that are not included in CML databases, the impact has been estimated by applying the average of the other applied pesticides. This is described in more detail in Annex E.2.

4.1.4 Alternative land use

To produce feedstock requires the occupation of agricultural land. This land is also used in the alternative fossil fuel chain, see Figure 4-1 (c). The alternative land use could have been for the production of other crops, it could have had other uses, or it could have been set-aside agricultural land. If, in the alternative situation, also a useful product was produced on the plot of land, this would mean that the alternative chain has two products, whereas the biofuel chain only has one. To keep the chains comparable, the biofuels chain must also deliver this product. This can be done by e.g. import from another country, but at another location then again a plot of land is required to produce this product. This plot of land also had an alternative use before the interference of the biofuels chain. This reasoning encompasses two risks:

- An endless series of substitution, which leads to modelling the world.
- The biofuels chain will have multiple products that have no relation with fuels.

We assume that, since the introduction of biofuels will, at least up to 2010 (worldwide), not lead to the loss of another product (Van den Broek et al. 2003), sooner or later the plot of land substituted will have no alternative useful product. By subtracting all the intermediate substitutions that the biofuel and fossil fuel chain have in common, it follows that the alternative land use delivers no useful products. A clear agricultural alternative land use that delivers no useful product, is set-aside.

In the case of set-aside land, still machinery and fertiliser are used to keep the land in good condition. These actions can be subtracted from the agricultural actions in the biofuel chain. The same holds for the emission burden.

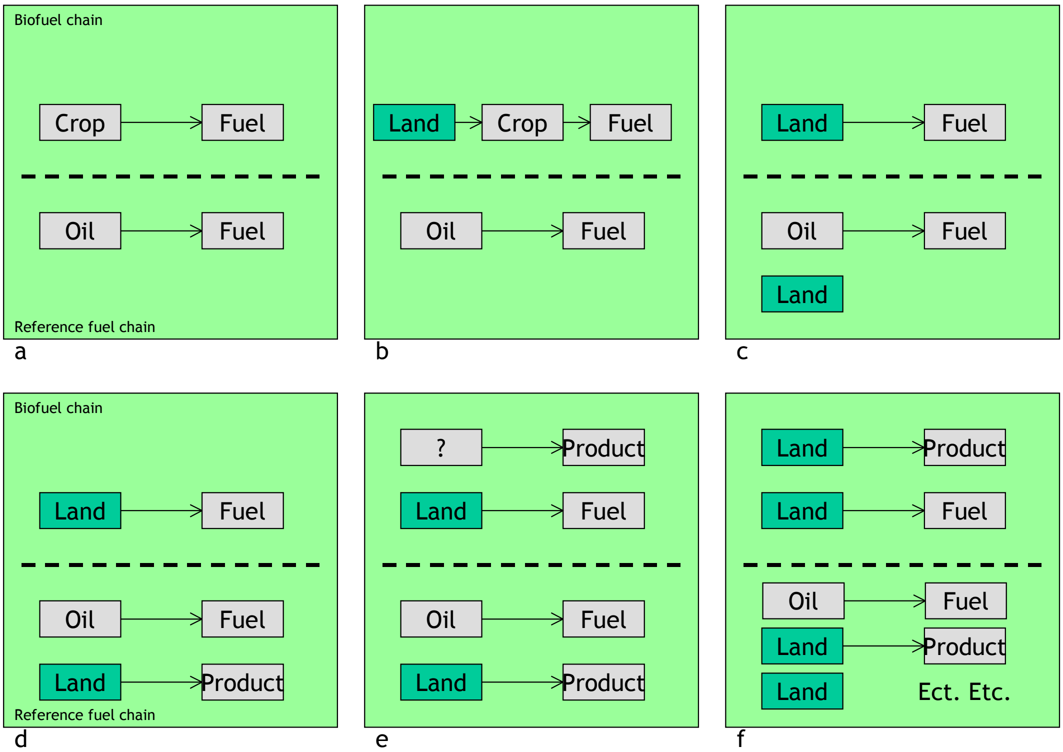


Figure 4-1. **Alternative land use producing a useful product would lead to endless system enlargement.**

4.2 Fertiliser production

The production of fertiliser demands much energy and generates considerable greenhouse gas emissions. It has been estimated that fertiliser production consumes about 1.2 % of the worlds energy and is responsible for approximately 1.2 % of the total GHG emissions (Wood et al. 2004).

We assume that the nitrogen fertiliser used in crop production is CAN[4] (calcium ammonium nitrate). Production of this fertiliser emits both large amounts of CO_2 (ammonium production), and N_2O (nitric acid production). As greenhouse gas, N_2O is per kg almost 300 times stronger than CO_2.

The production of CAN fertiliser and the accompanying emissions are described in Annex E.3.

4.3 Conversion

The conversion of rapeseed to biodiesel and of wheat to ethanol has been modelled using data from Elsayed et al. (Elsayed et al. 2003). Mass balances and economic values underlying the allocation are given in Annexes E.6 and E.8. The production of ETBE as compared to MTBE is discussed in E.7.

[4] Besides nitrogen fertiliser, potassium and sodium fertiliser are also applied in this LCA.

All biofuel production processes consume heat, which is assumed to be produced from fuel oil, natural gas or straw. The associated emissions are discussed in Annex E.9. In variation A1, straw is used for the heat and electricity supply of the ethanol factory. Logistic and pre-treatment actions for straw are given in Annex E.10.

In variation C1, rapeseed cake substitutes soybean meal, which would otherwise be produced from soy beans in the USA, and transported by ship to Europe. The growth and harvest of soy beans and the oil extraction that yields oil and meal is modelled (parameters in Annex E.11); part of the emission burden of the growth and pressing is allocated to the oil, which is sold in the USA, and part is allocated to the meal.

4.4 End-use

The functional unit for the comparison of biofuels and fossil fuels chains is 1 kilometre driven by an average car. For the comparison of ethanol versus gasoline, the car is an average passenger car in 2008. This car has a certain efficiency and certain emissions (see Annex E.12). Biodiesel and diesel are compared in an average of passenger cars and heavy cars using diesel, both with average 2008 performance.

Ethanol has a lower energy content per litre than gasoline. Therefore, one would expect that one can drive less distance on a litre ethanol, than on a litre of gasoline. In Ecofys' earlier fact-finding study (Van den Broek et al. 2003), it was suggested that using small blends of ethanol may possibly lead to an octane increase and car-efficiency gain, such that not more litres are consumed when driving 1 km on E5, than when driving 1 km on pure gasoline. Uncertainties in measurement make it difficult to distinct between efficiency gain and no efficiency gain. The expert on vehicle performance and emissions, advised that unless the cars would be recalibrated for optimum results with the use of E5, they would not be able to employ the higher octane for a higher car-efficiency. Also, oil companies may compensate for the higher octane by adapting the gasoline and removing other octane enhancers. For average cars it can be expected that there is no efficiency gain. This latter assumption was used in this study.

4.5 Incidents and accidents

Some of the stakeholders have stressed that negative impacts from oil production and transport should be accounted for. Oil spills are included in the Ecoinvent database, which is applied within this study. The Ecoinvent guidebook mentions that "impacts from exceptional events are not considered. Accidents which might have very dramatic impacts, but which do occur only seldom are thus not considered. An example for this is the risk of a serious accident in a nuclear power plant like it happened in Chernobyl. On the other side incidents happening more regularly are considered in the inventories. Examples are oil spills due to ruptures of transport pipelines. These spills occur frequently and are reported regularly. One can see that the total amount of spills per year is not influenced so much by individual accidents." This implies that the existing impact of a product chain is described in a reliable manner.

Also, the use of chemicals in oil drilling and the flaring of associated gas is included in the Ecoinvent database. Where country specific data were not available worldwide average data have been used (Dones et al. 2004).

5 LCA methodology

5.1 Lifecycle assessment planning structure

Lifecycle assessments, according to ISO14040, are subject to an organised structure:

1. Goal and scope
2. Inventory
3. Impact assessment
4. Interpretation

5.1.1 Goal and scope

In this phase the initial choices are made that fix the workplan for the complete LCA. The goal depends on the exact research question, the target group and the application. The scope considers the time frame, the geographical locations and the state of the technology. In this phase the productsystems (fuel chains) to be compared are defined in a broad and generic sense.

In the present LCA, the stakeholders together defined the goal and scope (see Chapter 1).

5.1.2 Inventory

The inventory defines the productsystems in more detail, by focussing on subprocesses, limiting the process trees, gathering data, and calculating allocation or defining system extension in case of multiproduct processes. Multiproduct processes are discussed in §5.3.

In the present LCA, Ecofys designed the process trees and delivered input for the subprocesses. Both stakeholders and experts assisted in filling-in data for e.g. the feedstock production, the conversion and the end-use processes. Use was made of Ecoinvent databases for the majority of subprocesses, which were expected to have less impact on the overall results.

The product of this phase is the input and output to the environment per subprocess and subproduct, in terms of emissions and energy and material use. These inputs and outputs are calculated for the complete process tree. This yields a table with inputs and outputs expressed in the functional unit (i.e. per km).

5.1.3 Impact assessment

In the impact assessment the effects of the emissions and inputs to the chain are multiplied by their respective impacts on different environmental categories. These impacts are expressed in equivalent units. For example, CO_2, N_2O and CH_4 have a respective impact on climate change of 1, 296 and 23 kg CO_2-equivalent.

The inventory step yields results for the biofuel and fossil fuel chain in comparative units on a comparative basis (per km). A normalisation step compares the contribution of this km fuel use to the total Dutch national environmental impacts.

5.1.4 Interpretation

In this step the results are evaluated and analysed, and conclusions can be drawn. The analysis encompasses the relative contribution of process steps to the total. For this reason, the total chain will be split into smaller parts.

A sensitivity analysis is done on several parameters, namely yield, fertiliser use, and direct N_2O emissions from the field to show their impact on the performance of the biofuel chains, see Sections 6.2.1.2 and 6.2.3.2.

5.2 Expert assistance

Several experts were involved in the LCA to advice on general LCA methodology, feedstock production, nutrient balances in agriculture, and end-use. At some stages they have advised on specific issues as reported in Annex C.

5.3 Use of by-products and allocation

When a process has multiple outputs, the impacts have to be allocated to these outputs. In order to avoid multiple products in the eventual comparison[5], co-products can be compensated within the system, or brought outside the system. The former is called system extension, the latter allocation.

In system extension, it is assumed that the co-product replaces a product elsewhere. This replaced product also resulted from a production process, which is now avoided. By subtracting this avoided production process from the biofuels chain (or adding it to the fossil fuel chain) one can make both chains comparable. However, if the discussed replaced product was not the only product of that process, one creates a new problem. Namely, one should also account for the unwanted avoidance of the second co-product. This could lead to a range of substitutions. Each of these substitutions nitoruce new assumptions, chain definitions and allocations. On the other hand, it may be impossible to find a substitution process[6]. While the ISO standard prefers to use system extension, it is not always possible.

Allocation is the other possible solution. Here, both products are valued, and the environmental burden of the upstream processes is allocated partially to the main output and partially to the co-product. There are different grades in allocation. As advised by the LCA methodology expert, economic allocation is used, which accounts for the economic value of products. The product share that represents x % of the economic output (amount times market price) also bears x % of the emissions. In some occasions, where market values are not

[5] Otherwise, results would be expressed very unnatural, e.g. per "km driven + 7 g glycerin produced".

[6] Envision a process that produces electricity from chicken litter. One of the co-products of the chicken litter is an egg. It is nearly impossible to produce an alternative egg without employing a bird that co-produces litter.

available, mass, or another physical parameter that is sufficiently representative for the economic value, may be used as an allocation basis.

Although in principle both allocation and system enlargement may be applied, the results could be very different. In allocation all impact burden is split over two products. This means that *all* impacts of the main product chain will decrease with the same fraction. When system enlargement is applied, this will typically affect some impacts more than others. For example, if CO_2 is a valuable by-product, system enlargement with replacing CO_2 production from natural gas would typically have more effects on fossil energy carrier depletion and climate change.

6 Results

Aggregated results of the lifecycle inventory and results of the impact assessment are presented. Sensitivity analyses are performed towards the amount of fertiliser applied and the feedstock yield per hectare. Also the influence of the applied nutrient balance method is shown in comparison with standard IPCC method.

6.1 LCI results on land use

For each process, the lifecycle inventory (LCI) yields emissions to air, water and soil. The results are aggregated per section of the fuel chain (Figure 3-1). The results of the LCI are used to calculate the impact on several environmental themes.

Feedstock production → Feedstock transport → Conversion → Distribution → End-use

Figure 6-1. The results for the fuel chains are aggregated into sections.

Space requirement is another type of results of the LCI. The space requirement can be calculated by dividing the end-use distance by conversion efficiencies within the car and in the fuel production process, and by the yield per hectare. Without reckoning with co-products, driving a car on ethanol for 1 km would require 0.421 m^2 land. When part of this land is (economically) allocated to the co-produced straw and later co-products, only 0.292 m^2 land is required for the ethanol, see Table 6-1.

Table 6-1. Calculation of the amount of land required for driving a car 1 km on ethanol. Part of the area is economically allocated to the co-products straw and animal feed.

	Without allocation		**With allocation**
End-use in car	1 km 2.4 MJ/km 0.0909 kg ethanol		
Conversion to ethanol	285 kg ethanol/tonne seeds 0.319 kg seeds	75.4 % allocation of seeds to ethanol 0.241 kg seeds	
Feedstock production	7.57 tonne/ha 0.421 m^2 land	0.318 m^2 land	92 % allocation land to seeds 0.292 m^2 land

For biodiesel, the total amount of land required to drive 1 km is 0.828 m^2 land. However, the biodiesel allocated amount of land is only 0.455 m^2. The remaining area can be namely be allocated (economically) to the co-production of straw, animal feed and glycerine.

Table 6-2. Calculation of the amount of land required for driving a car 1 km on biodiesel.

End-use in car	1 km 2.76 MJ/km 0.0740 kg biodiesel		
Distribution 50 km by 28 tonne truck	0.132 m		
Conversion to ethanol	352 kg biodiesel/tonne seeds 0.210 kg seeds	61.1 % allocation of seeds to biodiesel 0.128 kg seeds	
Feedstock transport 100 km by 28 tonne truck **7000 km by 150 ktonne ship (oil from world)** **1000 km by 1200 tonne barge (oil from E. Europe)**		0.459 m 0.00057 m 0.0102 m	
Feedstock production	2.54 tonne/ha 0.828 m2 land	0.506 m2 land	90 % allocation land to seeds 0.455 m2 land

6.2 Results of the LCA

6.2.1 Comparison of bioethanol with gasoline

6.2.1.1 Baseline comparison of bioethanol with gasoline

The results for ethanol compared to gasoline are shown in Figure 6-2. From left to right, 14 impact categories are presented. Within each category, the biofuels chain is compared to the fossil fuels chain. Results are normalised to 100 % for the highest score within each category. Most value should has been set to the four categories on the left: energy carrier depletion,

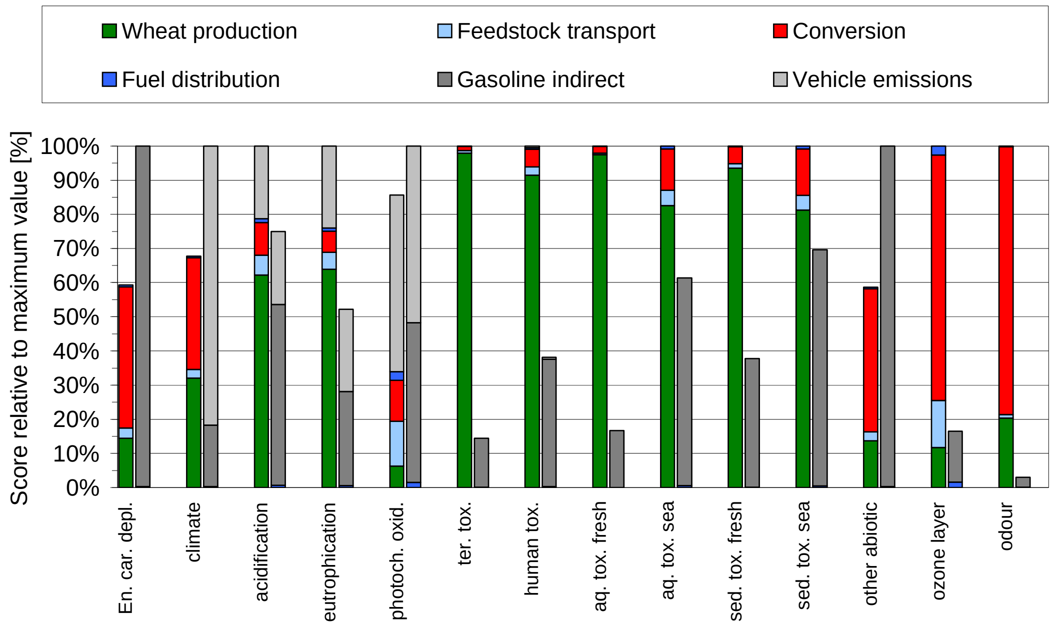


Figure 6-2. Results for chain A: Ethanol compared with gasoline.

climate change, acidification and eutrophication. These categories are often mentioned in relation to biofuels. The data used in this LCA especially aimed at shedding light on these categories. Results in the toxicity categories especially stem from the use of pesticides. On the far right, the odour emission acts very locally, near the agricultural plot and near the ethanol factory.

On energy use, the baseline ethanol chain performs 40 % better than the fossil fuel chain, which consumes 2.8 MJ/km. There is fossil energy use in feedstock production, but the largest contributor is the conversion step (the ethanol factory). In feedstock production, the energy use is 0.41 MJ/km distributed over machinery use (diesel) and fertiliser production. In the ethanol factory (1.2 MJ/km), the largest energy use resides in distillation, which requires relatively low temperature heat, which in the baseline comparison is assumed delivered from natural gas.

The total global warming potential[7] of the bioethanol chain is 142 g CO_2 eq./km, compared with 209 g CO_2 eq./km for the fossil fuel chain. This means that in this baseline comparison the bioethanol chain performs some 30 % better than its fossil equivalent. Note that other literature sources may report different values for gasoline baseline vehicles (e.g. 230 g/km (Van den Broek et al. 2003)) depending on timeframe, location, technological assumptions and applied research method.

Part of the climate impact can be related to energy use. This is the case in the conversion facility where natural gas is combusted to generate heat, and CO_2 is emitted. In agriculture, only 36 % of the emissions are actual CO_2 emissions that can be related with energy use (machinery and fertiliser production). The largest part stems from N_2O emissions (63 %). These N_2O emissions are caused by fertiliser production (37 %) and by application of the fertiliser on the field (26 %). N_2O emissions from fertiliser production may be reduced quite easily in the future (see annex E.3).

The bioethanol chain performs worse than gasoline on the items of acidification and eutrophication. This is mainly caused by emissions from agriculture. Acidification through agriculture is caused by air emissions of ammonia (56 %), NO_x (27 %) and SO_x (17 %). The ammonia emission is again largely related with fertiliser production and use. The NO_x emission stems partially from fertiliser production (13 %) and partially from tractor use (14 %). Eutrophication from agricultural actions is caused by ammonia (61 %) and NO_x (30 %) to air and phosphates to water (5 %). The end-use emissions responsible for acidification and eutrophication are assumed to be the same for the bioethanol and gasoline chain.

Photochemical oxidation (smog) originates mostly from the end-use, which is the same for the ethanol and gasoline chain, because the end-use emissions are assumed not to change when replacing gasoline with ethanol (see Annex E.12). In the ethanol chain, there are smaller contributions from feedstock transport and conversion. In the fossil chain the delivery of gasoline contributes to about half of the total smog impact. This mainly resides in the crude oil production.

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[7] Climate change is expressed as global warming potential (GWP) or kg CO_2 equivalent. Most relevant emissions in this respect are CO_2 itself, CH_4 and N_2O, for which we applied 1, 23 and 296 CO2-eq respectively. Elsayed et al. (2003) used the same values (except that they categorised the 500 years horizon as 200 years). In other studies, sometimes a GWP of 21 for CH_4 and of 310 for N_2O are used for the 100-year horizon, these values stem from the 1995 IPCC Second Assessment Report.

Toxicity is presented in six categories (terrestrial, human, aquatic toxicity for fresh water and for sea water, and sediment toxicity for fresh water and sea water). The uncertainties in toxicity impacts do not fully justify the presentation in six categories. The results can be very sensitive to a few toxic components. If that component, however small, is missed in one of the chains, the results can become distorted. Also, the uncertainty for toxicity impacts from the bioethanol chain is larger than for the first four categories, since there was less focus on this impact during the stakeholder interactions. Finally, there is still considerable discussion within the LCA community on the impact assessment indicators in this category (as opposed to other categories).

Terrestrial and human toxicity almost entirely stem from pesticide use in agriculture and further from small emissions of heavy metals.

Other abiotic depletion considers the use of materials from the earth, apart from fossil fuels: mineral ores, phosphates, etc. In the ethanol chain, conversion contributes the larger share, apparently as a result of natural gas consumption (the actual materials depleted are unknown). The delivery of fossil energy gives a higher impact. Again, the uncertainties in this category are large, especially because of limited stakeholder involvement.

Ozone layer depletion in the conversion step resides in the emission of halon-1301 (57 %) from electricity production in Europe from coal, oil and gas, and in the emission of HCFC-22 (39 %) that originates from the transport of natural gas.

The odour from the ethanol chain is completely caused by hydrogen sulphide emissions from the production of a small amount of natural gas in Russia. This shows, that a small, single odour emitter can distort the entire picture. This happens especially in impact categories that are less well-known or perceived less important. Also, odour emissions are very local.

The results have been normalised against emissions in Netherlands to show the relative importance of various categories (see Figure 6-3). This means that the impact assessment results are divided by the total impact of Dutch economy. The scale of the normalised score is very small (10^{-12}), since one km driving on either fuel is compared with the total Dutch score on each impact. One can conclude from this graph that in discussing replacement of gasoline with ethanol, the subjects energy carrier depletion, climate change and acidification are more important issues than e.g. eutrophicaton. However, some categories seem even more important: photochemical smog, and some toxicity categories. It must be stressed that these categories incorporate larger uncertainties in input data methodology. In order to draw conclusions on (dis)advantages of bioethanol in these categories, it would be necessary to examine these categories in more detail.

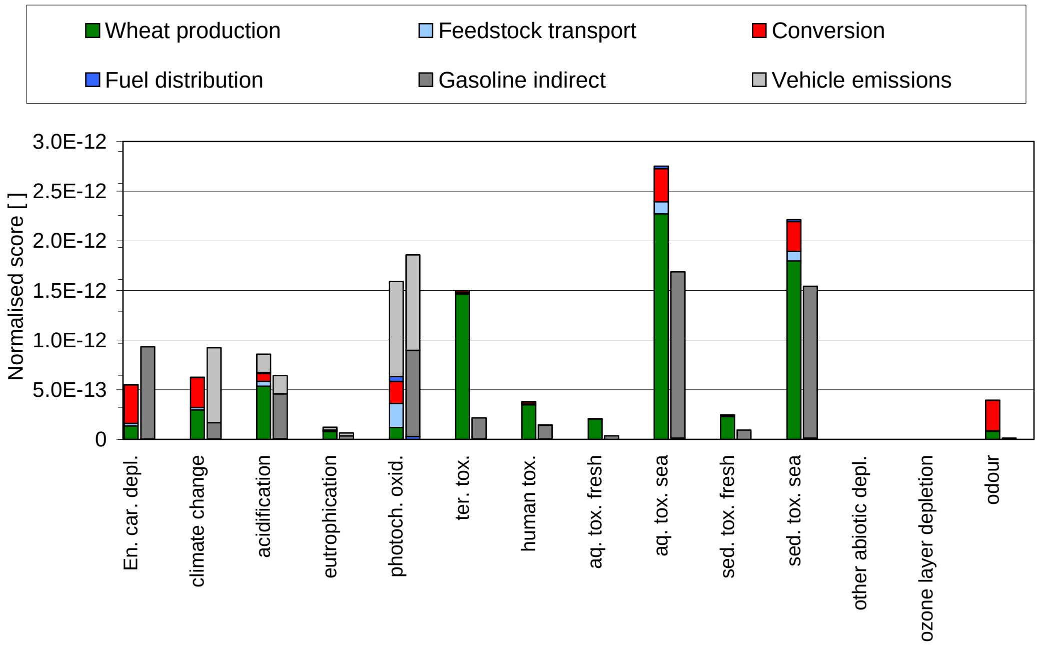

Figure 6-3. Results for chain A: Ethanol compared with gasoline, normalised against Dutch national impacts (1995).

6.2.1.2 Bioethanol parameter variations

Based on the conclusion that a large part of the energy, climate, acidification and eutrophication impacts relate to fertiliser (production and) use, a few variations are assessed:

a. The amount of fertiliser-N applied.

b. Accounting for the uncertainty in IPCC bandwidth for direct soil N-emissions.

c. Applying the standard IPCC method for agricultural N-balance.

The fertiliser-N assumed in the base-case ethanol chain, was the average of N-applications found for Netherlands, Germany, France and the United Kingdom, combined with the yields found for these countries (see Annex E.1). However, literature reports a broad range of fertiliser applied, see Figure 6-4. It is possible that the average value applied is pessimistic, that in fact the newest agricultural technologies and methods, combined with improved wheat varieties require less fertiliser.

These variations in fertiliser application coincide with variation in yields. Figure 6-4 shows the average value used for the base-case ethanol chain, and a “Low fertiliser” and “High fertiliser” variation. The graph shows even lower fertiliser use (around 50 kg N/ha) combined with a sustained high yield, but this is considered not realistic for Western Europe, by the agricultural experts of this LCA.

Variation of the amount of fertiliser applied, and the corresponding variation in yield influences the agricultural emissions and impacts, and therefore also the overall impacts. Figure 6-5 shows the results of these variations for the first four impact categories.

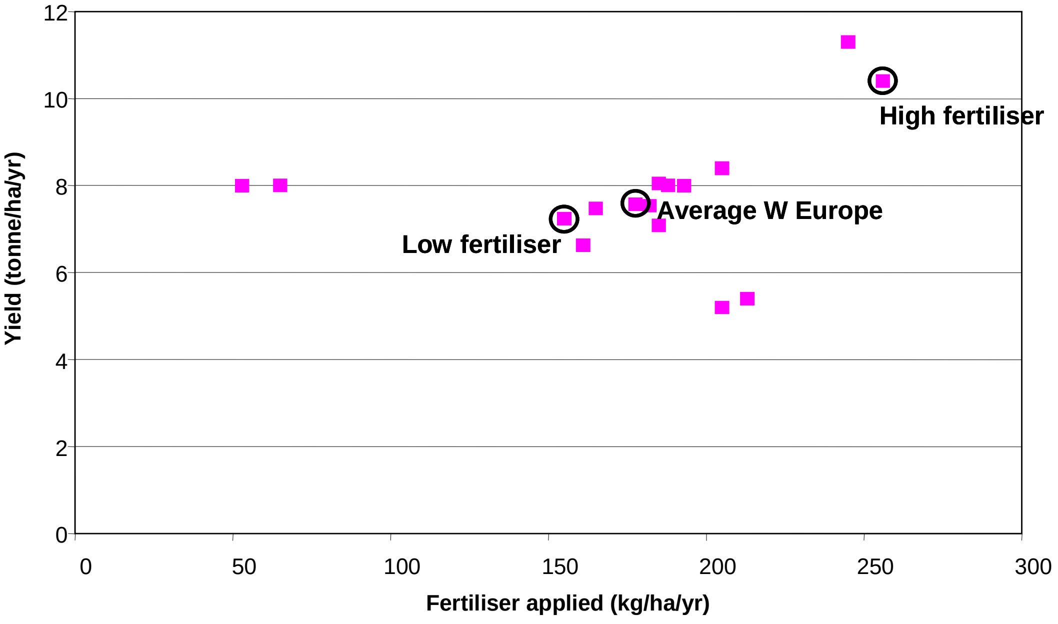

Figure 6-4. Amounts of fertiliser applied for the production of wheat, and the accompanying yields as reported in literature (Biewinga et al. 1996; Elsayed et al. 2003; FAO 2005; Goodlass et al. 2003; Kool 2005; PAV 2000). The circles indicate the assumed values for the baseline comparison (average of western and eastern Europe and world), and the variations with low high fertiliser application.

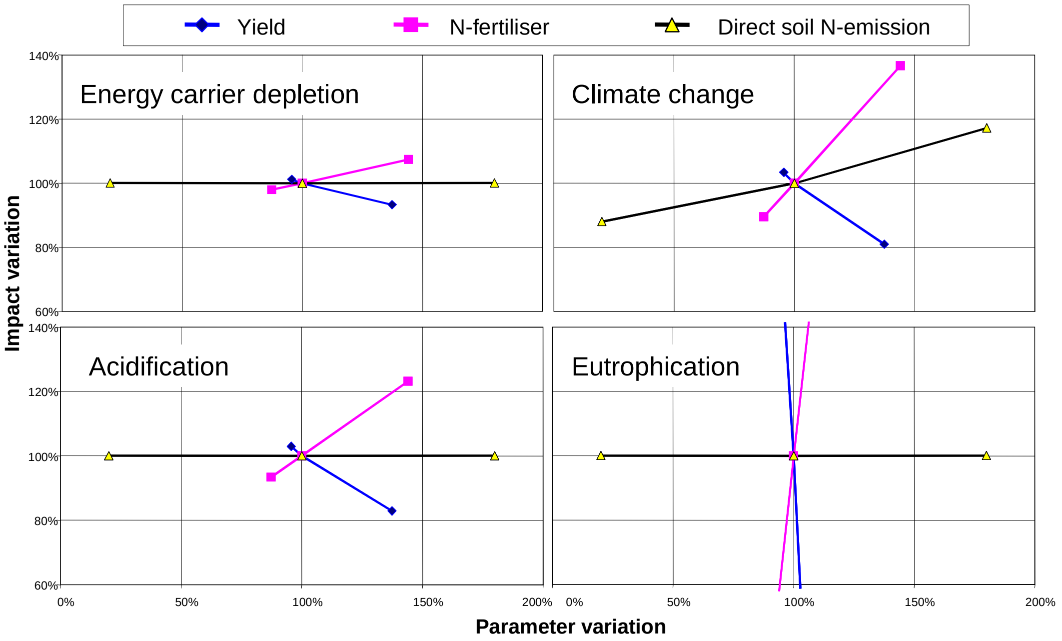

Figure 6-5. Sensitivity of LCA results on energy carrier depletion, climate change, acidification and eutrophication, for chain A to feedstock yield, fertiliser use and direct soil N-emissions.

Increase of the amount of fertiliser increases the impact on all four categories, according to the share that fertiliser use contributed to the total score on each impact. The graph shows that there is an almost linear effect on climate change. It has to be realised at the same time, that increased fertiliser use almost always coincides with higher yields, which decreases the overall effect on climate change, since the higher total score can be divided through a larger amount of kilometres driven, at the end of the chain.

A surprisingly strong impact change is seen for eutrophication. This can be explained by the fact that for the base case, the amount of nitrate originating from fertiliser use on the wheat plot is almost the same as for nitrate emitted by the reference fallow land. Although six times more fertiliser is applied for wheat production than on fallow land, the fertiliser surplus is rather comparable. Seen from this base-case point, every g of fertiliser that is added extra to the field, in the N balance applied, completely leaches to the soil (as 4.4 g nitrate) and is multiplied by the strong impact factor for eutrophication. The impact of yield is equally strong in the other direction.

The graph also shows the variation in direct soil emission, which is an uncertainty in the method rather than a parameter variation. The IPCC states that direct soil emissions from the application of N fertiliser are 1.25 % of the N applied, with a bandwidth of 0.25 - 2.25 %. Applying the lower or the higher percentage only influences the climate impact.

The next figure (Figure 6-6) shows the results for combined variations in yield and fertiliser. As expected, the total effect remains small when a higher fertiliser use is combined with a higher yield.

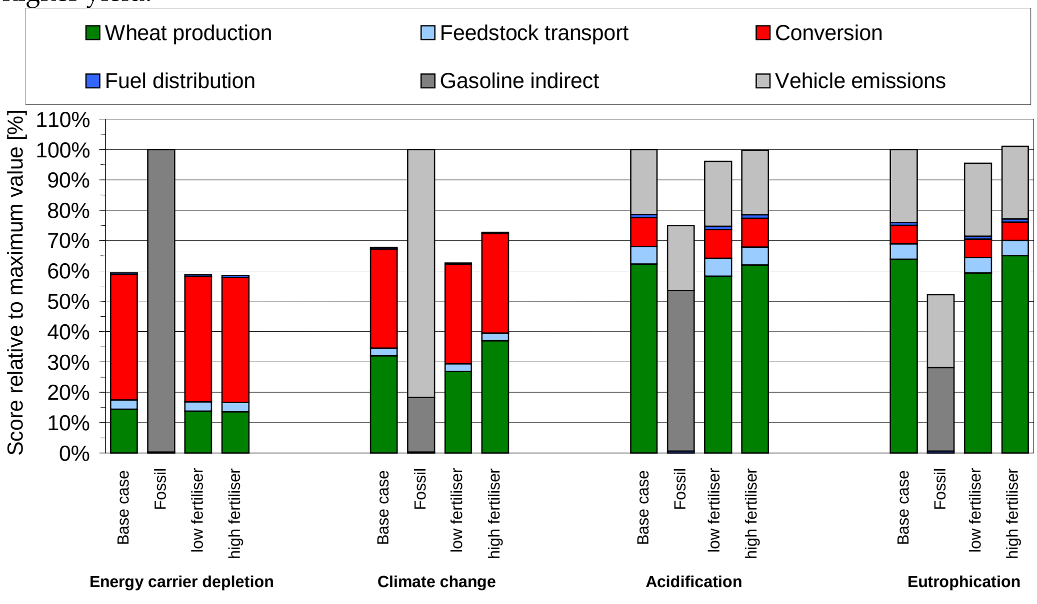

Figure 6-6. **Results for sensitivity variations for comparison A (ethanol with gasoline) on energy carrier depletion, climate change, acidification and eutrophication. Combined variations in fertiliser applied and yield as indicated in Figure 6-4. Base case as reported in Figure 6-2.**

6.2.1.3 Bioethanol – use of straw for CHP

A large part of the energy carrier depletion and the climate impact resides in energy use in the conversion of wheat to ethanol, more specifically in the heat required for distillation.

To improve the impact of the chain, the required energy could be supplied from sustainable sources. For scenario variation **A1** it is assumed that straw is used to produce the required amounts of heat and power. The straw stems from the same plot of land where the wheat is produced (see Figure 6-7).

The steam requirement within conversion equals 0.8 MJ/km (including allocation between ethanol and co-products). Reckoning with allocation between electricity and steam, this requires 0.041 kg straw, which is produced on 0.092 m^2. This is 31 % of the area demand for ethanol production (see Table 6-1) and (coincidentally) falls well within the assumption that $^1/_3$ of the straw would be used for CHP production.

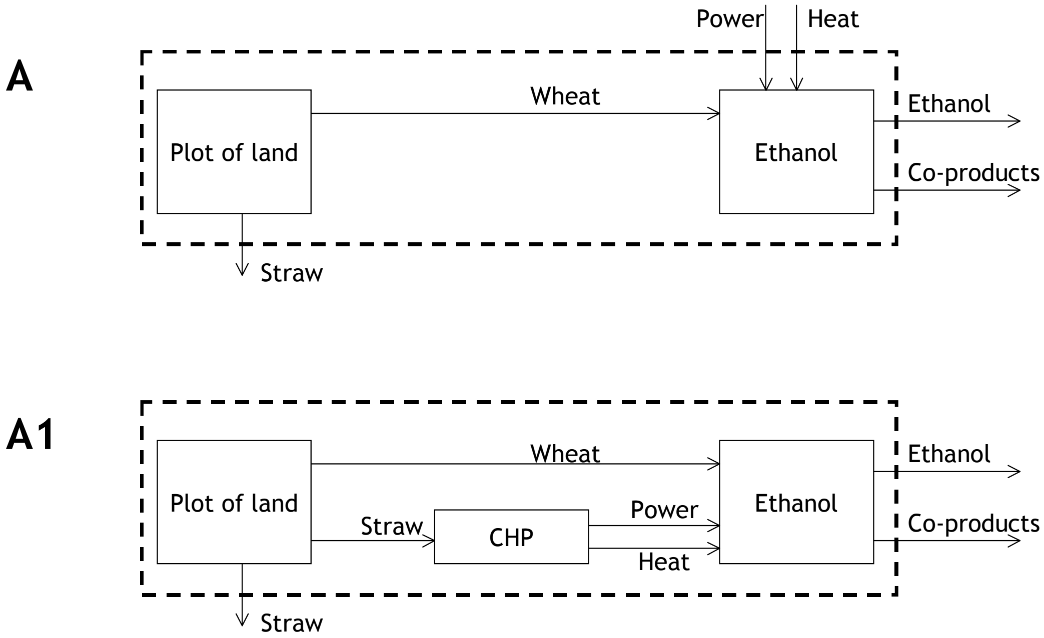

Figure 6-7. Variation A1 (as compared to the baseline comparison A) where heat and power for the ethanol factory is generated from straw.

Four impact categories have been analysed (see Figure 6-8). The contributions from the conversion step to energy carrier depletion and climate change are minimised, while the categories acidification and eutrophication are barely or not affected.

This variation shows that a different chain definition can have a large impact on the performance. A well-designed bioethanol chain can have a 5 times better fossil energy performance than a gasoline delivering chain. Climate impact can be reduced to 35 %.

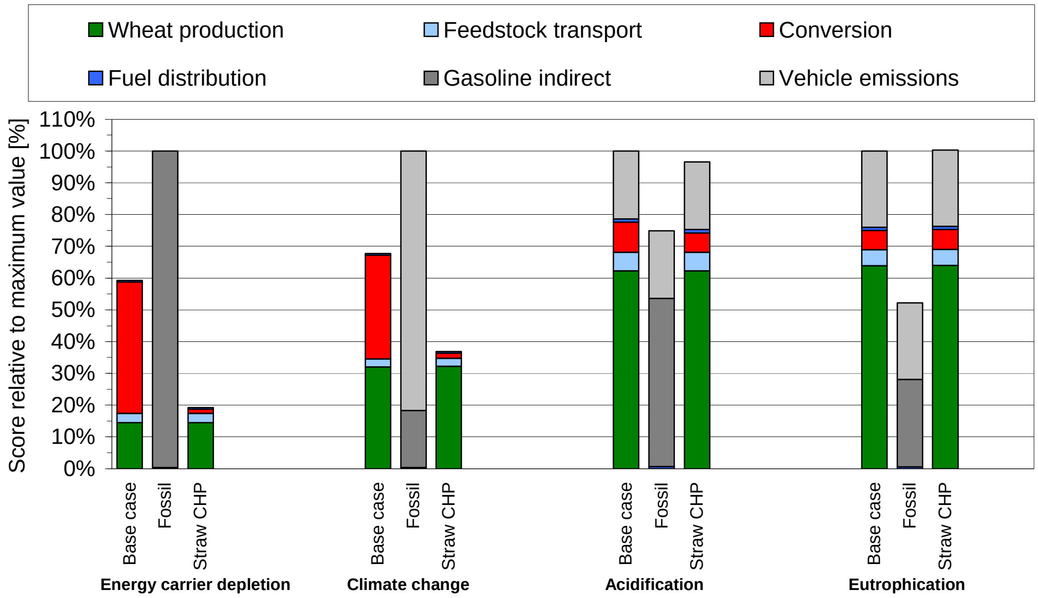

Figure 6-8. Results for variation A1. Ethanol compared with gasoline, with heat and power for the conversion process supplied from straw.

6.2.2 Comparison of BioETBE with MTBE

Ethyl tertiary butyl ether derived from biomass (bioETBE) is compared with Methyl tertiary butyl ether (MTBE). The results are shown in Figure 6-9. The comparison is done on pure biofuels basis, which means that only the ethanol part of ETBE is compared with an equivalent (on energy basis) amount of MTBE.

ETBE is derived from ethanol and incorporates an extra energy-consuming step. The energy use of the total ETBE chain is 2.0 MJ/km (bioethanol chain was 1.7 MJ/km). The production of MTBE also costs more energy since it is produced from methanol, which is produced from natural gas against a lower efficiency (when compared to gasoline production from oil).

Therefore, replacing MTBE with bioETBE gives an improved result compared with ethanol replacing an equal quantity of gasoline. On the other hand, if bioETBE would replace gasoline (this comparison has not been made), the improvement would be less. Note that regular gasoline is maximally allowed to contain 15 volume % of MTBE or ETBE (but usually contains less) and 5 volume % of ethanol.

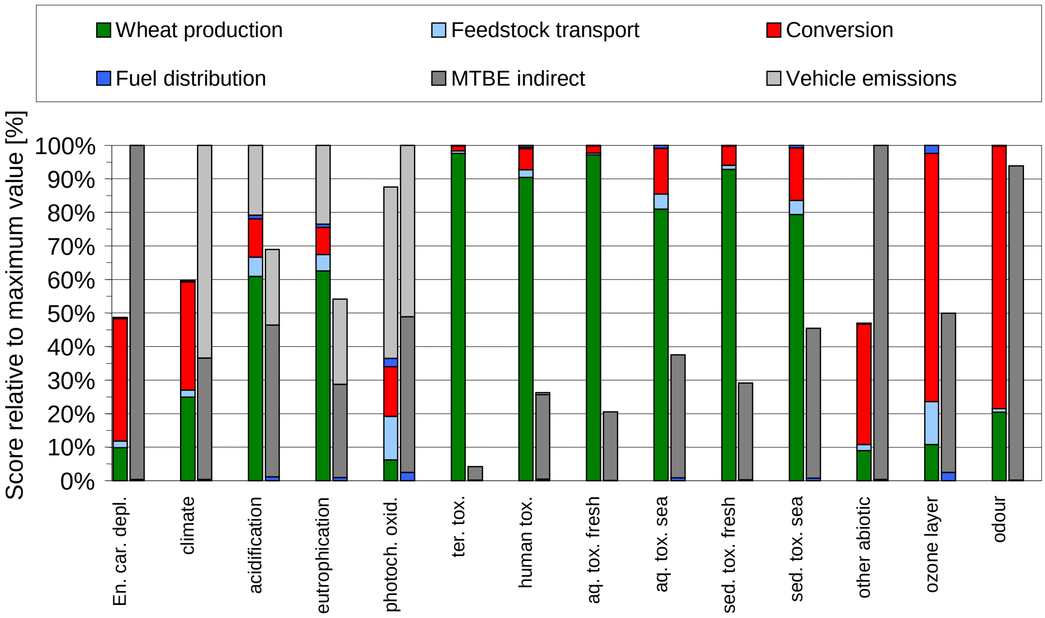

Figure 6-9. Results for chain B: ETBE compared with MTBE.

Most impact categories show similar results, except where natural gas plays a larger role. Odour from H_2S has increased tenfold, compared with the gasoline chain. But, again, this category is distorted by a single small H_2S emitter.

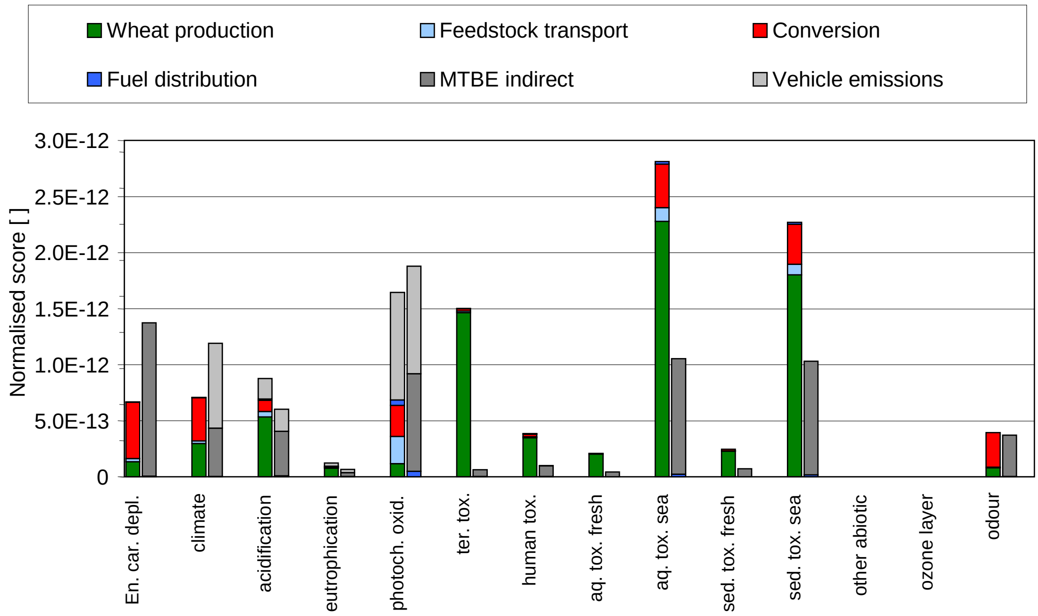

Figure 6-10. Results for chain BioETBE compared with MTBE, normalised against Dutch national impacts (1995).

6.2.3 Comparison of biodiesel with diesel

6.2.3.1 Baseline comparison of biodiesel with diesel

The results for biodiesel compared to diesel are shown in Figure 6-11. On fossil energy carrier depletion, the biodiesel chain performs about 57 % better than the fossil fuel chain, which consumes 3.1 MJ/km. There are equally large fossil energy uses in feedstock production and the conversion step. Producing rapeseed feedstock consumes 0.65 MJ/km, the larger part (80 %) is in fertiliser production, and the remainder mainly in tractor use.

In the conversion to biodiesel (0.64 MJ/km), the largest consumer of fossil fuel is the production of methanol from natural gas (38 %). Another 19 % energy share resides in heat for the biodiesel plant. Smaller amounts of gas and fuel oil are used for drying the raw rapeseed, and heat in the oil pressing plant.

If the fossil energy carrier depletion would all reside in direct energy use, a similar distribution between rapeseed production and conversion would be found in the climate impact category. However, the large role of fertiliser production leads to a relatively high CO_2-eq. emission, namely as N_2O in agriculture. On the other hand, energy use in the conversion step is mainly in natural gas for methanol production (for esterification), which does not directly contribute to CO_2 emission, since it continues as a material. For these reasons, we find that the climate impact stems mainly from agricultural activity, of which 34 % in energy use and about 64 % in fertiliser production (31 %) and application (33 %). N_2O emissions from fertiliser production will be reduced in the near future (see annex E.3).

On the impacts acidification and eutrophication, the biodiesel chain performs worse than the fossil diesel chain. Like in the comparison of ethanol with gasoline, this is caused by fertiliser production and use. The effect is much stronger here, due to the larger net fertiliser consumption per km driven.

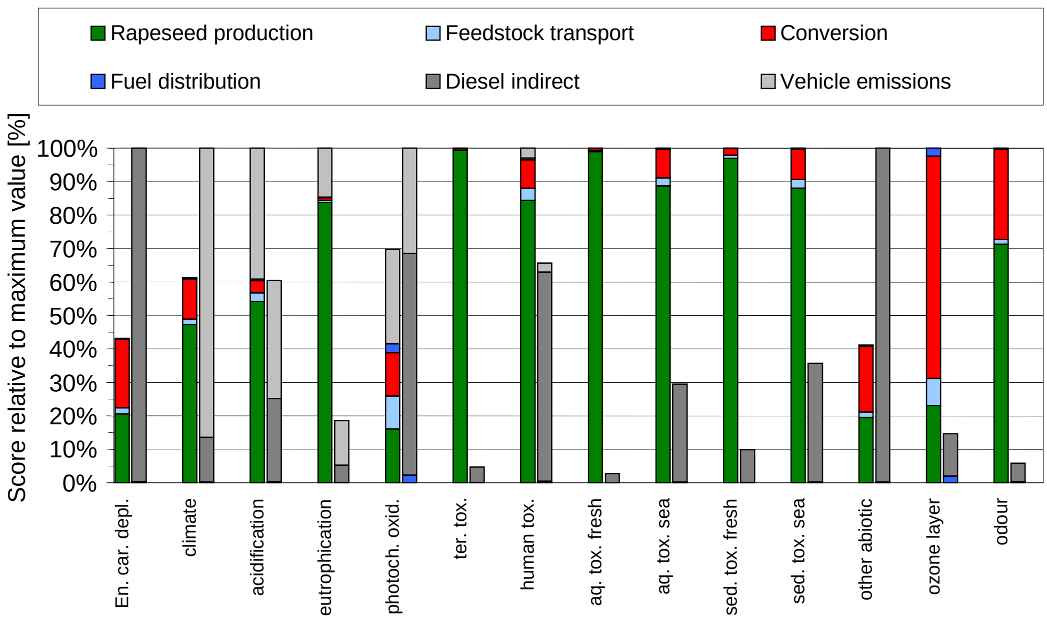

Figure 6-11. Results for comparison C: Biodiesel compared with diesel.

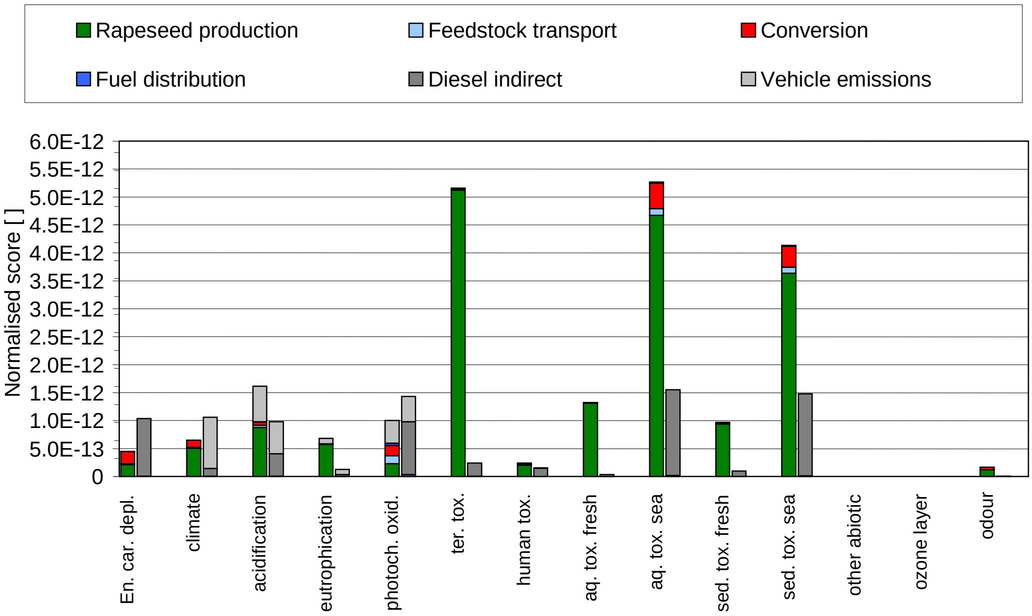

Figure 6-12. Results for comparison C: Biodiesel compared with diesel, normalised against Dutch national impacts (1995).

Also the results for this comparison have been normalised against emissions in the Netherlands to show the relative importance of various categories (see Figure 6-12). The scale and relative impacts of biodiesel and diesel chains are comparable with the results for the bioethanol-gasoline comparison. Again, the use of fertiliser leads to higher scores in acidification and eutrophication than in the bioethanol-gasoline comparison. Also note the much higher scores for toxicity. The terrestrial toxicity is for 77 % caused by the use of only two pesticides in the agricultural step. It could well be that the use of other pesticides would have much lower toxicity impact while maintaining seed yield. This is, however, not assessed.

6.2.3.2 Biodiesel parameter variations

Like for the bioethanol-gasoline comparison, the impact of a few variations relating to fertiliser and N_2O-emissions have been assessed:

a. The amount of fertiliser-N applied.

b. Accounting for the uncertainty in IPCC bandwidth for direct soil N-emissions.

c. Applying the standard IPCC method for agricultural N-balance.

The fertiliser-N assumed in the base-case biodiesel chain, was the average of N-applications found for Netherlands, Germany, France, the United Kingdom, and Poland, combined with the yields found for these countries (see Annex E.1). However, literature reports a broad range of fertiliser applied, see Figure 6-13. It is possible that the average value applied is pessimistic, that in fact the newest agricultural technologies and methods, combined with improved rapeseed varieties require less fertiliser. On the other hand, it is possible that the average value found only holds for very favourable conditions and that in case of larger scale rapeseed for biofuels production higher fertiliser application would be required.

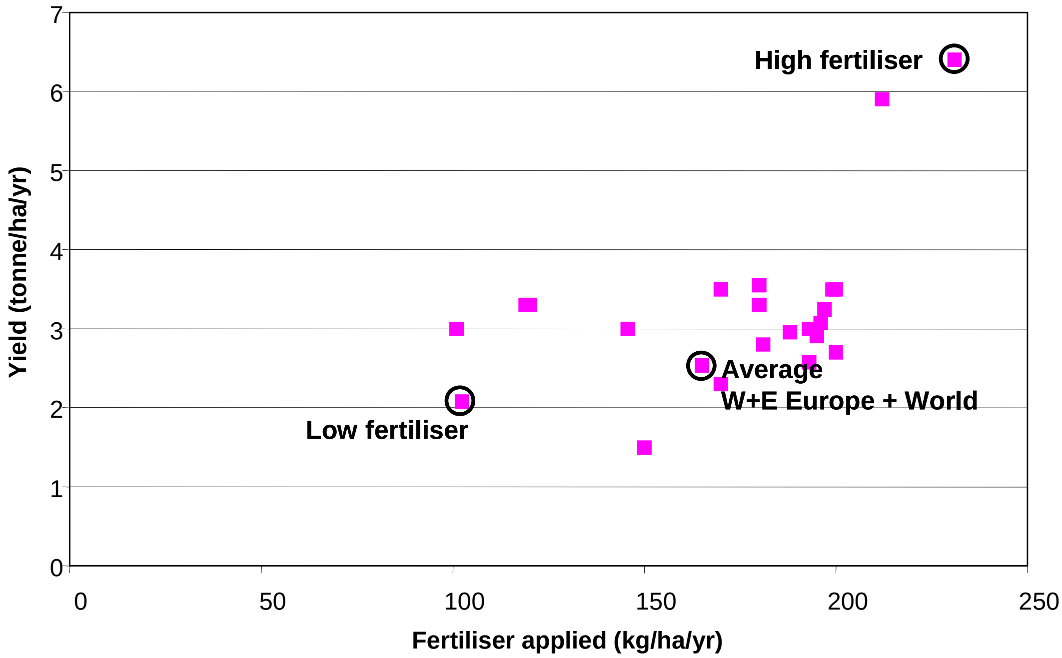

Figure 6-13. Amounts of fertiliser applied for the production of wheat, and the accompanying yields from various literature sources (Biewinga et al. 1996; Elsayed et al. 2003; FAO 2005; Goodlass et al. 2003; Kool 2005; PAV 2000). The circles indicate the assumed value for the baseline comparison (average of western and eastern Europe and world), and the values assumed for the variation with low high fertiliser application.

Variations in fertiliser application coincide with variation in yields. The figure shows the average value used for the baseline biodiesel chain, and further a "Low fertiliser" and "High fertiliser" variation. The impacts of these variations on the first four environmental themes are separately shown in Figure 6-14. For energy carrier depletion and climate change, the slopes of the lines are comparable with those of Figure 6-5. This means that a variation in yield or fertiliser application has a similar impact on these categories (although the width of the variation is broader). For acidification and eutrophication the impact changes are somewhat less than in the bioethanol-gasoline comparison.

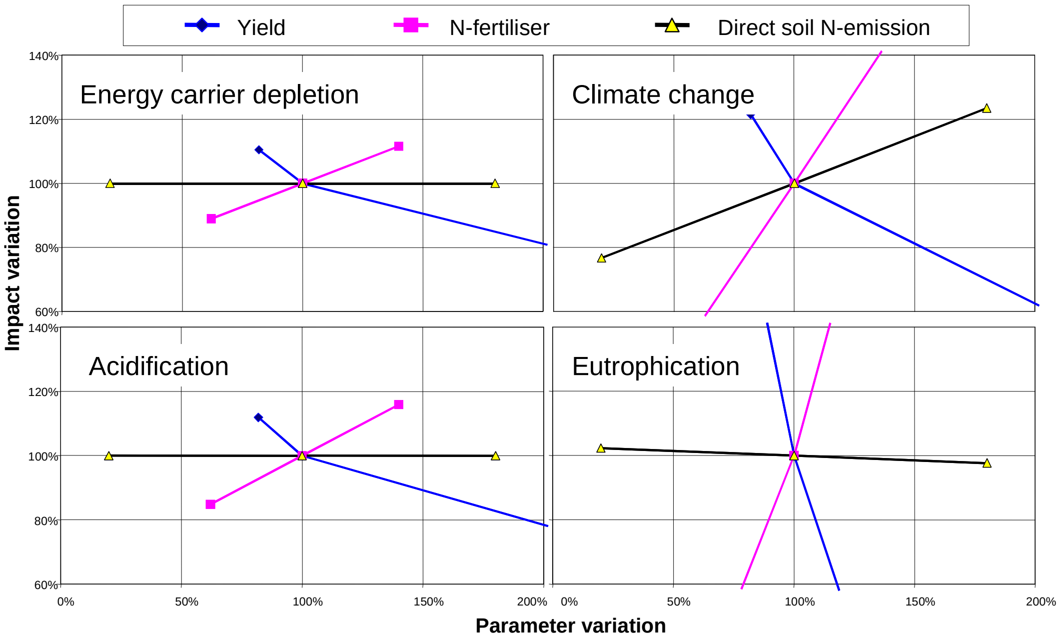

Figure 6-14. Sensitivity of results for biodiesel in chain C to feedstock yield, fertiliser use and direct soil N-emissions.

Combining variations leads both for the "Low fertiliser" and "High fertiliser" case to lower impacts (see Figure 6-15). This is caused by the relatively high yield per fertiliser of the chosen variations, when compared with the baseline chain. Visually, this could have been expected from Figure 6-13, since the "Low" and "High" lie above the line through "Average" and zero.

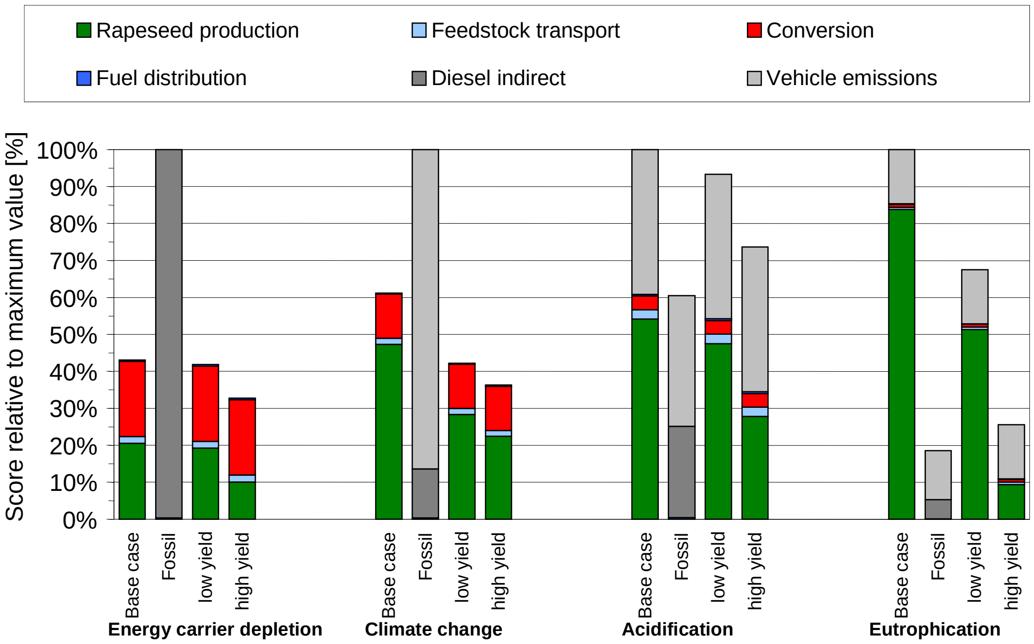

Figure 6-15. Results for sensitivity variations for comparison C (biodiesel with diesel). Base case as reported in Figure 6-11.

6.2.3.3 Biodiesel – system expansion with replacing soy

For the baseline calculations the allocation method has been used to deal with multiple products within processes. To show the impact of this choice, a variation has been done applying system expansion to the process of seed pressing. The produced rapeseed cake is assumed to replace soy based animal feed, reducing the import of soy meal from the USA to Europe.

The results of this variation are shown for the first four impact categories. The change from allocation to system expansion is shown in two consecutive steps

First the allocation between rapeseed oil and rapeseed cake is removed. Emissions from the oil pressing and agricultural and transport actions before pressing, are now allocated to the oil only (still, a part of the agricultural emissions remains allocated to straw). This does not impact the entire chain, since everything after the oil pressing remains the same, including the larger part of the conversion impacts. Thus, the lower part of the graphs – feedstock production, transport and part of conversion – is stretched. Since the original allocation was 72.4 %, the stretch amounts 100/72.4, or about 40 %.

Then, it is assumed that in the reference chain cake is produced as well, but from soybeans in the USA. The impact of soy cake production is derived from an American study on biodiesel production (Sheehan et al. 1998). More details are given in Annex E.11. The replacement ratio is derived from the respective economic values of both products.

Finally, the impact from cake production is subtracted from both chains, since the cake is not needed as end-product.

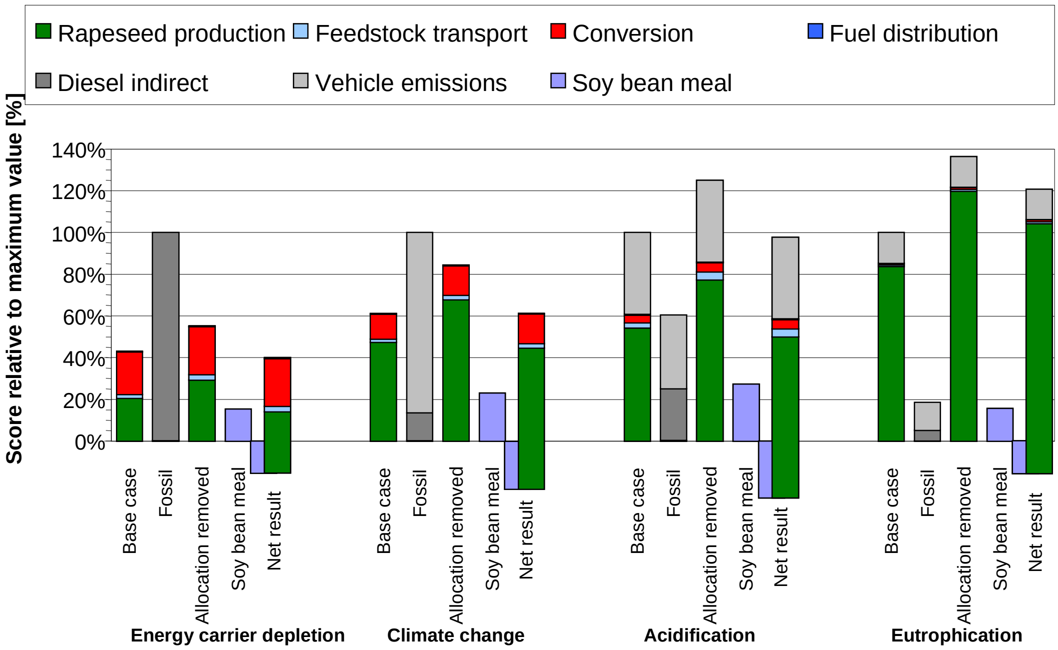

Figure 6-16. System enlargement versus the baseline biodiesel chain that applied allocation.

For the first three impact categories, the result is very comparable to the baseline comparison. This is rather coincidental, since the production of soy in the United States could be very different from the production of rapeseed in the EU, in terms of energy and fertiliser use expressed per car-km. Furthermore, the economic values of the cakes are based on nutritional content, which may not be equally correlated to the amount of biofuels that could be produced from the seeds or beans.

7 Conclusions

7.1 Participation

The main goal of the project was to involve stakeholders of the introduction of biofuels to decide over goals and scope, over parameter input, to learn about the process of lifecycle assessment and to understand its use and limitations. The researchers applied the choices and assumptions agreed upon with the stakeholders so that the final results follow from the joint view of stakeholders and researchers rather than from a researchers viewpoint only.

Stakeholders from the following groups were involved in the project:

- Raw material producers
- Biofuels producers
- Oil industry
- Environmental NGO
- End-users
- Government

These stakeholders were assisted by scientific experts in the areas of lifecycle assessment methodology, agriculture, field/crop N_2O balances, and automotive fuel end-use.

The interaction between stakeholders, experts, and Ecofys was organised in a series of meetings, and through email and internet communication (website). On a range of choices and general assumptions, the stakeholders agreed by consensus or vote majority. A few variations have been made where consensus could not be reached and where the stakeholders felt that alternatives should also be assessed or compared.

The stakeholders found several LCA issues difficult to understand. There was recurring discussion on the type of alternative land-use. Practically, the introduction of a biofuel feedstock in the Netherlands would mean the replacement of another agricultural product. The natural feeling was that this would define the alternative land-use. However, that agricultural product would still need to be produced, and, therefore, sooner or later new land will be taken into production elsewhere. The idea that this system expansion could be avoided by directly assuming a fallow land reference situation became gradually accepted.

The system expansion or allocation methods, necessary to deal with multiple products, are fundamental to lifecycle assessment, but very difficult to understand for relative outsiders.

Some stakeholders would have liked to include biodiversity in the LCA. However, because of a lack of reliable data this was not possible.

Where the main interest and knowledge of stakeholders related to the Dutch territory, LCA assesses the entire supply chain, including effects that may occur in other countries.

Eventually, when the final results were presented, some input parameters became again subject to discussion.

7.2 Results and sensitivity

First, it has to be stressed that the results from the present lifecycle assessment only hold for the cases and choices presented. If chains would be designed differently, the results would be different. E.g. the production of ethanol from agricultural residues can be more energy efficient and with less climate impact.

When driving a car on bioethanol instead of gasoline, 40 % less fossil energy is used. There is a small fossil energy requirement in the agricultural step (fertiliser production and tractor use). The largest demand for fossil energy is in the conversion of wheat to ethanol. This is especially caused by the heat required for distillation. Other separation technologies may reduce this heat demand. On the other hand, the energy and climate impact can also be improved by supplying the heat through renewable energy sources. In the baseline comparison, only 30 % greenhouse gas emission reduction is realised. When the heat is delivered from combusting straw (via CHP), the reduction can be 65 %. A closer look at the integration of heat, power, and biofuels within a bioethanol factory could further improve its performance.

The biodiesel chain performs about 57 % better than the diesel chain. There are equally large fossil energy uses in feedstock production and the conversion step. In the production of rapeseed feedstock, the larger part (80 %) is in fertiliser production, and the remainder mainly in tractor use. In the conversion to biodiesel, the largest consumer of fossil fuel is the production of methanol from natural gas (38 %). Another 19 % energy share resides in heat for the biodiesel plant. Smaller amounts of gas and fuel oil are used for drying the raw rapeseed, and heat in the oil pressing plant.

Compared to fossil fuels, biofuels have a reduced impact on climate change. Bioethanol performed about 30 % better than gasoline, biodiesel about 40 % better than diesel. Fertiliser use had a large impact on climate change in all biofuels' chains. This was caused by emission of N_2O during both the production and use of N-fertiliser. The N_2O emissions during fertiliser production can be reduced to almost zero by relatively easy and cost-effective technological measures. These technologies are expected to be applied when legislative or economic driving forces are introduced, such as when N_2O would be included in the European Union Greenhouse Gas Emission Trading Scheme ETS. This is likely to happen on foreseeable terms.

The assessed biofuels chains perform worse in terms of acidification and eutrophication, this is caused by the agricultural emissions of ammonia, NO_x, SO_x, and phosphates. End-use emissions relevant for these impact categories are the same for biofuels and their fossil alternatives.

The sensibility of four impact categories towards the use of fertiliser and towards the feedstock yield per hectare is considerable. However, since a lower fertiliser use correlates with a lower product yield, the combined effect is limited.

Besides the large influence from fertiliser production, a significant part of the NO_x emissions stem from tractor use. This was also previously reported in Ecofys' fact-finding study. Also these emissions can be expected to decrease through more stringent legislation.

The results on toxicity are subject to large uncertainties.

Combining variations leads both for the "Low fertiliser" and "High fertiliser" case to lower impacts (see Figure 6-15). This is caused by the relatively high yield per fertiliser of the chosen variations, when compared with the baseline chain

7.3 Improvement options and recommendations

In some sub processes, knowledge is limited while the process has a significant impact on one of the environmental themes.

The emission of N_2O from the field is an important contributor to the climate impact of all biofuel chains. This emission is influenced to agricultural methods, more specifically the amount and type of fertiliser applied, the method of application, timing of harvest, soil type, and the removal of agricultural residues.

More insight is required in tailpipe and lifecycle evaporative emissions from biofuel blends in vehicles.

The strong involvement of stakeholders in lifecycle assessments should be encouraged, both to bring assumptions in line with the real-world practice, to increase interaction between stakeholders, and to increase the understanding of the possibilities and limitations of this kind of analyses among stakeholders.

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Annex A Participants

Table A-1. Overview of Participants in the study.

Conversion, distribution	
Petroplus tankstorage	Mr. Wolfgang Hilbert
	Mr. Karl Frank
Nedalco	Mr. Martin Weissmann
ATEP	Mr. Piet van den Ouden
Interest groups	
VNPI	Mr. Dominic Boot
Agricultural organisations LTO	Mr. Jeroen Kloos
Society for Nature and Environment SNM	Mr. Hans Jager
End-users	
Milieucentraal	Mrs. Voline van Teeseling
City of Rotterdam	Mr. Ton Vermie
	Mr. John Akkerhuis
	Ms. Angelle Chang
Government	
Ministry of environment	Mr. Per Godfroij
EU DG TREN	Mr. Kyriakos Maniatis
SenterNovem	Mr. Eric van den Heuvel
	Mr. Jorg Raven
Knowlegde centres and consultancy	
Ecofys	Mr. Carlo Hamelinck
	Mr. Richard van den Broek
CLM	Mr. Anton Kool
CML	Mr. Jeroen Guinée
TNO automotive; TU/e	Mr. Rik Baert
Alterra	Mr. Jan Willem van Groenigen
	Mr. Peter Kuikman

Annex B Minutes Workshops

B.1 Minutes Workshop 1

Date and time: 2004 September 15, 0930-1230 h

Present

Present	
Voline van Teeseling (VT)	Milieu Centraal
Jeroen Kloos (JK)	LTO Nederland
Hans Jager (HJ)	Stichting Natuur en Milieu
Wolfgang Hilbert (WH)	Petroplus
Dominic Boot (DB)	VNPI
Ton Vermie (TV)	Gemeente Rotterdam
John Akkerhuis (JA)	Gemeente Rotterdam
Richard van den Broek (RvdB) – LCA work	Ecofys
Carlo Hamelinck (CH) – LCA work	Ecofys
Jeroen Guinée (JG) – expert	CML
Anton Kool (AK) – expert	CLM
Eric van den Heuvel (EvdH) – chairman	SenterNovem
Jorg Raven (JR) – organisation	SenterNovem
Absent	
Per Godfroij (PG)	VROM
Kyriakos Maniatis (KM)	EC DG TREN
Martin Weissmann (MW)	Nedalco
Gert-Jan Nabuurs (GJN) – expert	Alterra
Rik Baert (RB) – expert	TU/e, TNO Automotive

(Contact information is added to the Project website).

1. Reception & welcome

EvdH opened the workshop and explained in a short presentation the reasons for conducting this study. There are multiple purposes for this study: to yield results that have a broader support, to give insight in the complexities of LCA and knowledge about the sensitivity for inputs, to see how other stakeholders think. SenterNovem would like to gain insight in how this LCA process takes place *(Presentation is added to the Project website].*

2. Brief acquaintance

The participants introduced themselves.

3. Introduction to the study by Ecofys

RvdB introduced the content of the four workshops. *(Presentation is added to the Project website].*

WS1: system definition and WTW layout

WS2: data ranges, main data to be used?

WS3: intermediate results (LCA quick scan)
WS4: final results

To perform the LCA with this group of participants, experts and organisation, some rules are needed.
For all important choices that have to be decided upon, information or data will be given. Also alternative options will be explained. When a choice has to be made, this can be done by:

a. Reaching consensus
b. If there is no consensus, then by voting (directly or after a meeting, by e-mail)
c. If sufficiently important, then incorporate more variations to be dealt with in the study. The number of variations should be kept small to avoid an impracticable "tree of choices".

Experts do not vote, but when asked they give advice. They guard the workability of the LCA The participants agree on these procedures.

Discussion:
DB: One should not only look at the environmental effects, but consumer-effects are also an outcome. Cars should always be able to run on the produced fuel, The fuel should thus comply with demanded specifications.
RvdB: Those are difficult as impact category, but possibly call for a system definition: make no choices with negative impacts for consumers.
JK: That also holds for fossil derived fuels: at a certain moment consumers may not anymore be able to drive on fossil derived fuels because the oil is then depleted.
RvdB: This can indeed be an outcome from the study, it can be incorporated in the impact category energy carrier depletion. However, how the different impact categories should be valued is not within the scope of this study.
JA: What is the goal of the study?
EvdH: 1) open the LCA-black box. 2) deliver results, have discussion over the inputs. In a conventional LCA the researchers make the choices. Here we want to let you make them. So, from implicit decision-making to explicit discussion about the data to be used and assumptions to be made.
AK: Won't there be a broader scope next to environmental impacts?
RvdB: no, an earlier study covered that. *(Biofuels in the Dutch market: a fact-finding study; available from SenterNovem, gave.novem.nl]*.

4. Choice 1: set of biofuels

By email the first choice was made. The short-term option (biodiesel and bioethanol on the short term) got the most votes.

Discussion:
DB explains why he chose option 4 (biodiesel vs. FT diesel): There is a structural surplus of gasoline, the EU exports gasoline to the USA, while there is a EU shortage of diesel. This implies that choosing for bioethanol to replace gasoline leads to an increased export of gasoline!

TV adds that while in Stockholm busses are driven on pure ethanol, Scania wants to get rid of them.
WH: also chose option 4; but can agree with option 1. He remarks that the application of ethanol is still under discussion: not all blends fall within specifications, repeatability problems. He suggests that the ethanol chain be extended to ETBE.
DB: can agree with the ETBE case. it is more probable that ETBE would be marketed than bioethanol, for various reasons.
RvdB: An LCA on bio-ETBE would be quite new.
EvdH: asks the other participants what they think about incorporating ETBE.
The incorporation of ETBE is agreed upon. But, should ETBE be compared with gasoline or with MTBE? The consensus is that we must not have a discussion about what will be blended by the oil companies. WH illustrates that gasoline is not solely made from oil, many compounds are added to naphtha. MTBE is added to enhance the octane number (earlier one added lead for this purpose), this MTBE can easily be replaced by ETBE.
For LCA purpose a reference situation (what is being replaced?) must be chosen. *(Ecofys propose a reference situation].*
EvdH: VROM and Nedalco should be asked what they think about choice between ETBE and bio-ethanol.
Also, EvdH will ask for extra budget to maybe also assess future fuels.

5. Well to Wheel system layout

RvdB clarifies the remaining choices of the day. *(Presentation is added to the Project website].*

Choice 2. End use and functional unit

a. There is consensus about the functional unit (liter, GJ of km driven). Stakeholders would like to assess the biofuels chain including end-use, and to compare on basis of km driven.
b. Consensus about car type (passenger cars, Heavy Duty). Stakeholders opt for weighed average of passenger cars and Heavy Duty when diesel fuels are compared. For the ethanol case (replacing gasoline) only passenger cars are chosen.
c. Consensus about application of the biofuels (blend or pure). Stakeholders opt for blend. WH: In Germany the trend is towards blends instead of pure biodiesel. This avoids many problems. For the LCA this means that the distribution chain for existing fuels should be assessed, and the impact of introducing a blend.

Choice 3: Time horizon

WH: we should look at the short-term, and not go beyond 3 years, because fuel standards change, emission standards change and cars will have other performances that differ too much from the present situation.
JG: homogenity in the time horizon is important.
JK: This choice implies that the cars are less efficient using biofuels than when using fossil?
DB: No, a blend of max 5 % can be used in current cars without problems.

Stakeholders reach also consensus here, time horizon is set to 3 years from now. The cars' performance will be averaged from the current fleet. VT adds that Milieu Centraal earlier compared the performance of "average" cars with new ones. That study may contain interesting information.

Choice 4: Geography

Stakeholders have some discussion about the most plausible scenario of where production and conversion take place and what the resulting distribution scheme will be.
JK remarks that the questions at this meeting are quite supply oriented, while the situation of rapeseed cropping in the Netherlands is rather hypothetical. It would be more realistic to study the real market.
WH finds that subsidies drive the supply of biofuels, with a decreasing amount of subsidies and more countries in the EU, the question is where cropping is the most logic. One should also think about countries outside the EU (Brazil, Ukraine, Byelorussia).

EvdH ends the discussion, proposes to postpone the decision and to ask the experts which scenario would be the most plausible, e.g. x % of biodiesel is produced in the Netherlands, y % Germany, etc. The choice will be made by email. *(Experts will propose complete chains].*

Choice 5: Multi-product processes

When multiple products are generated, the problem of allocation arises. Stakeholders have to choose an allocation method that will be used in the LCA. There are 4 methods:

1. system expansion, unless that leads to non-realistic situations
2. economic allocation
3. allocation by physical parameter (e.g. litre, GJ)
4. 100 % allocation to the main product

This choice is postponed. *(Expert advice will be provided].*

Choice 6: Impact assessment strategies

The participants can choose between

- A standard set of impact categories:
    - Energy carrier depletion
    - Climatic change
    - Human toxicity
    - Acidification
    - Eutrophication
- The standard set + extra set:
    - Photochemical oxidation
    - Odour
    - Terrestrial toxicity
    - Land use
- The complete set, the above +
    - Other a-biotic depletion
    - Ozone layer depletion
    - Eco-toxicity for fresh water and fresh water sediment
    - Eco-toxicity for sea water and sea water sediment

More impact categories do not necessarily increase the insight, and may even make it more difficult to draw conclusions.

VT: what about biodiversity?
JG: Land use and biodiversity can be accounted for in qualitative way. It is better to include all impact categories from the beginning, than to add them later.

EvdH: recommendations from both experts and Ecofys are required, this choice will be done by email. *(Expert + Ecofys advice will be provided].*

6. Homework

For the postponed choices (4, 5, 6) the expert-team is asked to deliver recommendations by e-mail, clarifying the important considerations. Choices will be announced and made by e-mail or the VIEWLS website.

7. End

The date for the 2nd workshop was set on October 19th. Being not convenient for several stakeholders, a new date will be proposed by email.

The workshop is closed by EvdH

B.2 Minutes Workshop 2

Date and time: 2004 November 2, 1230-1700 h

Present

Present	
Voline van Teeseling (VT)	Milieu Centraal
Jeroen Kloos (JK)	LTO Nederland
Hans Jager (HJ)	Stichting Natuur en Milieu
Wolfgang Hilbert (WH)	Petroplus
Per Godfroij (PG)	VROM
Martin Weissmann (MW)	Nedalco
Piet van den Ouden (PvdO)	ATEP
Jeroen Guinée (JG) – expert	CML
Anton Kool (AK) – expert	CLM
Rik Baert (RB) – expert	TU/e, TNO Automotive
Richard van den Broek (RvdB) – LCA work	Ecofys
Carlo Hamelinck (CH) – LCA work	Ecofys
Eric van den Heuvel (EvdH) – chairman	SenterNovem
Jorg Raven (JR) – organisation	SenterNovem
Absent	
Gert-Jan Nabuurs (GJN) – expert	Alterra
Kyriakos Maniatis (KM)	EC DG TREN
Dominic Boot (DB)	VNPI
Ton Vermie (TV)	Gemeentewerken Rotterdam
John Akkerhuis (JA)	Gemeentewerken Rotterdam

(Contact information is available at Project website].

1. Opening and minutes

JK: Minutes p2: Depletion of oil is not the only argument for biofuels, also the balance of carbon dioxide and nitrogen oxides in the air should be taken into account.

EvdH: Next week there will be a decision on possible extension of the LCA with other fuels. *(Meanwhile, it has been decided by SenterNovem to include ETBE and its reference MTBE in the project]*

MW: It is important to dedicate as much attention to the fossil fuel chains. For Nedalco the extra value of this LCA would be also in implementing real world oil industry information, and in gaining insight in allocations within refineries. RB: methodological choices for both biofuel and fossil fuel chains will be equal and topical numbers will be used for both. JG will unravel allocations in some existing fuel chains, to make choices possible. *(This is expected to be possible with the Ecoinvent database].*

JK: Is it true that with ethanol in gasoline and biodiesel in diesel the 5.75 % biofuels goal cannot be met? RB: There a is limit set by EU fuel standards to 5 % *by volume* (which is even less by energy). For the short term (directive goal 2 % on average), this should not be a problem. However, it is one of the reasons to look at ETBE as well.

MW: the comparison of ETBE with MTBE is in fact a comparison of ethanol with methanol. *(CH: the amount of isobutylene to produce a 1 GJ of MTBE is about 21 % more than to produce 1 GJ of ETBE. Therefore, the isobutylene production will also be included].*

RB: if there will be any fundamental data choices while performing the LCA, these will be communicated between the meetings.

2. Remaining old choices

Some expert advices were given on remaining choices.

Choice 4.1 Feedstock production in the Netherlands

PvdO: In the Netherlands the rapeseed yields could go up. This has been seen in Germany. It is realistic to produce a large share in the Netherlands. This should of course be coupled to the amounts of applied fertiliser and pesticides. VT: Is that a realistic scenario? PvdO: yes. AK: But keep eye on the timeframe, the Netherlands cannot jump from 1 kha to the maximum rapeseed area in three years; some 50 kha may be achievable. PvdO: in the fifties, the production was 200 kha! Maybe we should question the chosen time-frame? WH: On short term, the applicable area will also depend on where the oil mills are located. PvdO: the oil mills in Germany close to Netherlands can also process Dutch rapeseed.

On the other hand, the exact borders are not important for the LCA. Production methods in Netherlands, Germany and France are more or less the same.

Choice 4.2 Biofuels target percentage

In between the 2005 and 2010 target: 2008 would have 4.2 % *by energy*.

Choice 4.3 Additional biofuel (feedstock) import

It is proposed to define a region “Western Europe”, a region “Eastern Europe”, and a region “World”. France and Germany do have their own biofuels target, which makes them less likely to export. However, the availability in of biomass/biofuels for the Dutch market in those countries depends on market. A part of the oil for biodiesel will come from the world market.

AK advices to use data from Poland for “Eastern Europe”.

MW: In Poland, only rye can be grown for ethanol. It will be assumed that all cereals for ethanol production will come from France, Germany and the UK. In practice, also ethanol from sugarcane from Brazil or ACP countries may enter the Dutch market, but that feedstock is outside the scope of the present project.

JG: After the quickscan, this choices should be evaluated and may be adjusted.

Table B-1. Regional origin of feedstock.

	wheat	rapeseed or oil
Western Europe	1	½
Eastern Europe	0	¼
World	0	¼

Choice 4.4 What commodity will be imported

The commodity for import from Eastern Europe and World will be bio-oil.

Choice 5 Multi-product processes

JG: The ISO standard advices to enlarge the system. For the present LCA, which has also an educational objective, it is advisable to show the consequences of system enlargement compared with allocation. This will be done by taking economic allocation as basis for all chains, and applying other allocation methods and system enlargement in a sensitivity analysis. MW: We also would like to see how the fossil reference chains deal with multiple products (e.g. in refineries). RvdB: this will be communicated next time.

Choice 6: impact assessment categories

Expert advice: incorporate all categories and let the choice eventually depend on the resulting impact. VT: I would like to follow the expert's advice, to avoid the risk that we omit issues that later may turn out to be more relevant. All find this appropriate.

The relevance of impacts will be expressed on a relative basis, using normalisation against e.g. Dutch or EU impact scores. The impacts are free of value judgements, which would be liable to culture and politics.

PvdO: eventually the applicability of this study should also be judged.

3. New choices

Because of the time, the new choices will be discussed backwards.

Choice 11.1: Blend applied

PvdO: depending on logistics, it could be attractive to blend a maximum fraction in part of the fuels. WH: depends also on how the duty exemption would be defined. PvdO: on other hand, some biodiesel in all diesel would improve lubrication, and could maybe increase the car's efficiency. WH: that has been denied by Volkswagen and Mercedes.

In general, it is expected that it is more attractive to apply 5 % ethanol in part of the gasoline, than 3.5 % in all. Unless there would be a difference in octane and car efficiency. RB: a higher octane does not automatically result in a higher car efficiency, because motor is calibrated at certain efficiency. RB is asked for further expert advice on this issue.

It is assumed that the maximum allowable blends will be used in part of the fuel.
(Biodiesel in diesel: 5 % by volume, or 4.6 % by energy. Bioethanol in gasoline: 5 % by volume, or 3.4 % by energy. BioETBE in gasoline: 15 % by volume, or 6.2 % by energy Biofuel (fraction that can be calculated as of biogenic origin].

Choice 11.2 drive cycle

RB: many test cycles exist. There is a difference between personal cars, light and heavy duty vehicles. Also there is a difference between emissions in actual practice and in test cycles. Test cycles only deal with regulated components in diesel and gasoline. But the non-regulated components are also important, e.g. aldehyds in biodiesel. Do we want to take these into account? The EU project ARTEMIS has developed alternative test cycles and conversion method to calculate actual emissions. Advice would be to use standard test cycle, and to separately deal with non-included components. It is also advised to clearly distinct between different cycle stages, such as cold start, highway, etc. RB will write an advice on this subject.

An average car will be assumed as end-user. The distribution between Euro I, II and III cars will be estimated. Result will be communicated next meeting.

Some results for the use of E5 are known from studies in the USA. For B5 this will be more difficult.

Choice 10: co-products

Straw from harvesting both feedstock could be left in-field and ploughed into soil, applied as bed-material for cattle, and applied for local electricity generation in a CHP unit. PvdO: prefers to include all three options. EvdH: the choice would among others depend on the feedstock production region.

Cake from both biodiesel and bioethanol production will be applied as fodder for cattle. WH: would the methane emission from cattle change when replacing soja with cakes? AK will advice on this.

Glycerine: at first, the glycerine could be sold to the pharmaceutical market. If that market would be satisfied, glycerine could be combusted to generate electricity. RvdB: How large is the glycerine for pharmaceutics market? WH: for the next 3 years, that market can still be expected large enough. EvdH: the pharmaceutical market in Austria switches gradually from animal to plant derived glycerine.

WH: also fertiliser could be a co-product in biodiesel production, depending on the actual process (catalyst).

Lignin residue from ethanol production will be combusted.

MW: CO_2 can be an important co-product of ethanol production within three years. In Spain, CO_2 is already sold. RvdB: would that be realistic in the Netherlands? MW will give further advice on this issue

Choice 9.1: Conversion organisation

WH: biodiesel standard production facility will be about 150 ktonne/year. MW: bioethanol about 200 Ml/yr.

Choice 9.2: Process type

WH: There are two main processes for the production of biodiesel, both are equally plausible.

MW: The choice for ethanol processes mainly depends on the feedstock and the desired ethanol quality, these are already fixed. One can choose for dry co-products (to be sold further away), or semi-wet.

Choice 9.3: Auxiliaries

PvdO: part of the residu will be used for heat and electricity generation in the ATEP proces.
WH: in practice, heavy full oil will often be used for heating the oil press. The heat requirement is 15 tonne/h steam for 150 ktonne/y oil. Electricity will often come from the grid.

MW: the Bergen op Zoom plant can serve as starting point for the ethanol production.

4. Homework for Ecofys

Next meeting (January 11, 2005) the quick-scan results will be presented.

If necessary, exact data and extra choices will be communicated to the participants between the meetings.

B.3 Minutes Workshop 3

Date and time: 2005 January 11, 1230 – 1700 h

Present

Present	
Voline van Teeseling (VT)	Milieu Centraal
Jeroen Kloos (JK)	LTO Nederland
John Akkerhuis (JA)	Gemeentewerken Rotterdam
Angelle Chang (AC)	Gemeentewerken Rotterdam
Wolfgang Hilbert (WH)	Petroplus
Per Godfroij (PG)	VROM
Martin Weissmann (MW)	Nedalco
Piet van den Ouden (PvdO)	ATEP
Jeroen Guinée (JG) – expert	CML
Anton Kool (AK) – expert	CLM
Jan Willem van Groenigen – expert	Alterra
Richard van den Broek (RvdB) – LCA work	Ecofys
Carlo Hamelinck (CH) – LCA work	Ecofys
Eric van den Heuvel (EvdH) – chairman	SenterNovem
Jorg Raven (JR) – organisation	SenterNovem
Absent	
Kyriakos Maniatis (KM)	EC DG TREN
Dominic Boot (DB)	VNPI
Ton Vermie (TV)	Gemeentewerken Rotterdam
Hans Jager (HJ)	Stichting Natuur en Milieu
Rik Baert (RB) – expert	TU/e, TNO Automotive
Gert-Jan Nabuurs (GJN) – expert	Alterra

(Contact information is available at Project website].

1. Opening and minutes

Gert-Jan Nabuurs is not available for this meeting; he is represented by Jan Willem van Groenigen, who is expert on nitrogen emissions from agriculture.

Minutes WS2 page 4; The suggestion that the pharmaceutical market in Austria switches gradually from animal to plant derived glycerine was not made by EvdH. It is not clear who made this remark; it will be deleted.

2. Interpretation of results

RvdB explains how the interpretation of LCA calculation results, in general, work. In the quick scan results there may be items that give rise to questions. Especially where impacts or emissions are larger than was expected on beforehand. When these questions are solved, the item's impact may be substantially reduced and other items may pop-up that were not visible previously. This is an iterative process.

3. LCA quick scan fossil fuels

JG explains his note about the quick scan and the Ecoinvent databases. *(This note was distributed by email and is available at the Project website].* The database contains about 2600 processes, of which 1000 are very relevant for analysis of the fossil fuel chain. The database consists of a set of allocated and a set of unallocated processes. The allocated processes are in fact single-

output versions of the (multi-output) unallocated processes; an unallocated process with e.g. three products was translated into three allocated processes with each one product. The idea is to analyse the fossil fuel chains, by applying the same allocation method as for the biofuels chain to the available unallocated processes.
For this purpose the unallocated processes must be linked to the other (already allocated) processes. However, there is overlap between the two datasets, and it has proven difficult to unravel this overlap. Also, some of the data is "contaminated".

MW: How will you deal with fuel import? WH: there is only import from the Middle East. Certain types of crude oil influence processes in the refinery, and emissions from the refinery. All refineries are different. There are differences between gasoline from one refinery and the other. JG: Ecoinvent database applies an average for Europe.

MW is glad that the LCA on fossil fuels gets equal attention in this project. Transportation routes should also be included. E.g. because of flaring off methane, which does not happen in Saudi Arabia. WH: flaring happens everywhere.

MW: Since 2000, there is less sulphur in diesel/gasoline; this induces an efficiency penalty for refineries. Extra hydrogen is required for the hydrotreating (?). JG: This will be included in the comments. MW: The difference in indirect energy use for gasoline can be found in a Concawe report. *(This report will be posted to the Project website].*

WH: There are large differences in the supply routes. Oil from Russia, perhaps 10 % is lost, Nigeria, there are other environmental (forest damage, contamination of surface water) and socio-economic impacts.

For the allocation, gasoline and diesel prices from the last 5 year will be used.

If there are other questions about the fossil fuels database, they should be passed on to JG a.s.a.p. Questions can also be asked via the Virtual Office.

4. Input for the LCA

The biofuels production chain layout and input parameters are presented by CH. *(presentation send with these minutes and available at Project website].*

Wheat to be produced in France, Germany and UK. Information is required about:

- Use of CAN fertiliser, ureum fertiliser, or animal manure
- Crop yield
- Pesticides

PvdO: Is this amount of pesticides necessary? RvdB: Note that the yield correlates with the amount of pesticides, less pesticides would lead to lower yield. AK: in the Netherlands, the emission of pesticides to surface water is limited by new application technologies, it is unclear how this is in other countries.

JK: CLM developed an "environmental point system." Based on the toxicity of pesticides, points are attributed for the compartments soil, groundwater and surface water. With this system, farmers can compare the different pesticides.

MW questions the diesel requirement. With 65 – 130 litre diesel per hectare. Assume that the tractor's fuel efficiency is 1 litre for 5 km, then 325 – 650 km can be driven. If tractor lanes of 2 meter are assumed, there are 50 lanes of 100 meter in a hectare → 5 km. Thus, the tractor would be 65 – 130 times at the plot of land. This seems very much. CH will specify this.

Most assumptions about the feedstock production were taken from the so-called "Kwantitatieve Informatie" (quantitative information) about agricultural practice in the Netherlands. *(This publication will be available at the project website].*

JK: If biodiesel is used in the tractor, the greenhouse gas balance is better. CH: This basically does not make a difference, while the CO_2 emissions from the agricultural part decrease to zero, the amount of biodiesel produced by the chain also decreases. The total emissions from the chain must thus be divided by a smaller amount of km driven by the end-user. The overall effect for CO_2 depends on the ratio between CO_2 emissions from agriculture compared to other processes in the chain (if agricultural processes are responsible for 10 % of the chain CO_2 emissions, and also consume 10 % of the biodiesel produced, then the net effect for CO_2 is zero). On the other hand, the other emissions from agriculture stay the same, but will be divided by the smaller amount of km driven by the end-user, so that the impact per km increases.

For wheat and straw prices, use data from HPA (Hoofdproductschap Akkerbouw – Commodity Board Arable Farming). Apply five-year average from after agricultural reform.

EvdH: Next time please supply us with a fact-sheet of the choices made. *(The overview of choices will be updated and sent to the participants].*

PvdO can supply rapeseed yields.

Nitrogen balance. The balance as presented by CH is commented upon by JWvG. There is an international accepted method from the IPCC, which is very generic. Also there is knowledge about specific crops and agricultural situations, and about how to deal with residues. The balance will be adapted in cooperation with CLM (AK), Alterra (JWvG), PPO (Wim van Dijk and Chris de Visser) and LTO (JK). WH: We also need insight in how the balance works in other countries.

The applied distances for international transport will be checked with distances previously applied by CE in a "food-study".

The rapeseed oil (from "the rest of the world") will be assumed to come from Canada

MW: Ethanol yield depends on C6 sugars. The fraction of starch may be different per country. A theoretical maximum is about 395 litres per tonne. The price of ethanol (for allocation purposes) is about 650 €/tonne (long-term Rotterdam price). MW: Ethanol improvement opportunity: What happens when CO_2 from the process (about 1 kg CO_2 per kg ethanol produced) is collected and sold?

B.4 Minutes Workshop 4

Date and time: 2005 March 1, 1230 – 1700 h

Present

Present	
Voline van Teeseling (VT)	Milieu Centraal
John Akkerhuis (JA)	Gemeentewerken Rotterdam
Angelle Chang (AC)	Gemeentewerken Rotterdam
Wolfgang Hilbert (WH)	Petroplus
Per Godfroij (PG)	VROM
Piet van den Ouden (PvdO)	ATEP
Hans Jager (HJ)	Stichting Natuur en Milieu
Anton Kool (AK) – expert	CLM
Peter Kuikman (PK) – expert	Alterra
Rik Baert (RB) – expert	TU/e, TNO Automotive
Richard van den Broek (RvdB) – LCA work	Ecofys
Carlo Hamelinck (CH) – LCA work	Ecofys
Eric van den Heuvel (EvdH) – chairman	SenterNovem
Jorg Raven (JR) – organisation	SenterNovem
Absent	
Kyriakos Maniatis (KM)	EC DG TREN
Dominic Boot (DB)	VNPI
Jeroen Kloos (JK)	LTO Nederland
Ton Vermie (TV)	Gemeentewerken Rotterdam
Martin Weissmann (MW)	Nedalco
Jeroen Guinée (JG) – expert	CML
Gert-Jan Nabuurs (GJN) – expert	Alterra

(Contact information is available at Project website].

1. Opening and minutes

There are no comments on the minutes

2. Interpretation of results

Sulphur emissions from end-use were not yet included. These will be very low for the fossil fuel chain as well, because of narrower fuel specification (10 ppm). This has, however, consequences for energy use in the refinery.

PK: Elsewhere in Europe, fertilisers are ammonia based rather than nitrate based, this gives lower N_2O emission, but higher NH_3 emission. Furthermore, the crop residues of wheat contain slightly more N than those of rapeseed.

Land use is not yet assessed. This will be done for the land use for biofeedstock cropping only. Land-use for factories/refineries will not be included. Allocation will be taken into account.

There are a few unexpected results that should be double-checked:

- Photochemical oxidation is large with ETBE.
- Effects of mineral toxicities in the sea are relatively high.
- Conversion process wheat into ethanol has unexpected high energy use.

PvdO: would like to have more insight in how the allocation has been done. CH: the assumptions underlying the allocation will be distributed.

HJ: These calculations are based on average yields. Can a range be given, and what is the improvement potential.

3. LCA quick scan fossil fuels

WH: What spills (CH_4, Br, Ba and Sr to sea), flaring and shipwreck are included in the fossil fuels chains? CH: We will check in how far those emissions are included. WH: And what about the noise induced by drilling that disturbs whales? CH: There may be other impacts than those that we calculate in this study. In the report, it will be described that these cannot be taken into account. *(JG: Flaring, and chemical spills from oil drilling are accounted for in the Ecoinvent database. Acoustic disturbance of animals is not].*

In the quick scan report not all the captions are right. These should be double-checked.

Will biodiversity be included as an impact? That would be very difficult. Biodiversity is still subject to many discussions and cannot easily be expressed in a number. This subject is currently being assessed in the EEA study "Assessing the potential impact of large-scale biofuel production on agricultural land use, farmland habitats and related biodiversity". This study may come available before the end of our project.

WH: Can the different impacts be compared, e.g. GHG balance with acidification? Which impact is more important and which is less important? RvdB: There are methods to group impacts into fewer categories and eventually into one number, but that is still under discussion in LCA

What losses and spills from refineries are taken into account? *(JG: Losses and spills are taken into account].*

4. Discussion on land use

In the first meeting it had been argued that in the reference situation set-aside land is assumed.

PvdO finds set-aside land not a realistic alternative to cropping of bio-energy feedstock. In the Netherlands, all agricultural land has a current use. Cropping for biofuels therefore implies that another crop will be pushed aside. RvdB explains that if bioenergy crops e.g. replace sugar beets that were cropped for sugar, than in the new situation a source for sugar must also be produced. This would require e.g. import of sugar, which in turn requires that somewhere else land is used that was previously used for other products. Hence this will lead to extreme wide system boarders (“modelling the world”). PvdO argues that the sugar beet production may be very uneconomic, in that case it may be sensible to replace it by wheat production for ethanol. RvdB explains that many crops may be uneconomic, but still they have an economic value. If the value is too low, the crop may be replaced by fallow land. Then, this fallow land would be the reference situation for bio-energy cropping. Since, in that case, not the energy crop causes the sugar beet to be replaced, but an autonomous economic motive. For the assessment of local environmental impacts it can be useful to look at this replacement of a food crop with a biofuel crop. However, this is a different objective than the objective of this LCA (comparing two products). PvdO sees the problem, but finds the idea that in Western Europe set-aside land is assumed as a reference still very unsatisfactorily. He accepts the reference if this is clearly explained in the report.

5. Sensitivity analysis

A sensitivity analysis should comprise:

- Yields –30 % to +30 %
- IPCC methodology for the nitrogen balance versus the crop specific balance
- Direct N_2O emission between 0.25 and 2.25 % (in Spider diagram)
- Vary ammonia
- Real fallow versus green fallow.

6. Actions

The following actions should be taken:

- Jeroen Guinée: refinery efficiency correction for low sulphur. Economic allocation with better numbers from stakeholders if available.
- Biofuel chains: find yield versus fertilisation data for Germany, France and UK
- Direct comparison of biodiesel, ethanol and ETBE (when possible).
- Make list of improvement options:
    - 30 % higher rapeseed yields in Germany (PvdO)
    - Future fertiliser production with lower N_2O emission
- Check the ethanol production plant, the energy use in the current results is very high.
- The report should clearly describe what an LCA can be used for, and what not. Local (environmental impacts).
- Mention biomethanol as source for biodiesel esterification.
- Land-use will be incorporated quantitatively, but only for the feedstock production.
- Improve the pesticides use with newest version of the KWIN (PvdO).
- In analysis discuss to what extent the KWIN advises are reality.

Annex C Overview stakeholder choices made

Choice 1: Chains to be compared

Biodiesel and bioethanol on the short term will be compared with diesel and gasoline respectively. There is the wish to incorporate ETBE. (Meeting 1), this will be done (Meeting 2).

Choice 2: End use and functional unit

Choice 2.1: The biofuels chain including the end-use will be assessed. The comparison will be on basis of km driven. (Meeting 1)
Choice 2.2: The diesels will be used in a weighed average of passenger cars and heavy duty vehicles. Ethanol will be compared with gasoline in passenger cars only. (Meeting 1)
Choice 2.3: The biofuels will be applied as blends. (Meeting 1)

Choice 3: Time horizon

Time horizon is set to 3 years from now. The cars' performance will be averaged from the current fleet. (Meeting 1)

Choice 4: Geography

Choice 4.1: Maximum possible feedstock production in the Netherlands. (Meeting 2)
Choice 4.2: Biofuels target percentage is 4.2 % by energy. (Meeting 2)
Choice 4.3: All feedstock for ethanol will be from wheat from Western Europe. Half of the feedstock for biodiesel will be from rapeseed in Western Europe, one quarter from Eastern Europe and one quarter from World. (Meeting 2)
Choice 4.4: Import commodity from Eastern Europe and World is bio-oil. (Meeting 2)

Choice 5: Multiproduct processes

Economic allocation is taken as basis for all chains. Other allocation methods and system enlargement will be used for sensitivity analysis on one chain. (Meeting 2)

Choice 6: Impact assessment categories

Initially all categories will be assessed. For the presentation of results, the relevance of impacts will be expressed on a relative basis (Meeting 2)

Choice 7: Feedstock production

Ecofys assumed the aggricultural practice as reported in the KWIN.
Choice 7.1: Type of agriculture
Choice 7.1a: Type of system is EKO agriculture or Common agriculture

Choice 7.1b: Level of modernisation (Eastern European agriculture) is current local agriculture or Modernized agriculture.
Choice 7.2: Soil type is clay or sand. Ecofys assumed the soil type to be mineral (advice by Alterra).

Choice 8: Transport

Choice 8.1: For international transport one could choose the most economic option or the most energy efficient option. Ecofys assumed for transport from "world" a large sea-vessel (150 ktonne) and for transport from Eastern Europe a barge (1200 tonne).
Choice 8.2: Return trip. Each transport step could carry freight on its return or the return could be empty. The stakeholders chose, after a suggestion by Ecofys that other freight is carried on the return trip (only the actual biomass material transport is allocated to the biofuels chains.

Choice 9: Conversion

Choice 9.1: Biodiesel facility 150 ktonne/year. Bioethanol about 200 Ml/yr. (Meeting 2)
Choice 9.2: Biodiesel standard process and Ethanol semi-wet process. (Meeting 2)
Choice 9.3: Heavy fuel oil for heating the oil press. Electricity from grid. (Meeting 2)

Choice 10: Co-products

- Wheat and rapeseed straw is $^1/_3$ left in-field and ploughed into soil, $^1/_3$ applied as bed-material for cattle, $^1/_3$ applied for local electricity generation in a CHP unit.
- Cake from both biodiesel and bioethanol production is applied as fodder for cattle.
- Glycerine from biodiesel production sold to pharmaceutical market.
- Co-product fertiliser from biodiesel production sold.
- Lignin residue from ethanol production could be combusted to produce heat and power. This is not considered in the baseline comparison. One variation will be analysed that uses straw from the field for heat and power.
- CO_2 from ethanol production could be emitted or sold for other purposes. This will not be considered.

Choice 11: End-use

Choice 11.1: The maximum allowable blends will be used in a part of the fuel market.
Choice 11.2: Baert will advice on the driving cycle and end-of-pipe emissions, see Annexes D.4 and D.5.

Annex D Expert advices

D.1 Geography of fuel chains

Section written by Antol Kool of CLM Research and Advice

During Workshop 1 the Stakeholders discussed about what would be the most plausible scenario of where production and conversion take place and what the resulting distribution scheme would be.

Large-scale rapeseed cropping in the Netherlands was considered rather hypothetical. It would be more realistic to study the real market. Based on land availability, acceptable transport distances, (expected) production costs and (expected) local subsidies, one may sketch a realistic scenario of where feedstock production takes place. E.g. x % of biodiesel is produced in the Netherlands, y % Germany, etc. One should also think about countries outside the EU (Brazil, Ukraine, Byelorussia).

The timeframe for the study was set to three years from now (see minutes first meeting). For the geography choice it is important to know what is the amount of biofuels concerned. As the amount that can be produced within the Netherlands is limited, a larger amount of biofuels implies more import. So, it should be defined what percentage of biofuels would be realised in three years from now: the 2005 target, the 2010 target, or between.

Biodiesel

Ecofys' Fact finding study (Van den Broek et al. 2003) states that maximally about 20% of the 2010 target for the Netherlands (of 5.75 %) can be realised from feedstock within the Netherlands. This statement is based on Van der Voort (2003) who assumes that 71 kha can be made available annually (in a 4 year rotation) for rapeseed cropping.

The set-aside land currently left fallow could be used. This is 26 kha in a two year rotation (fact finding study). Existing grasslands, green maize (fodder), and orchards will not be replaced. Rapeseed cannot be cultivated in rotation with sugar beet. About 70 kha of other crops (cereals) could be rotated with rapeseed every two years. This brings the total of additional crop area to about 50 kha (0.5 x 70 + 0.5 x 26).

Note that in 2004 there was only about 1000 ha of rapeseed in the Netherlands. It will be difficult in practice (machinery, etc) to increase this area in 3 years with 50 or 70 kha.

The 50 kha of additional crop area could supply 72 million liters of biodiesel, or 2.4 PJ. The Fact finding study splits the biofuels target to a target for biodiesel replacing diesel and a target for ethanol replacing gasoline. Compared with the biofuels target for 2005 (5.4 PJ biodiesel) this would be 45 % of the biodiesel demand. Compared with the 2010 target (16 PJ biodiesel), this represents about 15 %.

This means that additional biodiesel or feedstock must be imported. Even if feed crops available in the Netherlands would be used for biofuels production, this would in one way or the other, lead to additional import of feed, which can be equated with import of biomass feedstock.

At present, the largest area of rapeseed production is in Germany (1.2 Mha) and France (1.1 Mha), respectively 32 and 27 % of the total EU25 production [Elbersen e.a. 2004]. These countries are close to the Netherlands. Considering the short term of 3 years, it may be plausible to import from these countries.

It must be noted, however, that Germany and France will have to double their current rapeseed production, in order to fulfil their domestic biofuels target for 2005. This makes import from these countries less logic.

In Eastern Europe a large area is potentially available for additional crops, and the demand for biofuels is lower. The largest potential is in Poland, which could produce a surplus of 30 - 40 PJ biodiesel to its 2010 target (Hamelinck et al. 2004).

The conversion of the rapeseed to biodiesel could take place near the production of the rapeseed (France, Germany, Poland), or near the end use in the Netherlands.

Bioethanol

For the production of bioethanol similar reasoning holds. From additional crops on 50 kha about 144 Ml or 3 PJ could be produced. This represents 80 % of the 2005 or 25 % of the 2010 target (for ethanol).

Ecofys' fact finding study also suggested the application of existing feed crops (grain), but it must be realised, as was also stressed in the fact finding study, that this would imply the import of a same amount of feed crops (animals will not eat less). This can therefore be taken equal to import of grain for ethanol production.

Additionally, a large amount of residues could become available: sugarbeet molasses, potatowaste and C starches. About 4.5 PJ bioethanol could be produced from this (Fact finding study).

The largest producers of grain in the EU are France and Germany (4,9 Mha and 2,9 Mha, or 22 and 13 % of the total EU25 areaal wheat, Elbersen et al 2004). For 2010 it is projected that Germany has no surplus ethanol to the EU biofuels target. France may have a large surplus. In Eastern Europe, again Poland has a large potential acreage (about five times the target). The current acreages for cereals are: Poland (2.3 Mha wheat), Romenia (2 Mha wheat), Bulgaria (1.1 Mha wheat and 0.3 Mha barley), (Hongary (1.1 Mha wheat).

In conclusion, there is a lot of wheat potentially available in neighbouring countries (esp. France), and in Eastern Europe. The latter may be more interesting from a cost point of view.

Also, potentially, a large amount of bioethanol may be imported from South America. It must be noted, that this concerns a very different crop from the wheat as considered in this study.

ETBE

ETBE is produced from ethanol and isobutylene. The ethanol stems from the ethanol chain above. The isobutylene is assumed to be produced from crude oil by steam cracking (limited amount) or by fluid catalytic cracking.

We propose that ETBE replaces MTBE in gasoline, because ETBE has the same function as MTBE (octane enhancing). MTBE is produced from methanol and isobutylene; the methanol is produced from natural gas.

D.2 Multi-product processes

Section written by Dr. Ir. Jeroen Guinée of Leiden University Centre of Environmental Science department of Industrial Ecology.

When multiple products are generated, the problem of allocation arises: how do the by-products influence the environmental performance of a chain, or how can impacts be divided over the main and by products (see Figure D-1).

The stakeholders were asked to choose the multi-product method to be used in this LCA.

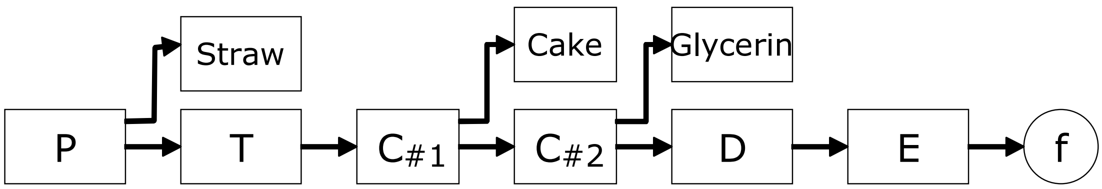

Figure D-1. Example of multiple products in the chain from rapeseed cropping to biodiesel.

System expansion

The chain that was meant to produce a biofuel, co-produces a cake that can be used as animal feed. One can keep this amount of feed within the chain, but that means that the functional unit will be an amount of km driven, and an amount of feed (kg). This is shown in Figure D-2 (top). The reference situation must have the same functional unit, and thus must also produce a same amount of animal feed. The source of the animal feed may be different, as long as the functional amount is the same (same nutrition value), see Figure D-2 (bottom).

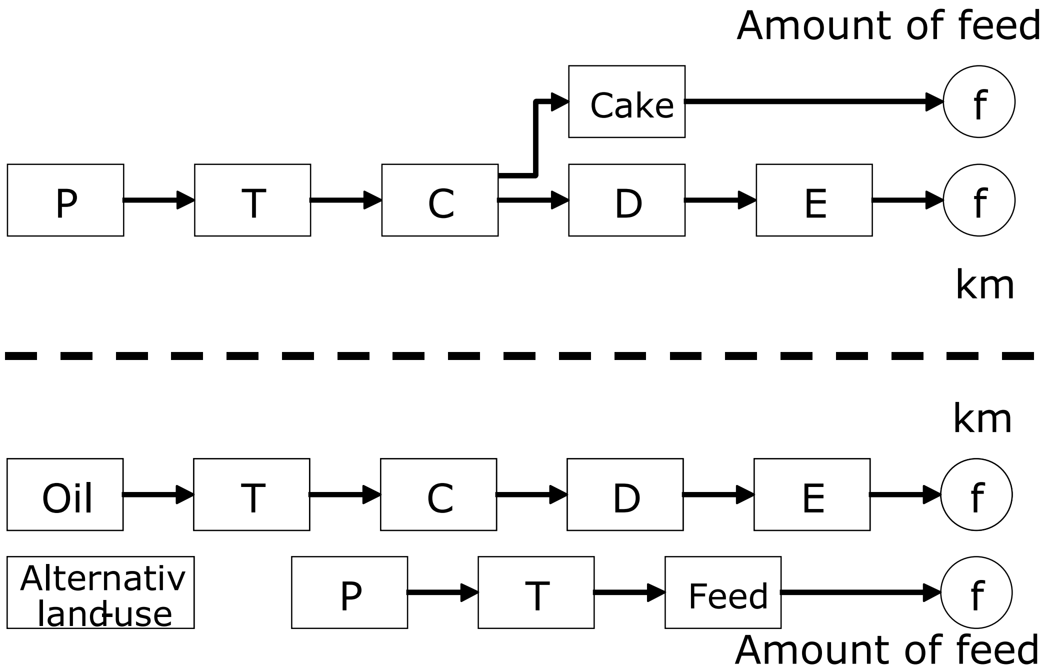

Figure D-2. System expansion of the biofuel chain (top) and of the reference system (bottom).

In the actual LCA calculation, the reference chain with the amount of feed can be subtracted from the assessed system, so that the functional unit stays a km.

System expansion can lead to unrealistic reference scenarios. Imagine a chain that produces electricity from chicken manure. One of the "co-products" of such a chain is a chicken-egg. So, we should add a chain that produces an egg to the reference system as well. We don't want this egg to be produced by chickens (because that would add manure to the chain). Hence a complicating situation.

Allocation

Another way to deal with the co-products is by allocation (Figure 4). All the emission burden up to the split is divided in certain shares over the co-product and the path to the main product.

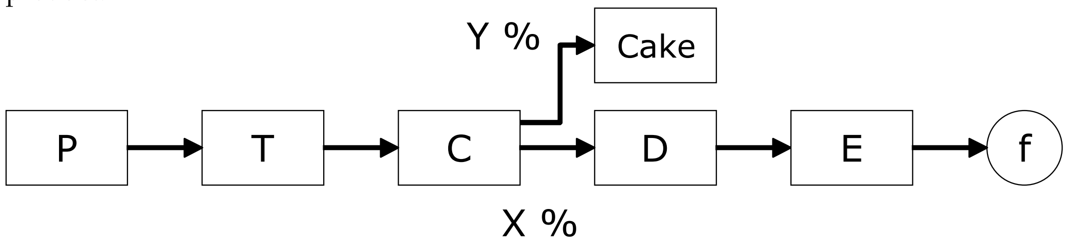

Figure D-3. A multi-product system with allocation of the emission burden over the continuing biofuels chain and over the co-products (X + Y = 100 %).

The allocation can be done by economic value, this requires that we know the market price of e.g. cake and pressed oil. In some situations, the market price is subject to discussion. In the case of glycerin (co-produced in the biodiesel from rapeseed chain) there is a small market for pharmaceutical applications. When this market is satisfied, the price for the glycerin will decrease and the share of the emission burden to the main product will increase.

It is also possible to allocate by physical parameter. Especially when two products have a similar function, it may be handy to divide the burden by mass, or by heating value. Sometimes the burden is allocated 100 % to the main product.

Expert advice (Jeroen Guinée of CML)

LCA Standards recommend Economic allocation. However, the choice between system expansion and allocation is fundamental to Life Cycle Assessment. Therefore it is recommended that all the methods are applied by the stakeholders, especially to gain insight in the consequences of this each method.

Choices at hand

There are 4 possible methods:

A System expansion, unless that leads to non-realistic situations
B Economic allocation
C Allocation by physical parameter (e.g. litre, GJ)
D 100 % allocation to the main product
E Apply all methods, to show the consequences of each **(Expert advice)**.

D.3 Impact Categories

Section written by Dr. Ir. Jeroen Guinée of Leiden University Centre of Environmental Science department of Industrial Ecology.

Impact assessment strategy

The first results from life cycle calculations will be in terms of direct and indirect energy use (feedstock), and direct and indirect emissions to water, air and soil, all per km driven. To interpret these results, they will be translated into environmental effects. There are many possible impact categories (see below).

Ecofys advice

During the first workshop, Ecofys suggested that more impact categories do not necessarily increase the insight, and may even make it more difficult to draw conclusions. It was proposed to choose between:

- A standard set of impact categories:
  - Energy carrier depletion
  - Climatic change
  - Human toxicity
  - Acidification
  - Eutrophication
- The standard set + extra set:
  - Photochemical oxidation
  - Odour
  - Terrestrial toxicity
  - Land use
- The complete set, the above +
  - Other a-biotic depletion
  - Ozone layer depletion
  - Eco-toxicity for fresh water and fresh water sediment
  - Eco-toxicity for sea water and sea water sediment

Expert advice (Jeroen Guinée of CML)

On the other hand, CML argues that pre-selection of impact categories rather decreases insight and that it would be better to include all (most) impact categories from the beginning, than to add them later. The calculations will not be more difficult. When results are produced, and based on relative impact, some categories will be turn out to be more relevant than others and for some categories inventory data may appear to be lacking.

It is also more in line with ISO Standards not to pre-select impact categories. According to ISO "the selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studies, taking the goal and scope into consideration". Without suggesting that other impact categories are not relevant for the current biofuels case, it is clear that land use impacts and fresh water ecotoxicity (due to agricultural emissions) are likely to be very relevant for this case-study.

If a choice would be made for the standard set only, then information to calculate e.g. land use and fresh water ecotoxicity would be left out. This cannot be added later.

Choice at hand

A For the time being include all impact categories, but let the choice (later) depend on the resulting relative impact **(Expert advice)**.

B Analyse the proposed standard set of impact categories.

C Analyse the standard + extra set.

D Analyse the complete set.

D.4 Effect of 5 vol% ethanol addition to gasoline (E5)

Section written by Prof. Dr. Ir. R.S.G. Baert of the Technical University of Eindhoven faculty of Mechanical Engineering / TNO Automotive

E5 combustion effect on SI engine efficiency

General observations and mechanisms

Ethanol has a higher octane number than gasoline. That means that this fuel has a lower tendency to auto-ignite when used in an internal combustion engine. Ethanol has Research Octane Number of 108 whereas most engines in Europe are developed to work on gasoline that has a research Octane number of 95. This difference allows to increase the compression ration (CR) of a normal SI (spark ignited) engine from 9.5 to 12.5 when switching from gasoline to ethanol. And a higher CR automatically results in a higher thermal efficiency (up to 5 % for a dedicated engine). Of course, when putting E5 on the market, the CR of the engines will remain at "gasoline" levels. Only if all SI fuel would be E5 fuel, then engine CR could be increased.

In principle, with a gasoline engine, spark timing is set at the level where the engine produces maximum torque. At some engine working conditions it is not possible to advance spark timing to this point because auto-ignition starts to occur. When switching to ethanol, recalibration is possible to achieve higher torque. For a given torque this will result in better efficiency. E5 has less than 2 Octane Number units higher than gasoline. There is as much difference in ON between different gasoline fuels.The scope for improved efficiency by re-calibration on E5 is limited. Furthermore, such dedicated E5 re-calibration is costly and would be usefull only for (small) fleets of vehicles. Alternatively, E5 can also be used in so-called Fuel Flexible Vehicles. These FFV's have technology to optimize fuelling strategy as a function of fuel quality.

Gasoline engines almost exclusively run on stoichiometric mixtures (because the exhaust gases of such mixtures can be cleaned up very effectively with the well-known 3-way catalyst). When running at full load, the majority of these gasoline engines however switch to socalled rich mixtures, that is mixtures containing more than stoichiometric amounts of fuel. In doing so the exhaust temperature can be reduced. With dedicated ethanol engines the higher CR will result in lower exhaust temperature levels. Therefore with these engines this rich combustion could be avoided. This would result in better efficiency at full load. This effect is however not visible when testing the engine in the New European Driving Cycle. And of course, this positive effect will be limited when running on E5 instead of on pure ethanol..

Pure ethanol has a considerably larger heat of vaporization than gasoline. Because of this, volumetric efficiency of the engine running on ethanol will be better than that on gasoline. For a given intake throttle position, engine torque will increase. As a consequence, for a given torque, more throttling will take place. Because of this, pumping losses will be larger and this will tend to reduce efficiency. Again, use of E5 will result in much smaller changes.

Conclusion

Efficiency of current gasoline engines running on E5 will be almost equal to the efficiency on gasoline. If the fuelling of these engines would be recalibrated for optimum results with E5, then efficiency gains in the order of (1 – 2 %) lower energy consumption could be possible. More experiments are needed. It is suggested that in these experiments efficiency would be registered across the engine operating range or in a test cycle that is more representative of actual driving conditions than the NEDC. Such a test cycle has been presented as a result of the EU Artemis project.

Literature survey

Most studies have been on blends with ethanol vol % between 15 and 85 % (E15 to E85). Furthermore, most studies in the past have been done in the US. It is important to point out that vehicle (and engine) types in the US tend to be different (larger) than those in Europe. Also the gasoline fuels in the US tend to differ from those in Europe. Finally in the US the test methods are different from those in Europe.

In general the data in the literature suggest that fuel consumption in the NEDC cycle with E9 will be very similar to that of gasoline, even with engine recalibration. There may be some gain in efficiency when looking at actual fuel consumption on the road (especially when a lot of full load driving would occur).

E5 effect on on SI engine emissions.

General observations and mechanisms

There is certainly an effect of ethanol addition on engine out emissions. These effects will however change with the engine design, its calibration and its operating point. Typically, adding ethanol will tend to reduce CO formation and also Particulate Matter emission.
In general little effect on NO_x is found. Emission of unburmed HC are expected to show a small increase. Part of these unburned products are ethanol and aldehydes (unregulated pollutant).
What is important is the effect of ethanol addition on the emissions after the catalyst. The effect of adding ethanol on cumulative emissions in a test cycle again shows no clear effect. A recent study by TNO on behalf of Senter/Novem confirmes this. Because 3-way catalysts are very efficient, there is no reason to expect large differences in the NEDC emissions on CO and NO_x. With conventional Pt/Rd 3-way catalysts conversion of aldehydes is good, they tend to have more problems with the reduction of unburned ethanol. Furthermore they might produce more methane emissions. So HC would be somewhat higher. More literature on the subject is being gathered.
The biggest effect is in other than NEDC test conditions :

- When enrichment can be reduced at full load, HC emission of a recalibrated ethanol engine will be lower than that of the gasoline counterpart,
- unless special action is taken, emissions during cold start on ethanol will be significantly higher.

Of course these effects will be smaller with E5.

Conclusion

Detailed data on E5 emissions are scarce; furthermore most of these data focus on regulated emissions determined in official (US or EU) test cycles. No data were found until now on the possible effect of recalibration (or CR increase) on emissions with E5. As with efficiency, it would be interesting to measure emissions on a number of (original and recalibrated) vehicles in a more representative test cycle.

At present, emissions from ethanol use in passenger cars can be expected to be the same as from gasoline use in these cars (see Table D-1).

Table D-1. Emissions from the use of gasoline and ethanol in passenger cars under Euro 1-4 regulation.

Gasoline in passenger cars		**CO**	**VOC**	**NOx**	**PM**
Euro 1	1992	2.72	0.485	0.485	0.14
Euro 2	1996	2.2	0.25	0.25	
Euro 3	2000	2.3	0.2	0.15	
Euro 4	2005	1	0.1	0.08	
Average NL 2008		**2.13**	**0.26**	**0.24**	**0.03**
Ethanol (as E5) in passenger cars					
Euro 1	1992				
Euro 2	1996				
Euro 3	2000	Same as for gasoline			
Euro 4	2005				
Average NL 2008					

Literature survey

Emission factors have been presented in the Auto Oil study. They should be treated with care however :

- in that study data from different test cycles were combined,
- only E85 data was presented,
- almost half of these data were on 1 vehicle type produced for the US market (Ford Taurus).

From the Auto-Oil data and other literature, suggestions for emission factors have been made for E5. They should be considered "best educated guess" rather than sound data.

D.5 Effect of 5 vol% biodiesel addition to diesel (B5)

Section written by Prof. Dr. Ir. R.S.G. Baert of the Technical University of Eindhoven faculty of Mechanical Engineering / TNO Automotive

B5 effect on CI engine efficiency.

General observations and mechanisms

All data in the literature suggest that the effect of biodiesel addition to diesel has little or no effect on energy consumption. This is in line with the combustion properties of biodiesel. CN of biodiesel is comparable to that of current diesel. As a consequence, rate of heat release will scale with that of diesel. When the calibration of the CI engine is kept at its "diesel" settings, the lower volumetric energy density of biodiesel results in a loss of power input. Of course recalibration can correct for this. Because CI energy efficiency shows little variation with engine load (at a fixed engine speed), fuel efficiency on B5 (with original calibration or recalibrated) will be the same as that of regular diesel.

However, adding biodiesel will result in a change in regulated emissions. There is a tendency for higher PM and NOx emissions in some operating points. This could make it necessary to recalibrate the engine (to reduce emissions). Such recalibration typically results in a loss of efficiency. With B5 this increase is expected to be such that the diesel engine emissions are still within its emission limitations. It is not likely that a recalibration for emissions reasons would be necessary.

Literature survey.

Literature studies all confirm small efficiency differences.

B5 effect on CI engine emissions.

General observations. Mechanisms.

Biodiesel is a fuel where the fuel molecule contains (a small number of) oxygen molecules. Like ethanol it is a so-called oxygenated fuel.
The oxygen in the fuel molecules tends to have the following effects :

- CO is expected to be reduced,
- NOx is often observed to increase; this is often attributed to the higher local O concentration in the reacting mixture, leading to higher thermal NO formation rate,
- Soot emission is reduced, however the amount of unburned hydrocarbons that are condensed on the soot particles increases; as a result PM emission (mass) increases,
- Emission of gaseous unburned hydrocarbons is reduced (a.o. because of the higher boiling point range of biodiesel),
- (Unregulated) aldehyde emission is expected to increase.

All the above observations are for diesel engines without aftertreatment. In the future, diesel engines will have some kind of aftertreatment. Already now some (Euro 4) passenger car diesel engines combine special exhaust temperature control strategies with a particulate filter. And large, socalled Euro V (heavy-duty) commercial vehicles that will come on the market in 2008 will have a NOx aftertreatment system (with oxydation catalyst). No data were found on the interaction of these aftertreatment systems with biodiesel-diesel blends.

Literature survey.

In Europe several studies have been done on the effect of biodiesel on combustion and emissions in a CI engine. There is quite some scatter in the effect on emissions mentioned. The reasons for this are :

- there is/was quite some variation in the quality of biodiesel (as biodiesel as such was not subject to production standard requirements),
- different engines concepts (TCA versus NA; Euro 1 versus Euro 2 versus Euro 3) will react differently to fuelling changes.

As part of the Auto Oil study a summary was made of emission factors for B30. From these numbers estimates were made for B5.
Again, these numbers refer to engines without aftertreatment.

Table D-2. Emissions from the use of diesel and biodiesel in passenger cars under Euro 1-4 regulation.

Diesel in passenger cars		**CO**	**VOC**	**NOx**	**PM**
Euro 1	1992	2.72	0.485	0.485	0.14
Euro 2	1996	1	0.4	0.4	0.09
Euro 3	2000	0.64	0.28	0.28	0.05
Euro 4	2005	0.5	0.15	0.15	0.025
Average NL 2008		**0.84**	**0.27**	**0.27**	**0.06**
Biodiesel (as B5) in passenger cars					
Euro 1	1992	2.448	0.41225	0.5335	0.154
Euro 2	1996	0.9	0.34	0.44	0.099
Euro 3	2000	0.576	0.238	0.308	0.055
Euro 4	2005	0.45	0.1275	0.165	0.0125
Average NL 2008		**0.76**	**0.23**	**0.30**	**0.06**

Annex E Assumptions

E.1 Feedstock production

Table E-1. Winter wheat growth and harvest in the north of the Netherlands[1)] clay area.

Process / material	Value assumed
Yield seeds[2)]	8.23 tonne/ha/yr
Yield straw	4.4 tonne/ha/yr
Fertiliser[3)]	205 kg N/ha/yr (CAN)
Herbicides[6)]	
Isoproturon (500)	4.5 litre/ha/yr
MCPA (500)	2 litre/ha/yr
Fenchlorazole-ethyl(39)fenoxaprop-p-ethyl(69)	0.50 litre/ha/yr
Fluroxypyr(200)	0.75 litre/ha/yr
Pesticides[6)]	
Chlormequat(400)	1.20 litre/ha/yr
Trinexapac-ethyl(250)	0.25 litre/ha/yr
Epoxiconazole(84)fenpropimorph(250)	1.00 litre/ha/yr
Epoxiconazole(125)kresoxim-methyl(125)	1.00 litre/ha/yr
Pirimicarb(50)	0.20 litre/ha/yr
Machinery[4)]	
Soil operations	4.5 h/ha/yr
Planting / sowing	0.9 h/ha/yr
Crop protection	2.9 h/ha/yr
Harvest and processing	2.4 h/ha/yr
Economic allocation[5)]	92 % to wheat

1) The yield and fertiliser input for other areas is discussed in Table E-4.
2) Netherlands: KWIN 8.4 tonne/ha/yr, minus 175 kg/ha/yr for sowing. Range 5.42 – 9 tonne/ha/yr in Ecofys' Fact-finding study, which gives no range for fertiliser.
3) Fertiliser is CAN (nitrate synthetic fertiliser, not ureum).
4) From KWIN, sums up to 87 liter diesel/ha/yr. Tractor uses 0.34 liter diesel/km (0.28 kg/km, from Simapro).
5) Straw (Choice 10): 1/3 left in field, 1/3 applied as bed material, 1/3 applied for local CHP generation. Wheat 127 €$_{2000}$/tonne (PAV 2000), Straw 50 €$_{2000}$/tonne (PAV 2000) or 25 UK pound1992/tonne (Elsayed et al. 2003) when applied as bed material. Straw harvesting costs 21 €$_{2000}$/tonne (PAV 2000).
6) The numbers within brackets indicate the concentration in g/l.

Table E-2. Rapeseed growth and harvest in the Netherlands[1].

	Value applied
Yield seeds[2]	3.3 tonne/ha/yr
Yield straw[3]	2.5 tonne/ha/yr
Fertiliser	180 kg N/ha/yr (CAN)
Herbicides	
Fluazifop-p-butyl(125)	0.75 litre/ha/yr
Nonylfenol-polyethoxyethanol(250)	1.00 litre/ha/yr
Metazachlor(500)	3.00 litre/ha/yr
Pesticides	
Vinclozolin(500)	1.00 litre/ha/yr
Parathion-methyl(240)	2.00 litre/ha/yr
Deltamethrin(25)	0.40 litre/ha/yr
Machinery[4]	
Soil operations	5.5 h/ha/yr
Planting / sowing	1.1 h/ha/yr
Crop protection	2.3 h/ha/yr
Harvest and processing	2.6 h/ha/yr
Economic allocation[5]	91 % to rapeseed

1) The yield and fertiliser input for other areas is discussed in Table E-5 and Table E-4.

2) 3300 kg/ha/yr minus 6 kg/ha/yr for sowing (PAV 2000). Range is 2.2 – 4.08 tonne/ha/yr in Ecofys' fact finding study.

3) Straw yield 2.5 tonne/ha/yr [Jansen quoted by CE 2004] – 2.78 (Elsayed et al. 2003).

4) From KWIN (PAV 2000), sums up to 130 litre diesel/ha/yr. Tractor uses 0.34 liter diesel/km (0.28 kg/km, from Simapro).

5) Rapeseed 210 $€_{2000}$/tonne (PAV 2000), assumed straw same as wheat straw 50 €/tonne (PAV 2000). Assumed costs for rape straw harvesting 21 €/tonne, same as wheat straw.

Table E-3. Fallow land in the Netherlands.

	Value applied
Sowing seeds	20 kg/ha/yr
Fertiliser	30 kg N/ha/yr (CAN)
Machinery[1]	
Soil operations	3.3 h/ha/yr
Planting / sowing	0.9 h/ha/yr
Crop protection	0.3 h/ha/yr
Harvest and processing	2.4 h/ha/yr

1) From KWIN (PAV 2000), sums up to 65 liter diesel/ha/yr. Tractor uses 0.34 liter diesel/km (0.28 kg/km, from Simapro).

Feedstock production in a selection of countries

All winter wheat feedstock comes from Western Europe (Netherlands, Germany, France and UK).

Table E-4. Winter wheat production

	Yield (tonne/ha)	Fertiliser (kg/ha)		
		Nitrate N	Phosphate P_2O_5	Potash K_2O
Netherlands[1)]	8.24	205		
Germany[2)]	7.0	165	30	40
France[3)]	6.9	200		
United Kingdom[4)]	7.7	187	43	48

1) As reported in Table E-1.
2) Actual yield 5.2 tonne/ha/yr at 205 kg N/ha/yr, possible up to (model calculation) 10.4 tonne/ha/yr at 256 kg/ha/yr (Biewinga et al. 1996). Average over 1999/2000 7.48 tonne/ha/yr at 165 kg N/ha/yr, 30 kg P_2O_5/ha/yr and 40 kg K_2O/ha/yr (Kool 2005). Average over 1991 – 2004 is 7.1 tonne/ha/yr (FAO 2005).
3) Average over 1990 – 2004 is 6.9 tonne/ha/yr (FAO 2005). Nitrogen fertiliser rate is typically 3 kg/quintal of grain (1 quintal is 100 kg) up to 200 kg/ha (Ademe 1998).
4) 8.0 tonne/ha/yr at 53 kg N/ha/yr (Elsayed et al. 2003). Actual yield 5.4 tonne/ha/yr at 213 kg N/ha/yr, possibly up to (model calculation) 11.3 tonne/ha/yr at 245 kg N/ha/yr. Winter wheat production in Great Brittain overall applied 187 kg N/ha, 43 kg P_2O_5/ha and 48 kg K_2O/ha (Goodlass et al. 2003). Average yield over 1990 to 2004 is 7.5 tonne/ha (FAO 2005).

Half of the rapeseed feedstock comes from Western Europe (Netherlands, Germany, France and UK), one quarter from Poland, and one quarter from "the world".

Table E-5. Rapeseed production

	Yield (tonne/ha)	**Fertiliser (kg/ha)**		
		Nitrate N	**Phosphate P_2O_5**	**Potash K_2O**
Netherlands[1)]	3.3	180	-	-
Germany[2)]	3.5	170	45	90
France[3)]	3.1	175	50	33
United Kingdom[4)]	3.0	194	45	46
Poland[5)]	2.1	70	33	42
World[6)]	3.0	146	24	22

1) As reported in Table E-2.
2) 3.0 tonne/ha/yr at 145.6 kg N/ha/yr (Kaltschmitt et al. 1997). 3.0 tonne/ha/yr at 101 kg N/ha/yr (Dreier et al. 1998). CLM assessed the region of Hessen: actual yield is 2.8 tonne/ha/yr at 181 kg N/ha/yr, while projected (model calculation) up to 6.4 tonne rapeseed/ha/yr at 231 kg N/ha/yr (Biewinga et al. 1996). Average over 1999/2000 3.50 tonne/ha/yr at 170 kg N/ha/yr, 45 kg P_2O_5/ha/yr and 90 kg K_2O/ha/yr (BMVEL 2004) (Kool 2005). Average over 1991 – 2004 is 3.2 tonne/ha/yr (FAO 2005).
3) Average over 1990 – 2004 is 3.1 tonne/ha/yr (FAO 2005). Nitrogen fertiliser rate is 170 – 180 kg N/ha/yr [Agreste, Cetiom websites]. Other fertilisers: phosphate 50 kg P_2O_5/ha/yr, potash 33 kg K_2O/ha/yr, Magnesium 13 kg MgO/ha/yr, Calcium 26 kg CaO/ha/yr (Ademe 1998). Yield 3.3 tonne/ha/yr at rates 180 kg N/ha/yr 90 kg P_2O_5/ha/yr, 130 kg K_2O/ha/yr and 75 kg SO_3/ha/yr (Ademe 1998).
4) Rapeseed yield 3.07 tonne/ha/yr at 196 kg N/ha/yr (Elsayed et al. 2003). East Anglia: actual yield is 3 tonne/ha/yr at 193 kg N/ha/yr, up to (model calculation) 5.9 tonne/ha/yr at 212 kg/ha/yr (Biewinga et al. 1996). Average 1990 – 2003 is 3.0 tonne/ha/yr (FAO 2005). Oilseed rape production in Great Britain overall and on average between 1998 and 2002 applied 194 kg N/ha, 45 kg P_2O_5/ha and 46 kg K_2O/ha (Goodlass et al. 2003).
5) Yield average 1990 – 2004 is 2.1 tonne/ha/yr (FAO 2003).
6) No agregated data for world has been found. World is assumed as an average of the 5 countries above. Fertiliser rate/tonne product is averaged (instead of per ha).

E.2 Production and application of pesticides

The production of pesticides applied in the present study is not included in the Ecoinvent database (or other databases available to Ecofys). However, information on the production of a generic pesticide (Roundup) is available. For the production process, we assume that energy use and greenhouse gas emissions are more important than other (toxic) emissions. Also, the toxic emissions from application of the fertiliser are assumed to contribute more to environmental impacts than emissions from production. Therefore we assume that a certain amount of this generic pesticide is produced corresponding to the total amount of active components in the actually necessary pesticides.

The application of 1 kg pesticides is assumed to lead to a direct emission to soil of that pesticide of 0.5 kg, a direct emission to air of 0.1 kg and a direct emission to water of 0.01 kg (Van den Broek 2000) based on the LEI database. The impact (Ecotoxicity Potential[8]) of these emissions on the aquatic and marine water, on sediments, on the soil and the human for most pesticides and herbicides are included in the Impact Table of CML (CML 2004). The department of Environmental Studies of the Radboud University Nijmegen (Huijbregts 2005) supplied the impacts of a few missing pesticides. Table E-6 gives an overview of the available impact data for the applied pesticides:

Table E-6. Overview of impact data available for the applied pesticides.

Active component	CAS numbers[1)]	Impact data available
Herbicides		
Isoproturon	034123-59-6	yes
MCPA	000094-74-6	yes
Fenchlorazole-ethyl	103112-35-2	no
Fenoxaprop-p-ethyl	071283-80-2	no
Fluroxypyr	069377-81-7	yes
Fluazifop-p-butyl	079241-46-6	no
Nonylfenol-polyethoxyethanol	009016-45-9	no
Metazachlor	067129-08-2	yes
Pesticides		
Chlormequat[2)]	007003-89-6	yes
Trinexapac-ethyl	095266-40-3	no
Epoxyconazole[3)]	135319-73-2 (formerly 106325-08-0)	yes
Fenpropimorph	067564-91-4 (and 067306-03-0)	yes
Kresoxim-methyl	143390-89-0	yes
Pirimicarb	023103-98-2	yes
Vinclozolin	050471-44-8	no
Parathion-methyl	000298-00-0	yes
Deltamethrin	052918-63-5	yes

1) Impact assessment database CML and various websites: http://environmentalchemistry.com/; http://www.hclrss.demon.co.uk/fluroxypyr.html; www.milieumeetlat.nl

2) Chlormequat is assumed to have the same impacts as its salt chlormequat chloride CAS 999-81-5.

3) banned by European commission

8 Ecotoxicity Potential is expressed as kg 1.4-dichlorobenzene equivalents after a period of time (usually 100 years). There are 6 different Ecotoxicity Potentials: FAETP (Freshwater Aquatic Ecotoxicity Potential), MAETP (Marine Aquatic Ecotoxicity Potential), FSETP (Freshwater Sediment Ecotoxicity Potential), MSETP (Marine Sediment Ecotoxicity Potential), TETP (Terrestrial Ecotoxicity Potential) and HETP (Human Ecotoxicity Potential).

Some of the pesticides for which no direct impact information is available are present in the Environmental Measuring Rod [Milieumeetlat 2005]. The Environmental Burden Points of the missing pesticides fenchlorazole-ethyl(39)fenoxaprop-p-ethyl(69) (Puma S EW), Fluazifop-p-butyl(125) (Fusilade max), Trinexapac-ethyl(250) (Moddus 250 EC), and Vinclozolin(500) (Ronilan DF) can be extracted for Water Life, Soil Life and Soil Water. Because also many of the pesticides with known impacts are present in the Environmental Measuring Rod, we have analysed the correlation between the Environmental Burden Points and the Life Cycle Impact. Figure E-1, Figure E-2 and Figure E-3 show the result.

There is no correlation between Ecotoxicity potential and Environmental Burden Points. Therefore we assume that the impact of the missing pesticides is the average of the known pesticides applied in this study.

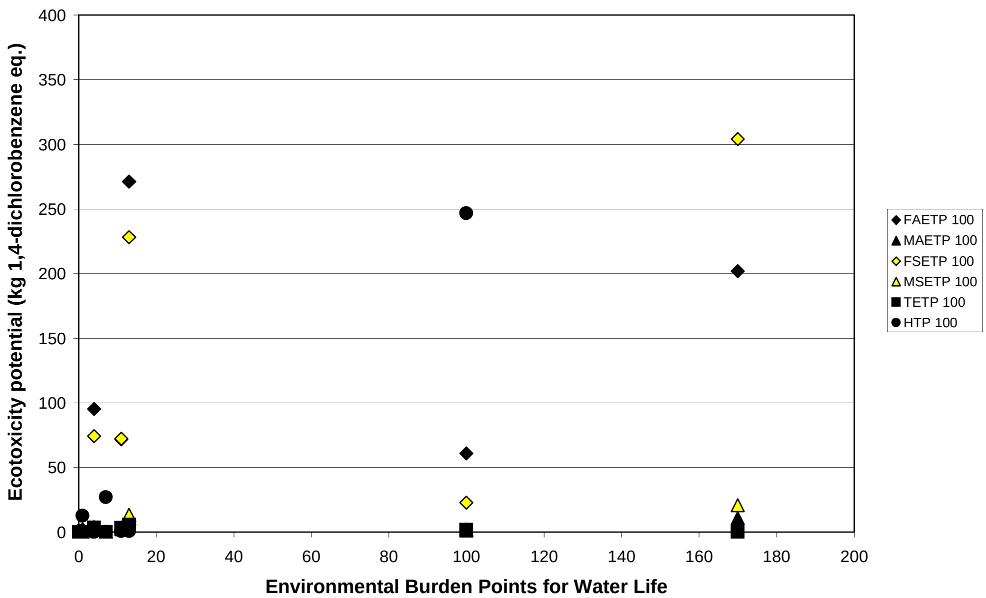

Figure E-1. Ecotoxicity potential versus Environmental Burden Points for Water life.

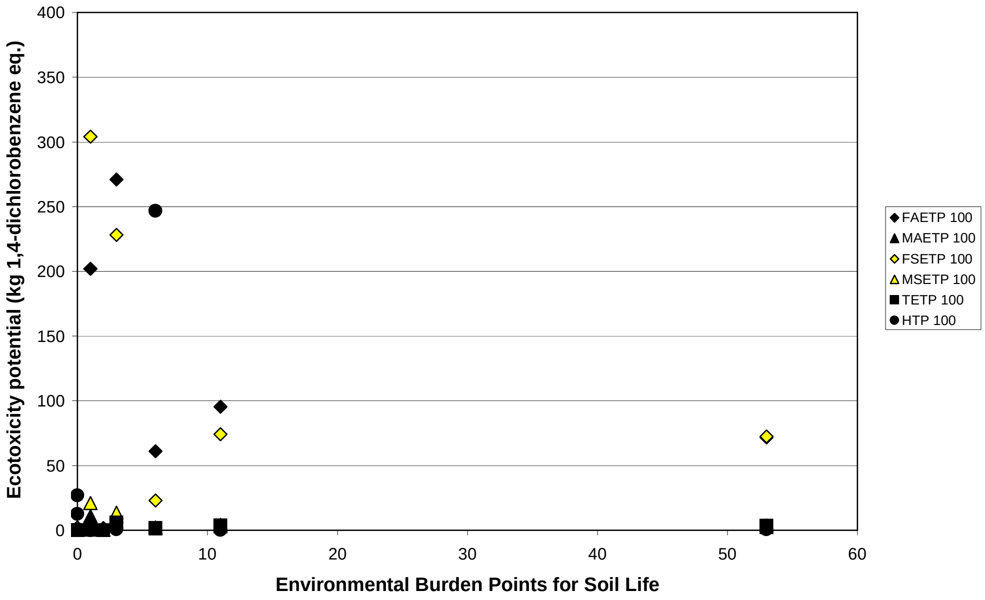

Figure E-3. Ecotoxicity potential versus Environmental Burden Points for Soil Life.

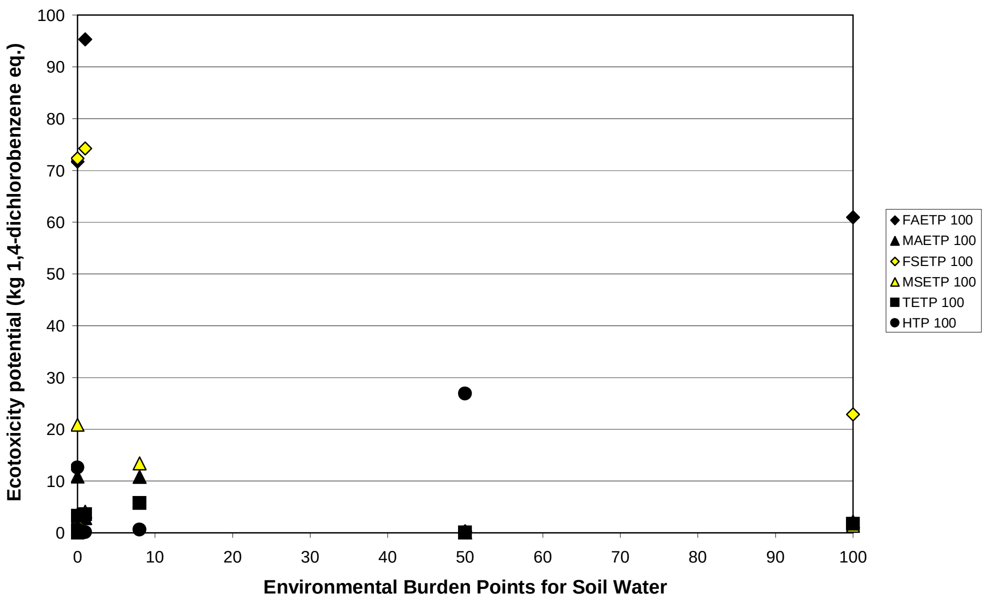

Figure E-2. Ecotoxicity potential versus Environmental Burden Points for Soil Water.

E.3 Fertiliser production

The production of fertilisers demands energy and generates greenhouse gas emissions. It has been estimated that fertiliser production consumes about 1.2 % of the worlds energy and is responsible for approximately 1.2 % of the total GHG emissions (Wood et al. 2004). Therefore, fertiliser production is an important component of this LCA.

Fertiliser emission factors vary widely depending on production technology. Wood and Cowie (2004) provide an overview of published GHG emission factors associated with the production of a range of nitrogen, phosphate and multi-nutrient fertilisers. The studies were generally coupled with energy LCA. They also remark that emission factors for similar fertiliser products differ markedly between reports, but that a lack of transparency limits the comparison between sources.

GHG emission from nitrogen fertiliser production

Key nitrogen fertilisers are:
- Ammonium nitrate (AN)
- Calcium ammonium nitrate (CAN)
- Urea
- Urea ammonium nitrate (UAN)

Ammonia is the primary input for the majority of nitrogen fertilisers. Along with N_2O emissions from subsequent nitric acid production, CO_2 emissions from ammonia production dominate GHG emissions from nitrogen fertiliser manufacture (Wood et al. 2004). Ammonia is generally produced by the Haber-Bosch process where three volumes of hydrogen react with one volume of nitrogen over an iron catalyst. Nitrogen stems from air, and hydrogen (in Europe) generally from natural gas. The process is very energy demanding and CO_2 emissions range from 1.4 to 2.6 kg CO_2/kg N in NH_3 (Wood et al. 2004).

Weak nitric acid is used in the manufacturing of ammonium nitrate, calcium nitrate and potassium nitrate, which, in turn, are used either as straight fertilisers or mixed into compound fertilisers. Most weak nitric acid production is based on the Oswald process (Smit et al. 2001; Wood et al. 2004):
- Catalytic oxidation of ammonia with air into nitric oxide
- Oxidation of nitric oxide into nitrogen dioxide
- Absorption of nitrogen dioxide in water to produce nitric acid.

Nitrous oxide (N_2O), nitrogen monoxide (NO, also known as nitric oxide) and nitrogen dioxide (NO_2) are produced as unwanted by-products during catalytic oxidation of ammonia. IPCC currently believes that nitric acid production is the largest industrial source of N_2O (Wood et al. 2004). The amount of N_2O emitted depends on combustion conditions, catalyst composition, burner design and emission abatement technology.

The N_2O emissions reported by Wood and Cowie range from 2.5 to 13.4 kg CO_2 equivalent/kg N (or 0.55 to 2.9 kg CO_2 equivalent/kg nitric acid, or 0.0018 to 0.0095 kg N_2O/kg nitric acid). The broad variation is attributed to the installation of emission abatement technologies. IPCC reports emission factors as high as 5.8 kg CO_2 equivalent/kg nitric acid.

6 Nitric acid plants in the Netherlands produce together 7010 tonne nitric acid per day and emit 54.1 – 59.1 tonne N_2O per day, this is 0.00807 kg N_2O/kg nitric acid (Smit et al. 2001), or about 2.5 kg CO_2 equivalent/kg nitric acid.

In both the reports of Wood and Cowie and that of Smit it is unclear what the concentration of this nitric acid is. We assume that emissions are expressed on pure HNO_3 basis.

IPCC applies default coefficients for nitric acid production facilities (see Table E-7).

Table E-7. Nitric acid production, default global coefficients [IPCC 2000].

Technology	N_2O emission factor (kg N_2O /t HNO_3)
Atmospheric pressure plant	4 - 5
Medium pressure plant (< 6 bar)	6 - 8
High pressure plant (> 7 bar)	9
Abatement technology	N_2O abatement factor
Non-selective catalytic destruction	80 – 90 %
Selective catalytic destruction[1)]	0

1) Under certain conditions, selective catalytic reduction can even result in an increase of N_2O emissions [IPCC 2000].

Ammonium nitrate is produced by neutralising gaseous ammonia with aqueous nitric acid. The solution is evaporated and then formed into solid fertiliser by prilling or granulation. Before solidification, the solution may be mixed with dolomite or limestone to make calcium ammonium nitrate (Wood et al. 2004).

The majority of the emissions associated with production of AN or CAN are CO_2 from the ammonia synthesis and N_2O from nitric acid production. Emissions arising from processing of intermediate products into final products are of minor importance (Wood et al. 2004). The emissions reported by Wood and Cowie are summarised in Table E-8.

Urea accounts for almost 50 % of world nitrogen fertiliser production. It is synthesised by reacting ammonia and carbon dioxide at high pressure to form ammonium carbonate, which is subsequently dehydrated to form urea and water. Liquid urea-ammonium nitrate (UAN) is formed by mixing and cooling concentrated urea and ammonium nitrate solutions (Wood et al. 2004).

Table E-8. **Greenhouse gas emissions for ammonium nitrate (AN) and calcium ammonium nitrate (CAN), as reported in several studies (Wood et al. 2004).**

	kg CO_2/kg N in product	kg N_2O/kg N in product	Total kg CO_2 equivalent/kg N in product
AN[1)]	1.5 – 2.8	0.013 – 0.017	3.0 – 7.1
CAN	2.6 – 3.2	0.013 – 0.020	3.0 – 9.6
Urea	0.9 – 4.0		0.9 – 4.0
UAN	1.3 – 3.4	0.0073 – 0.0075	2.0 – 5.7

1) Ammonium nitrate has chemical formula NH_4NO_3; nitrogen content is 35 %.
2) Calcium ammonium nitrate is a mixture of ammonium nitrate with a minimum of 20 % calcium carbonate. The nitrogen content is 25 – 28 %.

Table E-9. **Greenhouse gas emissions from phosphate fertiliser production as reported in several studies (Wood et al. 2004).**

	Composition N:P:K:S	Total kg CO_2 equivalent/kg product
SSP	0:21:0:23	-0.050 – 0.22
TSP	0:48:0:0	-0.20 – 0.52
DAP	18:46:0:0	-0.070 – 0.87
MAP	11:52:0:0	-0.27 – 0.70

Emissions from urea production are dominated by CO_2 from ammonia production. UAN production entails significant N_2O from the nitric acid intermediate in ammonium nitrate synthesis. CO_2 from the production of ammonia is often used for the production of urea, but different interpretation leads to a broad range in Table E-8.

N_2O abatement

Smit assessed the available technologies, and those under development, to reduce N_2O emission from nitric acid production. Direct decomposition of N_2O, either in the NH_3 combustion reactor or downstream the absorber, is the most cost efficient technique costing less than 1 €/tonne CO_2 avoided. These options cannot be applied to every nitric acid plant, depending on reactor space and temperature. Other technologies are selective catalytic reduction (SCR) and catalytic decomposition downstream the expander, which have a cost efficiency of typically 2 €/tonne CO_2 avoided (Smit et al. 2001).

Non-selective catalytic reduction (NSCR), a typical tail gas treatment in the USA and Canada, may reduce N_2O emissions by 80 – 90 % (Wood et al. 2004); [IPCC 2000].

These technologies will only be applied when legislative or economic driving forces are introduced (Smit et al. 2001). The EC considers to include N_2O in the European Union Greenhouse Gas Emission Trading Scheme ETS within the foreseeable future. Since the current prices of CO_2 in the ETS are about 20 €/tonne, it is expected that the relatively cheap N_2O abatement technologies will then be swiftly installed.

GHG emission from phosphate fertiliser production

Key phosphate fertilisers are:

- Single superphosphate (SSP)
- Triple superphosphate (TSP)

- Di-ammonium phosphate (DAP)
- Mono-ammonium phosphate (MAP)

The majority of phosphate fertilisers are based on phosphoric acid, which is produced by reacting sulphuric acid with naturally occurring phosphate rock. Ammonium phosphate fertilisers (MAP and DAP) are produced by reacting phosphoric acid with anhydrous ammonia. SSP is made by reacting ground phosphate rock with various concentrations of sulphuric acid, and TSP is produced by combining ground phosphate rock or limestone with low concentration phosphoric acid.

Emissions are dominated by CO_2, related to the consumption of fossil fuels in sulphuric acid production. The estimates in Table E-9 assume that the majority of sulphur used is recovered from natural gas and fuel oil. The exothermic reaction to sulphuric acid may generate a net energy export, which explains the negative CO_2 emission in some studies.

GHG emission from NPK fertiliser production

Multi-nutrient NPK fertilisers can be produced via a nitrophosphate route and a mixed acid rout, or alternatively by simply mixing dry fertilisers. Emissions differ per exact composition, process type and status of the technology, and range from 0.060 to 2.1 kg CO_2 equivalent/kg product (Wood et al. 2004).

Assumptions for the present LCA

In the present LCA CAN is used as fertiliser for both wheat and rapeseed production. The data are taken from the Ecoinvent database for production processes in Europe. For the production of 1 kg "calcium ammonium nitrate as N" 0.608 kg ammonia and 2.25 kg nitric acid (50 % solution) is required. 1 kg of this 50 % solution is produced by 0.294 kg ammonia in 2 liter water. The resulting emission is 0.00839 kg N_2O/kg HNO_3.

This compares with the 0.00807 kg N_2O/kg nitric acid average for the Dutch facilities reported by Smit, and is in the high range of the IPCC default coefficients (refer to Table E-7).

E.4 Nutrient balances in agriculture

Emissions as a result of fertilisation are assessed by means of a nutrient balance. Different studies have described (parts of) this balance. The IPCC applies a generic method to calculate the N_2O emissions from agriculture. Velthof and Kuikman describe how to deal more specifically with N_2O emissions from crop residues. Van den Broek (2000) summarises a method for the complete nutrient balance, based on Audsley (1997), van Zeijts and Reus (1996) and Wegener Sleeswijk et al. (1996). The summary by Van den Broek functions as a frame for the proposed nutrient balance in the present study, and is completed with details from the IPCC and Velthof and Kuikman.

IPCC method

Generally the emission of N_2O from agriculture can be calculated by the IPCC default method. This is a generic (black box) method that calculates the emissions from the applied N in fertiliser. Countries have to report their emissions to the UN FCCC (by National communications) using this default method, unless they have a scientifically based and documented alternative method. At this moment, neither the Netherlands nor our neighbouring countries have such an alternative method implemented.

The amount of N applied as N-fertiliser (synthetic or manure) is called the N-applied. Of the applied N, IPCC assumes that 10 % volatilises to NH_3 in the case of synthetic fertiliser. In the case of animal manure and urine this is 20 %. Van den Broek (Van den Broek 2000) assumes that only 2 % of the N in synthetic fertilisers volatilises to NH_3 in Dutch agriculture, as most of the fertiliser used is calcium ammonium nitrate, while the high IPCC value is merely based on the application of fertilisers such as urea and aqueous ammonia (Van Groenigen 2005). Emissions from manure may also be much lower than in surrounding countries (< 5 %) due to low-emission application techniques practised in the Netherlands. 1 % of the N in emitted NH_3 is assumed to be converted to N_2O, but less NH_3 and more N_2O may result from specific application techniques for manure in the Netherlands (2 % instead of 1 %).

The default value for direct soil emission of N_2O from synthetic fertiliser within the IPCC method is 1.25 % (0.25–2.25%) of the applied N. This is the emission from fertilized plots minus the emission from unfertilized control plots (Bouwman et al. 2002). For animal manure in the Netherlands this standard emission value is 2 %.

Of the applied N, according to IPCC eventually 30 % is leached as nitrate (NO_3^-) to groundwater. The IPCC states that of this NO_3^-, 2.5 % is indirectly emitted as N_2O in the deeper soil, drainage ditches, etc. It does not matter very much how deep the groundwater is (Van Groenigen 2005).

Mineralised N in crop residues behaves like N applied as fertiliser, with the same direct N_2O emissions. The IPCC does not explicitly account for nitrate leaching from crop residues. The IPCC does apply one direct emission factor of 1.25 % as N_2O from the total amount of N in residues that are returned to the soil (Velthof et al. 2000), being the same as applied for direct N_2O emissions from fertiliser application. The total amount of N in residues is estimated

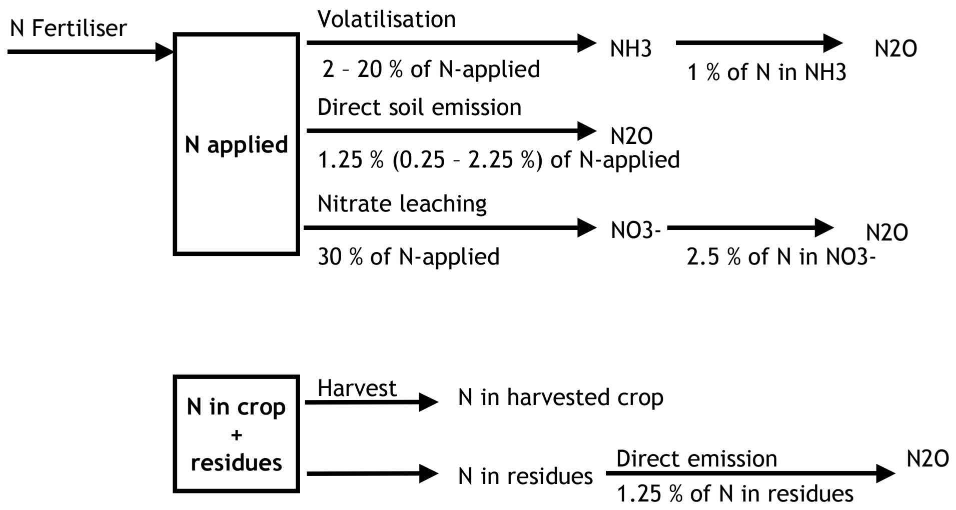

Figure E-4. The N_2O emissions according to the IPCC method.

from FAO statistics on total crop yields, assuming that half of the N is in harvested crops and half in the residue, combined with a default fraction N (45 %) removed from the field.

Adapted Dutch method for nitrate leaching and N_2O emissions

Velthof and Kuikman propose a method to explicitly account for emissions from crop residues. The adapted Dutch method applies the following steps (Velthof et al. 2000):

The total N-applied follows from the application of synthetic fertiliser and manure.

The volatilisation to NH_3 and subsequent indirect N_2O emission, and the direct soil N_2O emission are calculated according to the IPCC method described above.

The difference between the N-applied and the N-uptake is the N-Surplus. The N-uptake is different for each crop, see Table E-10.

Table E-10. Amounts of nitrogen in crop and residue (Velthof et al. 2000).

	Rapeseed	Wheat
Fertiliser advice (kg N/ha)	180 (clay)	200 – 230 (clay) / 160 (sand)
Yield Seeds (kg/ha/yr)	3250	7653
N in Seeds (g/kg)	35	20
N in Seeds (kg/ha/yr)	114	153
N in Above ground residues (kg/ha/yr)	42	28
N in Under ground residues (kg/ha/yr)	21	23

From this surplus, 60 % is assumed to leach as nitrate; 2.5 % of the leached nitrogen is subsequently emitted as N_2O. In the Netherlands, data for N-*surplus* leaching from agricultural land has been recently and authoritatively estimated by the WOG-workforce[9] (Schroder et al. 2004):
- Mineral soils, Gt IV: 35 %
- Mineral soils, Gt VI: 53 %
- Mineral soils, Gt VII: 67 %
- Mineral soils, Gt VIII: 81 %

The higher the category number, the dryer the soil (determined from the average high and low groundwater level). Categories 6 through 8 are the most common in the Netherlands for rapeseed cultivation. Category 4 (typical for polders) are rare in other countries. Categories 6 or 7 would be acceptable as an average for the Netherlands.

There is a direct N-emission to N_2O from residues and an indirect emission via leaching. The direct emission from crop residues would be 1.25 % according to the IPCC, but this is probably too high (Kuikman 2005) because the C/N ratio of these residues is relatively high. Velthof and Kuikman apply 0.5 - 2 % depending on the C/N ratio. Residues from rapeseed, which is richer in nitrogen, probably have a slightly higher emission factor than residues from wheat (Van Groenigen 2005).

To calculate the indirect emission via leaching, it is assumed that 75 % of the nitrogen in crop residues (when left in field and after the direct emission) is mineralised, of which 25 % is used by the subsequent crop. The remaining 81 % returns to the available N pool, with associated N_2O losses (leaching, direct N_2O emission, etc.).

The part of the N-surplus that was not leached is in principle denitrified to N_2. On a net balance, no nitrogen is fixed in the soil. During denitrification, also N_2O is emitted, but this was already accounted for in the 1.25 % topsoil flux.

Resulting nitrogen balance

The information from the IPCC method and the adapted method by Velthof and Kuikman is combined in Figure E-5. In this figure, N from deposition is added to the N available for the crop.

In the figure, ranges for emission and leaching are given at several points. For the crops under study we assume:

- That 2 % of the N in synthetic fertilisers volatilises to NH_3.
- That the direct soil emission from synthetic fertiliser is 1.25 % of the N as N_2O.
- That the direct emission to N_2O from crop residues is 1.25 % for rapeseed, and 0.75 % for wheat.
- That nitrate leaching from the N-surplus is 60 %.

---

[9] The WOG (Werkgroep Onderbouwing Gebruiksnormen) was established by the Dutch ministries of Agriculture and of Environment to underpin the standards for the use of fertiliser in response to a judgement by the European court about the Dutch manure policy. Plant Research International (PRI), the Environmental Science Department of the Wageningen University (Alterra), Applied Plant Research (PPO), the Expert Centre of the Ministry of Agriculture, Animal Sciences Group of the Wageningen University (PV), and the National Institute for Public Health and the Environment (RIVM) were members of the workforce.

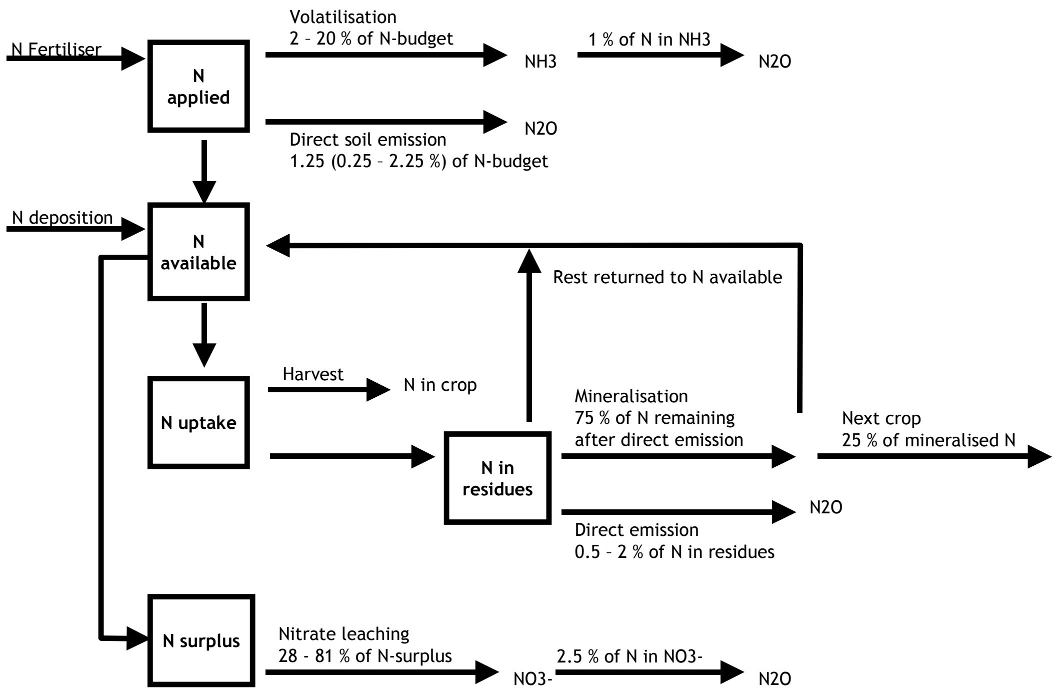

Figure E-5. Nitrogen balance as applied in the LCA .

Nitrogen balance in other countries

The presented method and values are based on the Dutch context. Within this study, for other countries the same specific method will be followed. Where available, country specific values will be used for the leaching or the surplus, the amount of N-applied and the yield.

E.5 Transport operations

The energy and GHG emissions for biomass transportation from source to a conversion facility are generally considered a minor part of well-to-wheel chains (Edwards et al. 2004). The transport distances assumed in the present assessment are given in Table E-11.

Table E-11. (Inter)national transport distances assumed in this study.

Type	Material	Route	Means	Distance	Capacity
Local	Wheat / rapeseed	In Western Europe	Truck	100 km	28 tonne
		In Eastern Europe	Truck	100 km	28 tonne
		In World	Truck	100 km	28 tonne
International	Pressed oil	From Eastern[1)] to Western Europe	Barge	1000 km	1200 tonne
		From World[1)] to Western Europe	Sea ship	7000 km	150 ktonne
Local	End-product	In Western Europe			

[1)] 1/4 of transported feedstock

E.6 Ethanol production from wheat

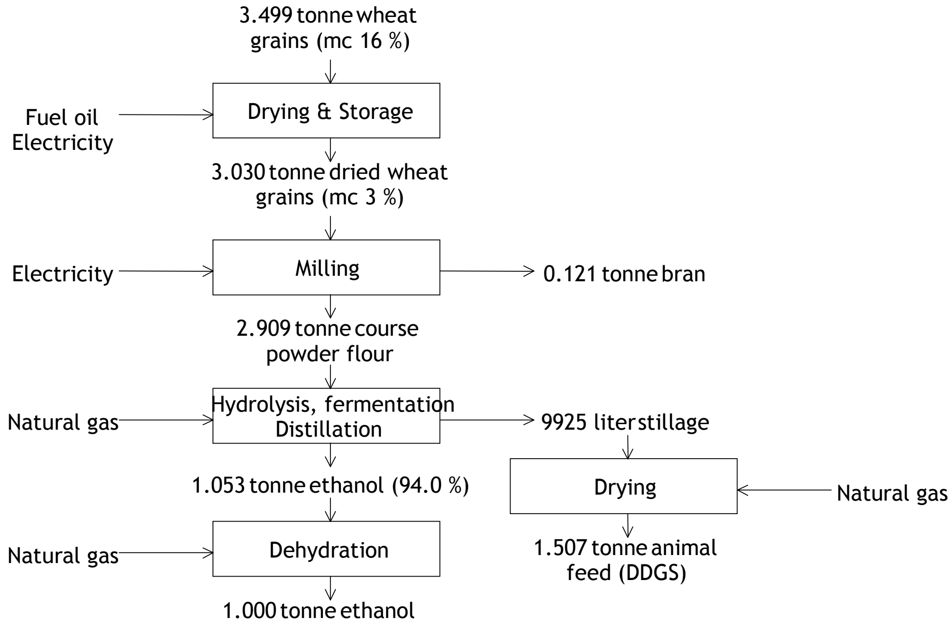

Figure E-6. Flow chart for the produciton of ethanol from wheat (Elsayed et al. 2003, appendix R).

Table E-12. Ethanol conversion (Elsayed et al. 2003, appendix R).

Process / material	Value applied
Drying from mc 16 → 3 % Fuel oil	661 MJ/tonne fresh grains
Storage[1)] Electricity	11.6 kWh/tonne dried grains
Milling Electricity	12.3 kWh/tonne dried grains
Yields	34.6 kg Bran/ tonne fresh grains 831 kg course powder flour/tonne fresh grains
Allocation	99.9 % to course powder flour
Hydrolysis, fermentation, distillation Natural gas	6091 MJ/tonne ethanol (94 %)
Drying stillage Natural gas	3487 MJ/tonne animal feed
Yields	431 kg animal feed/tonne fresh grains
Dehydration Natural gas	35 MJ/tonne ethanol
Yields	360 l ethanol/tonne fresh grains[3)]
Overall allocation[2)]	Ethanol 75.4 % Animal feed 23.3 % Bran 1.3 %

1) Mainly cooling energy.

2) Ethanol 555 €/tonne (Elsayed et al. 2003). DDGS (Distillers dried grains with solubles) has a high nutrition value (27% protein, 11% fat, and 9% fiber (Graboski 2002)). Its market value as animal feed is 114 €/tonne (Elsayed et al. 2003). Bran also has value as animal feed (about 14 – 18 % proteins and rich in fat): Elsayed applies 14 €/tonne (Elsayed et al. 2003), but the actual market value is 70 – 90 €/tonne. Course powder flour 433 €/tonne (Elsayed et al. 2003).

3) 285.8 kg ethanol/tonne fresh wheat grains (at mc 16 %), or 361 l/tonne grain. The Fact-finding study found a range of 346 – 385 l/tonne.

E.7 ETBE production from ethanol

MTBE

MTBE is produced worldwide by reacting methanol with isobutylene (see Figure E-7). Several companies license MTBE reaction technology worldwide. There are different sources of the isobutylene feedstock, often depending on the type of MTBE producer. Unlike methanol, isobutylene is generally not available commercially and thus must be either obtained from process streams available in-house or manufactured separately, generally starting from butane (Nesbitt et al. 1999)

There are four primary MTBE processes, depending on the source of the isobutylene (Nesbitt et al. 1999):

- Steam crackers: Isobutylene obtained directly from C_4 streams[2] generated by steam crackers during the manufacture of ethylene. Butadiene is usually extracted from the steam cracker stream before use; the resulting stream can be called raffinate 1. Refineries generally consume the isobutylene produced.
- Fluid catalytic cracker units (FCCUs): Isobutylene obtained directly from C_4 streams generated by FCCUs in refineries. The refineries that produce these streams consume them captively.
- Tertiary-butyl alcohol (TBA): Isobutylene produced from TBA, a coproduct of propylene oxide (PO), that is itself derived from isobutane. The isobutylene produced is then used captively to manufacture MTBE.
- Butane dehydrogenation: Isobutylene produced from the dehydrogenation of isobutane. The isobutylene produced is consumed captively. An isomer of isobutane, *n*-butane, can also be used as a starting material for this process but must be converted, or isomerized, into isobutane before the dehydrogenation step. Whereas many U.S. production facilities start with either *n*-butane or isobutane, some facilities, generally those in Europe and Saudi Arabia, start with a feed of mixed butanes (also called “field butanes”).

The latter three processes are used to varying degrees in the United States. In Saudi Arabia, the primary production process used is butane dehydrogenation (Nesbitt et al. 1999).

ETBE relative to MTBE

The production of MTBE vs the production of ETBE is shown in Figure E-7.

Ethanol	+	Isobutylene	$\longrightarrow$	ETBE
451 kg		549 kg		1000 kg
11.9 GJ		24.9 GJ		36 GJ

Methanol	+	Isobutylene	$\longrightarrow$	MTBE
364 kg		636 kg		1000 kg
7.2 GJ		28.8 GJ		35.1 GJ

Figure E-7. Mass balance in the production of ETBE vs the production of MTBE (Van Walwijk 1996). The higher heating value of isobutylene is 48.8 MJ_{HHV}/kg, with hydrogen content of 14.3 wt% the LHV is 45.29 MJ_{LHV}/kg.

Van Walwijk assumes that the energy consumption for ETBE production is very close to corresponding numbers for MTBE production (Van Walwijk 1996). There is a difference in isobutylene consumption, which Van Walwijk does not take into account because of a lack of data. Information on the production of butenes is available within the Ecoinvent databases.

IFUE summarises the inputs and outputs for an ETBE plant (Table E-13). We assume that the CLM/IFEU values for energy use and emissions hold for both the ETBE and MTBE production per tonne end product. We assume that the major difference between ETBE and MTBE is in the input from the technosphere, according to above :

- ETBE: 1 tonne ethanol + 1.22 tonne mixed butenes
- MTBE: 0.81 tonne methanol + 1.41 tonne mixed butenes

Table E-13. Inputs and outputs to ETBE plant in three studies (Jungk 2000).

	Unit	IFEU	CLM	INRA
Inputs from the technosphere (materials and fuels)				
C4-Hydrocarbons (→ mixed butenes)	Mg	1.22	1.22	1.12766
Ethanol	Mg	1	1	1
natural gas	MJ	10477	10477	10477
Inputs from the technosphere (electricity and heat)				
electricity	kWh	0	0	29.78723
Outputs to the technosphere (products)				
ETBE	Mg	2.22	2.22	2.13
Emissions to air				
Ammonia (NH3)	g	2.56	2.56	2.56
Benzene (C6H6)	g	0	0	0
Benzo(a)pyrene (C20H12)	g	2.2E-05	2.2E-05	2.2E-05
Cadmium (Cd)	g	0	0	0
Carbon dioxide (CO2)	g	573882.5	573882.5	573882.5
Carbon monoxide (CO)	g	219.912	219.912	48.8
Chromium (Cr6+)	g	0	0	0
Copper (Cu)	g	0	0	0
Dioxines (2,3,7,8-tetrachlorodibenzo-p-dioxin)	g	1.19E-08	1.19E-08	1.19E-08
Hexane	g	0	0	0
Hydrochloric acid (HCl)	g	1.15	1.15	1.15
Iron (Fe)	g	0	0	0
Lead (Pb)	g	0	0	0
Manganese (Mn)	g	0	0	0
Mercury (Hg)	g	0.000662	0.000662	0.000662
Methane (CH4)	g	52.36	52.36	25
Nickel (Ni)	g	0	0	0
Nitrous oxide (N2O)	g	10.472	10.472	88
Nitrogen oxides (NOx)	g	293.216	293.216	982
Particulates (< 10 um)	g	0	0	0
Particulates (unspecified)	g	1.0472	1.0472	32
Selenium (Se)	g	0	0	0
Sulphur dioxide (SO2)	g	4.1888	4.1888	4000
Volatile Organic Compounds	g	52.36	52.36	52.36
Zinc (Zn)	g	0	0	0

ETBE is almost identical to MTBE except that it has a higher boiling point, which is an advantage in blending fuels because it results in a lower RVP and is less soluble in water. It has excellent octane enhancement properties, reduced sulfur, handling advantages, and high renewable component. ETBE is also more biodegradable than MTBE. Unlike ethanol, ETBE does not have properties that corrode fuel systems (Nesbitt et al. 1999).

E.8 Biodiesel production from rapeseed and rape-seed oil

Biodiesel is produced from rapeseed oil through transesterification with alcohol. Most commonly, methyl esters are produced, especially because methanol is the least expensive alcohol. The general scheme of the transesterification reaction is shown in Figure E-8.

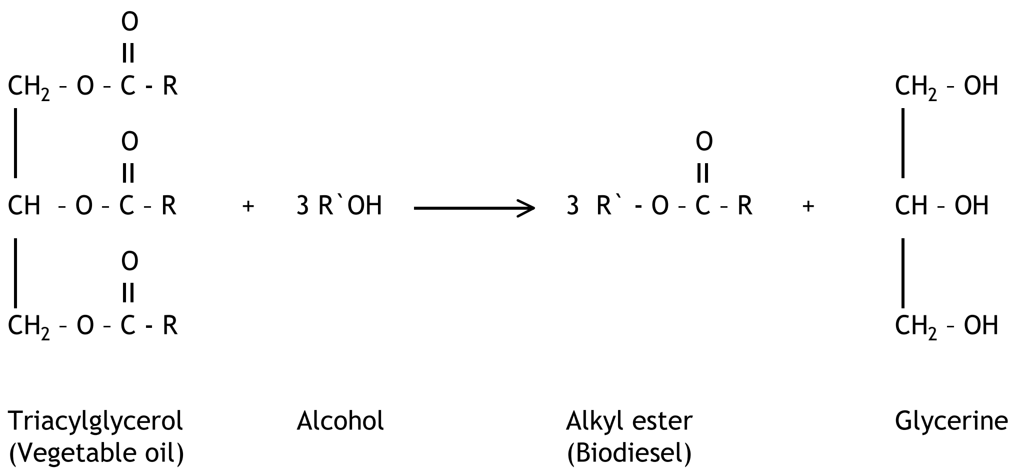

Figure E-8. The transesterification reaction. R is a mixture of various fatty acid chains (Knothe et al. 2004).

Generally, transesterification can proceed by base or acid catalysis. In homogeneous catalysis, alkali catalysis (sodium or potassium hydroxide) is a much more rapid process than acid catalysis (Knothe et al. 2004).

For the present study, we assume the process as described by Elsayed et al. (Elsayed et al. 2003).

This process produces no free fatty acids (FFA). FFA are formed through hydrolysis of the feedstock triacylgycerols or the formed alkyl esters. Therefore, the presence of moisture during the reaction should be avoided. Free fatty acids present in the oil on beforehand can be converted to methyl esters by reaction with methanol, catalysed by acid, but this leads to water formation.

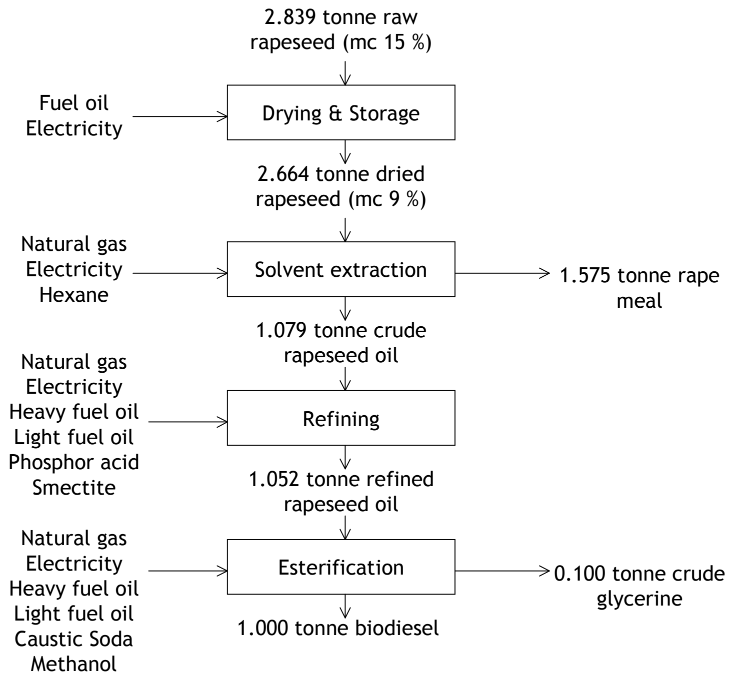

Figure E-9. Conversion of rapeseed to biodiesel (Elsayed et al. 2003, appendix B).

Table E-14. Rapeseed to biodiesel conversion (Elsayed et al. 2003, appendix B).

Process / material	Value applied
Drying from mc 15 → 9 % Fuel oil	 305 MJ/tonne dried oilseeds
Storage[1)] Electricity	 11.6 kWh/tonne dried oilseeds
Solvent extraction[3)] Natural gas Electricity Hexane	 1790 MJ/tonne oil extracted 84 kWh_e/tonne oil extracted 2.5 kg/tonne oil extracted
Yields	0.4 kg oil/kg dried oilseeds 0.6 kg rape meal/kg dried oilseeds
Allocation before refining[2)]	Crude rapeseed oil 72.42 % Rape meal 27.68 %
Refining[4)] Electricity Natural gas Heavy Fuel oil Light Fuel oil Phosphoric acid Smectite	 3.1 kWhe/tonne refined rapeseed oil 178 MJ/tonne refined rapeseed oil 20 MJ/tonne refined rapeseed oil 152 MJ/tonne refined rapeseed oil 1 kg/tonne refined rapeseed oil 6 kg/tonne refined rapeseed oil.
Yields:	98 kg oil refined/kg oil extracted
Allocation	87.44 % to biodiesel
Esterification[5)] Electricity Natural gas Heavy fuel oil Light fuel oil Caustic soda (50 % concentration) Methanol	 23 kWh/tonne biodiesel 1402 MJ/tonne biodiesel 161 MJ/tonne biodiesel 161 MJ/tonne biodiesel 12 kg/tonne biodiesel 109 kg/tonne biodiesel
Yields	95 kg biodiesel/kg refined oil 9.5 kg glycerine/kg refined oil
End allocation	Biodiesel 87.44 % Crude glycerine 12.56 %
Overall allocation[2)]	Biodiesel 61.1 % Rape meal 30.1 % Crude glycerine 8.8 %

1) Mainly cooling energy.

3) Solvent extraction consumes steam, generated from natural gas 716 kg steam /tonne crude rapeseed oil, and 2.5 MJ natural gas/kg steam (Elsayed et al. 2003). Electricity 84 kWhe/tonne crude rapeseed oil extracted, hexane 2.5 kg/tonne of crude rapeseed oil extracted.

4) 3.1 kWhe/tonne refined rapeseed oil. Natural gas 178 MJ/tonne refined rapeseed oil (Elsayed et al. 2003). Heavy fuel oil 20 MJ/tonne refined rapeseed oil (Elsayed et al. 2003). Light fuel oil 152 MJ/tonne refined rapeseed oil (Elsayed et al. 2003). Phosphoric acid consumption 1 kg/tonne refined rapeseed oil (Elsayed et al. 2003). Smectite 6 kg/tonne refined rapeseed oil.

5) (Elsayed et al. 2003). Caustic soda is NaOH. Smectite is not included in the model.

2) Biodiesel 383 €/tonne (Elsayed et al. 2003). Animal feed 120 €/tonne (Elsayed et al. 2003). Crude glycerine 550 €/tonne (Elsayed et al. 2003). Crude bio-oil 460 €/tonne (Elsayed et al. 2003). The overall allocation is the part of the rapeseed impact burden that can be allocated to the three products.

In case of system enlargement with soy bean meal, the overall allocation becomes 87.4 % to biodiesel and 12.6 % to glycerine.

E.9 Emissions from stationary combustion

In the bioethanol and biodiesel factories, fuels are used to produce heat and power. This is assumed to lead to local emissions, as reported in Table E-15.

Table E-15. Emissions from stationary combustion (mg/MJ input)

	NO_x	SO_x	CO	PM
Natural gas[1)]	26.2	0	4.2	1.87
Fuel oil lowS	58.4	0	4.2	48.7
Straw	48.7	0	4.2	9.7

1) Offgas flow is 1282 kg/h at a gas use of 82 m^3_0/h and 31.68 MJ_{LHV}/m^3_0, or 494 kg/GJ gas input [Remeha 2001 Apeldoorn the Netherlands]. Offgas flow is 24.7 tonne/h at 14.5 MW nominal, or 473 kg/GJ gas input [Viessmann 2001]. We assume 483 kg offgas/GJ gas input. Gas volume is about 1.29 kg/m^3. Emissions according to adapted BEES A [2005] (article 13.1f, 13.4d and 13.5c) are: SO_x < 35 mg/m^3, NO_x 70 mg/m^3 and particles 5 mg/m^3. Carbon monoxide is assumed 15 mg/kWh_{th} [Viessmann 2001]. SO_x from natural gas is assumed to be 0.

2) The offgas volume for fuel oil is larger than that of natural gas: it contains 13 % CO2 instead of 10 %, which requires 30 % more air. We assume that the offgas flow is 628 kg/GJ fuel input. Emissions according to BEES A (Article 12.1c2, 12.4d and 12.5a) are: SO_x 850 mg/m^3, NO_x 120 mg/m^3 and particles 100 mg/m^3. We assume that the SO_x emission from low sulphur fuel oil is negligible. CO emission is assumed the same as for natural gas.

3) The offgas volume for straw is assumed to be the same as for fuel oil: 628 kg/GJ input. Emissions according to adapted BEES A [2005] (Article 11.1c2, 11.3c4 and 11.4b) are: SO_x 200 mg/m^3, NO_x 100 mg/m^3 and particles 20 mg/m^3. We assume that the SO_x emission from straw is negligible. CO emission is assumed the same as for natural gas.

E.10 Heat production from wheat straw

The production of straw was included in both wheat and rapeseed cropping. 1/3 of the straw is left in the field, 2/3 is available for other purposes. The straw needs to be baled and transported to the ethanol plant were heat is produced for the conversion process of Annex E.6.

Figure E-10 shows the process of collecting wheat straw up to CHP production.

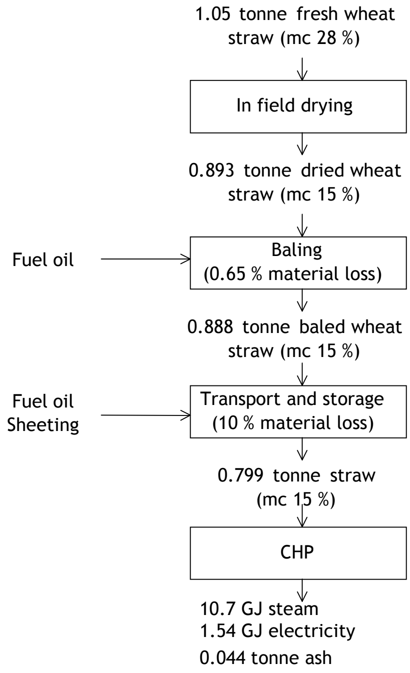

Figure E-10. Conversion of straw to heat (Elsayed et al. 2003, appendix O).

Table E-16. Conversion of straw to heat[1] (Elsayed et al. 2003, appendix O).

Process / material	Value applied
In field drying[2]	
Baling[3] Diesel fuel Twine	 232.0 MJ/ha/yr 101.8 MJ/ha/yr
Loading Diesel	 138.1 MJ/ha/yr
Storage Diesel Sheeting	 65.8 MJ/tonne straw 2 tonne polyethylene sheeting /ktonne straw
Conversion[4] Heat output Power output Ash output	 13.4 GJ steam/tonne dried straw (mc 15 %) 1.93 GJ electricity/tonne dried straw 0.055 tonne/tonne dried straw

1) Elsayed et al. (Elsayed et al. 2003) assume a reference system in which straw is chopped and ploughed into the ground. Since the straw in the present LCA is coproduced with wheat (or rapeseed), the reference situation is fallow land with no straw production at all.

2) It is assumed that straw co-produced with wheat initially contains 28 % moisture.

3) Straw yield is 4.4 tonne/ha. Energy demand for twine is "primary", this is assumed to be crude oil.

4) The ratio heat/electricity requirement for 1 tonne ethanol production is 9.4 GJ steam (from 11.7 GJ natural gas) versus 73 kWh electricity or 261 MJ. We have, however, chosen for a more efficient heat/power combination. Wheat straw has HHV of 17.51 GJ/tonne$_{dry}$, H content is 5 %, thus LHV = 13.69 GJ/tonne$_{15\%}$. The ash output is 5.5 % of the total straw input (at mc 15 %).

E.11 Animal feed production from soy beans

The biodiesel system is enlarged with the production of animal feed from soybeans. Instead of bringing rapeseed cake outside the system through allocation, it replaced by soybean meal imported from the USA.

The crude protein content of rapeseed cake is 39.6 % on dry mass basis according to Concawe (Edwards et al. 2004). Other studies give higher protein content when the rape is extracted with hexane (48 – 50 % (Bagger et al. 2004)). Pure soy bean meal contains 49 % protein on dry mass basis. However, the economic value of soy meal is found to be much higher than that of rape meal: 165 €/tonne compared to 120 €/tonne. Therefore, we assume that 1 kg rape meal can be replaced by 0.73 kg soy meal, this compares to the value applied by Concawe (0.80 kg).

The soy bean meal is transported by ocean freight over 7000 km.

Table E-17. Soy bean growth and harvest in USA. Net values, accounting for a reference situation (Edwards et al. 2004, module SY1 and SY3 WTT appendix 1).

Process / material	Value assumed
Feedstock production Fertiliser[1)]	0.0020 kg N/kg soy meal 0.0080 kg K_2O/kg soy meal 0.0040 kg P_2O_5/kg soy meal
Pesticides[2)]	0.0005 kg/kg soy meal
Machinery Diesel use	0.84 MJ/kg soy meal
Oil extraction Energy use Electricity Natural gas n-Hexane	0.3 MJ/kg soy meal 1.4 MJ/kg soy meal 1.13 MJ/kg soy meal
Allocation[3)]	Soy oil 91.0 % Soy bean meal 9.0 %

1) The K_2O fertiliser is assumed potassium chloride.
2) The composition of the pesticides mix is unknown.
3) The Concawe study assumes that as a by-product of soy bean meal, soy oil is produced and calculates a CO2 credit from soy oil substituting rapeseed oil. This method is not suitable for our calculation since it would lead to a infinite system enlargement. Instead we apply allocation. It is assumed that per kg plant oil, 0.23 kg bean meal is produced (Edwards et al. 2004). Soy oil costs 0.223 $/lb (CBOT 2005), or 382 €/tonne. Soy meal costs 193 $/ton (CBOT 2005), or 165 €/tonne.

E.12 End use

The end-use of the biofuels is as blends in weighted averages of the Dutch car park. Ethanol and ETBE will be used in passenger cars only, while biodiesel is to be used in both passenger cars and heavy-duty vehicles. Since it is not possible to estimate a distance average, the average is based on the number of cars.

The scope of the LCA is the year 2008. The exact car park composition of that year is not yet known. To estimate this composition, the distribution of passenger car ages on January 1st 2004 (CBS 2004) has been transposed four years. No information was available on the age of heavy-duty vehicles. Therefore, the age distribution has been estimated to be the same as for passenger cars on diesel.

Table E-18. Estimated car park composition at January 1st, 2008, divided over Euro types.

		Gasoline	Diesel
Passenger vehicles			
1904 - 1991	pre Euro	13.27%	5.18%
1992 - 1995	Euro 1	10.88%	4.79%
1996 - 1999	Euro 2	21.84%	11.52%
2000 - 2004	Euro 3	34.53%	46.29%
2005 - 2007	Euro 4	19.48%	32.23%
Heavy duty vehicles			Diesel
1904 - 1991	pre Euro		5.18%
1992 - 1996	Euro I		7.12%
1997 - 1999	Euro II		9.18%
2000 - 2004	Euro III		46.29%
2005 - 2007	Euro IV		32.23%

Ethanol vs gasoline

In the Fact-finding study (Van den Broek et al. 2003), the vehicle efficiency for ethanol and gasoline was assumed to be 2.59 MJ_{LHV}/km.

The IEA (Van Walwijk et al. 1999) compared vehicular emissions from ethanol with gasoline (see Table E-19). NO_x and CO emissions were found to decrease.

Table E-19. Vehicular emissions (g/km) (Van Walwijk et al. 1999).

	NO_x	CO	VOC	Pm	CO_2
Gasoline	0.3 (0.2 – 0.4)	4 (2.1 – 6)	0.45 (0.1 – 0.8)	-	219 (181 – 256)
Ethanol	0.10 (33 %)	1.6 (40 %)	0.45 (100 %)	-	n/a

Prof. Baert (see Annex D.4) concludes that for these fuels available engine efficiency and emission data are very difficult to compare. It is not possible to conclude whether ethanol leads to different emissions of NOx, CO and VOC. Emissions are expected to be the same because all vehicles have a three way catalyst and the European test cycle does not include the effects of cold start. The efficiency of cars on ethanol will not be higher than those on gasoline, unless the cars would be recalibrated for optimum results on E5.

The emission of sulphur from future gasoline is so low that the sulphur in the lubricant becomes likewise important. The small sulphur emission from gasoline and ethanol will be very similar and is therefore not taken into account (deducted from both the biofuel and the reference case).

Combination of the passenger car park composition of Table E-18 with emission limits for Euro 1 – 4 vehicles gives average emissions and fuel efficiency to be used in the present life cycle assessment.

Table E-20. Emissions and fuel efficiency of passenger cars on gasoline or ethanol averaged over the market share Euro 1-4 vehicles.

	Year introduction	Share (%)	Emission (g/km)				fuel efficiency (MJ/km)
			CO	HC	NOx	PM	
Euro 1	1992	24.15%	2.72	0.485 1)	0.485 1)	0.14	2.59 2)
Euro 2	1996	21.84%	2.2	0.25 3)	0.25 3)		2.46 4)
Euro 3	2000	34.53%	2.3	0.2	0.15		2.34 4)
Euro 4	2005	19.48%	1	0.1	0.08		2.21 4)
Average			**2.13**	**0.26**	**0.24**	**0.03**	**2.40**

1) The total of HC and NO_x is 0.97 g/km.
2) From Ecofys' fact-finding study (Van den Broek et al. 2003).
3) The total of HC and NO_x is 0.5 g/km.
4) Assuming "normal" gasoline, new fleet data (Baert 2005).

ETBE vs MTBE

In general, ETBE and MTBE aim for the same octane number, this means that no difference in efficiency should be expected.

Van Walwijk (Van Walwijk 1996) assesses the difference in vehicular energy consumption between a passenger car on gasoline with MTBE and with ETBE. It is not possible to give absolute values for the octane values of ETBE and MTBE blends in gasoline, because the way they blend depends on the other components that are present. But Van Walwijk comes to the conclusion that the fuel consumption (energy basis) of a passenger is the same for gasoline with 15 % ETBE and gasoline with 15 % MTBE.

Van Walwijk discusses end-use emissions. Overall, few differences are found between ETBE and MTBE use. Acetaldehyde emission is found to be up to 50 % higher. Van Walwijk also suggests that MTBE can result in significant MTBE emissions, but this is not further quantified.

Table E-21. Vehicular emissions (g/km) (Van Walwijk 1996).

	NOx	CO	HC	Aldehydes
MTBE				
ETBE	equal	-30 to + 45 %	same or higher	formaldehyde similar, acetaldehyde up to 50 % higher

ETBE vs MTBE: (Quirin et al. 2004) assume that the car efficiency (190 MJ/100 km) and emissions are the same for ETBE and MTBE as for ethanol.

Van Walwijk (Van Walwijk 1996) observed that the octane number of petrol is not constant for a certain volumetric ether (ETBE or MTBE) content. For example, for petrol containing 15 % by volume MTBE, octane values of 90.4 to 94.8 have been reported. The actual effect will depend on the vehicle, the composition of the fuel and method of testing (Owen et al. 1995).

Van Walwijk argues that a significant difference in energy consuption between ETBE and MTEB cannot be defended with available data. Therefore, equal fuel consumtpion is assumed.

Biodiesel vs diesel

In the Fact-finding study (Van den Broek et al. 2003), the vehicle efficiency for biodiesel and diesel was assumed to be 2.08 MJ_{LHV}/km.

The IEA (Van Walwijk et al. 1999) compared vehicular emissions from biodiesel with diesel (see Table E-22). NO_x was found to increase, while other emissions decrease.

Table E-22. Vehicular emissions (g/km) (Van Walwijk et al. 1999).

	NO_x	CO	VOC	Pm	CO_2
Diesel	0.92 (0.6 – 1.2)	0.81 (0.4-1.2)	0.27 (0.06 - 0.5)	0.2	170 (139 – 197)
Biodiesel	1.10 (120 %)	0.73 (90 %)	0.23 (88 %)	0.17 (87 %)	n/a

Prof. Baert concludes (see Annex D.5) that adding biodiesel will result in a change in somewhat higher PM and NOx emissions. This could be counteracted by recalibration of the engine, though that would typically result in a loss of efficiency. With B5 the increase is expected to be such that the diesel engine emissions are still within its emission limitations. It is not likely that a recalibration for emissions reasons would be necessary. There is little or no effect on energy consumption.

Combination of the passenger car park composition of Table E-18 with emission limits for Euro 1 – 4 and Euro I – IV vehicles gives average emissions and fuel efficiency to be used in the present life cycle assessment.

Table E-23. Emissions and fuel efficiency of passenger cars on diesel or biodiesel averaged over the market share Euro 1-4 vehicles.

	Year introduction	Share (%)	Emission (g/km)				fuel efficiency (MJ/km)
			CO	HC	NOx	PM	
Euro 1	1992	9.97 %	2.72	0.485[1)]	0.485[1)]	0.14	2.08
Euro 2	1996	11.52 %	2.2	0.25[3)]	0.25[3)]		2.34
Euro 3	2000	46.29 %	2.3	0.2	0.15		2.13
Euro 4	2005	32.23 %	1	0.1	0.08		2.02
Euro I	1992	12.31 %[1)]	4.5	1.1	8	0.35	8.33
Euro II	1997	9.18 %[1)]	4	1.1	7	0.15	8.37
Euro III	2000	46.29 %[1)]	2.1	0.66	5	0.1	8.81
Euro IV	2005	32.23 %[1)]	1.5	0.46	3.5	0.02	8.24
Euro V	2008		1.5	0.46	2	0.02	8.24
Average diesel cars 2008[2)]			**1**	**0.31**	**0.75**	**0.06**	**2.76**
Euro 1	1992	9.97 %	2.45	0.41	0.53	0.15	2.08
Euro 2	1996	11.52 %	0.9	0.34	0.44	0.099	2.34
Euro 3	2000	46.29 %	0.58	0.24	0.31	0.055	2.13
Euro 4	2005	32.23 %	0.45	0.13	0.17	0.013	2.02
Euro I	1992	12.31 %[1)]	4.05	0.94	8.8	0.39	8.33
Euro II	1997	9.18 %[1)]	3.6	9.34	7.7	0.17	8.37
Euro III	2000	46.29 %[1)]	1.89	0.56	5.5	0.11	8.81
Euro IV	2005	32.23 %[1)]	1.35	0.39	3.85	0.02	8.24
Euro V	2008		1.35	0.39	2.2	0.01	8.24
Average biodiesel cars 2008[2)]			**0.9**	**0.27**	**0.83**	**0.06**	**2.76**

1) The age composition of the truck car park is unknown, the same distribution as for the passenger car park has been assumed, although in reality, the truck car park is expected to be somewhat younger.

2) Averaged between 9 passenger car kilometres plus 1 truck kilometre.

Annex F Quick scan LCA of some fossil fuel chains using the Ecoinvent v1.1 database

Section written by Dr. Ir. Jeroen Guinée and Reinout Heijungs of the Leiden University Centre of Environmental Science department of Industrial Ecology

F.1 Introduction

As discussed and agreed upon during the workshop of November 2, 2004, I would try to unravel allocations[10] made in some of the modelled fuel chains in the Swiss Ecoinvent v1.1 database (see: www.ecoinvent.ch) to enable other allocation choices within these chains as well. As a result of this agreement, a quick scan LCA has been made elaborating a selected number of allocation scenarios for a selected number of multi-output (MO) processes for an average European passenger car as modelled in Ecoinvent v1.1.

Before we could perform this quick scan, some preparatory work had to be performed in order to be able to import the various Ecoinvent v1.1 databases needed for this work into the software program used for the calculations: CMLCA[11]. Ecoinvent v1.1 exists of three different databases:

1. A database including all multi-output processes that have thus not yet been allocated.
2. A database including all single-output processes, that is processes that are single-output by itself and all allocated multi-output processes.

[10] Allocation refers to the problem that some economic processes may produce more than one valuable output (product or service). These processes are called multifunctional or multi-output (multi-product) processes. The valuable outputs of a particular MO process are generally not used by just one product system in exactly the amounts (ratios) produced but by more than one in different amounts. The environmental impacts of a particular multi-output process need then to be partitioned over the various valuable outputs of that process. This problem and the way it is handled, is often referred to as allocation. The 'derived' processes that are the result of allocation are often referred to as (allocated) single-output processes.

[11] CMLCA is an LCA software program comparable to other LCA programs such as SimaPro. CMLCA is developed by Reinout Heijungs from CML-IE and is available to the public. CMLCA builds on the LCA handbook (Guinée et al., 2002) focusing on analyses rather than on user-friendliness, graphical outputs etc. There is no helpdesk or whatsoever for CMLCA (for more information, see: http://www.leidenuniv.nl/cml/ssp/index.html).

3. A database including all aggregated results, that is calculation results (inventory tables) of all products that one can find in the Ecoinvent v1.1 database; the individual background processes are not part of this database anymore thus.

Figure F-1 illustrates how database 1 and 2 relate to each other (database 3 is left out of consideration from here since, if we want to be able to calculate various allocation scenarios, database 3 is not of any use):

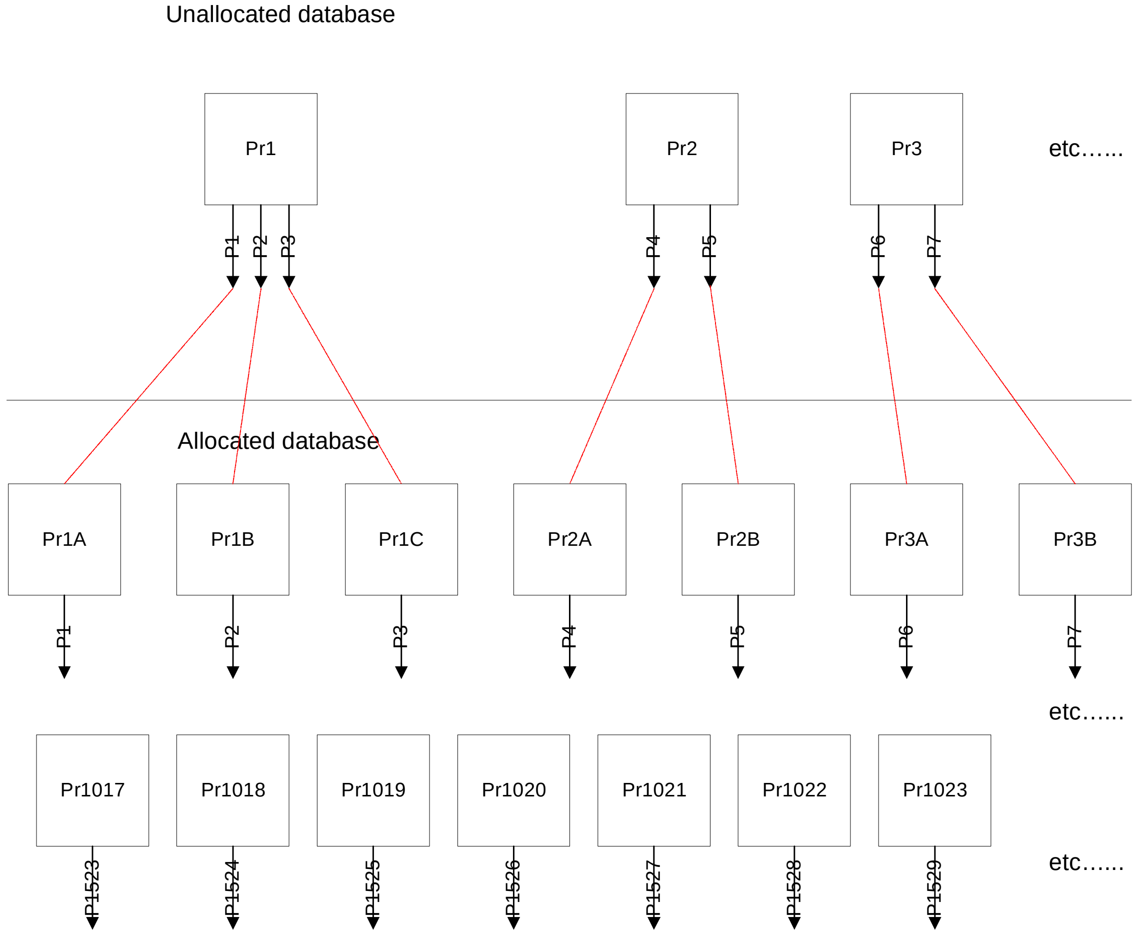

Figure F-1. The relation between Ecoinvent database 1 and 2.

For our quick scan, we needed to combine database 1 en 2 removing the allocated multi-output (MO) processes from database 1 and replacing these by the unallocated multi-output processes from database 2. This in itself is not a difficult operation, if nomenclature and numbering system of database 1 and 2 are fully consistent. That unfortunately appeared not to be the case in Ecoinvent v1.1. Processes and flows had the same names giving problems for multi-output processes that are split into single-output ones. The numbering for database 1 and 2 was also not unique (both start counting at number 1 although the MO number 1 and the SO number 1 process have nothing to do with each other). In addition to this there were a number of 'contaminations' in the database. The details of these contaminations are complex and are therefore not discussed any further here. Finally, two errors have been found and these have been found reported to the Ecoinvent designers and repaired for this quick scan[12].

We eventually succeeded to combine database 1 and 2 and were thus able to calculate results. For this quick scan we calculated results for an average European passenger car using an average mix of unleaded petrol and diesel as modelled in Ecoinvent v1.1. Below, first the main assumptions and limitations of these calculations will be discussed, then the flow charts will be presented including a discussion on the role of capital goods (infrastructure) in this quick scan. Subsequently, the allocation scenarios and the multi-output processes taken into account are presented, and finally results and conclusions are presented.

F.2 Main limitations and assumptions of quick scan fossil fuels

The main limitations and assumptions for this quick scan are:

- The amount of time available for this quick scan was limited to approximately 10 days. Therefore, the results of this quick scan should be handled with utmost care (!!). No attention has been paid to data collection; the data from Ecoinvent v1.1 have been copied without any further quality assessment etc. The results of this quick scan are therefore mainly intended for illustrating and learning purposes focusing on the possible influence of different allocation scenarios for fossil fuel chains.
- Price data needed for economic allocation have been taken from public statistical and web sources. These data often don't meet the demands formulated in Section F.4 (see below). It is not expected that better data will significantly change the current results, however.
- It has been strived for to have as much as possible a consistency between the choices made for the biofuel study and those for fossil fuel study. Unfortunately, this was not always possible:
    - In "Choice 5: Multi-product processes" the allocation method "system enlargement" has been selected. As this method cannot be applied to one of the main multi-output processes of the fossil fuel chains - the refinery; there are, for example, no single-output processes that can produce only diesel from crude oil - it has not been applied to the MO processes of the fossil fuel chains.
    - The Ecoinvent v1.1 data are representative for a given country or area, mostly Switzerland or Europe. This couldn't be changed in this quick scan. Therefore, Europe has been taken as representative area for the quick scan on fossil fuels.

F.3 Flowchart

In order to be able to evaluate the possible (in)consistencies between modelling the biofuel chains and modelling the fossil fuel chains, drawing the flowcharts of both system can be very helpful. Drawing a flowchart of a system including hundreds or even thousands of processes is, however, a nearly impracticable task.

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[12] It can of course not be guaranteed that there aren't any more errors in the Ecoinvent database as these are hard - if not impossible - to prevent in a database covering more that 2600 processes.

For this quick scan a part of the flowchart for the operation of an average Dutch passenger (diesel) car, as modelled in the Ecoinvent v1.1 database using specific car driving emission and fuel consumption data, has been drawn for illustration and for feeding the discussion on whether or not the biofuel and fossil fuel systems are modelled similarly and consistently. In Figure F-2 the flowchart for the operation of an average Dutch passenger (diesel) car has been drafted just following the upstream flow from the operation of the passenger (diesel) car (P2472). The consequence of this is that processes may be included twice in this figure. For example, P(rocess) 300, P1964 and P2429 occur two times, P585 three times and P1642 and P1680 occur four times in Figure F-2. The dashed oblique lines in the figure indicate the open ends of the flow chart, that is that at these points the flow chart has not been drawn until the boundary of the system (the real cradle process for that part of the flowchart).
In Figure F-3 the "double" processes drawn in Figure F-2 are replaced by recursion lines (loops) reducing the number of dashed oblique lines. Figure F-3 thus may look a bit more complex and it may be a bit more difficult to unravel relations between processes, but it better indicates the real number of open ends.
The meaning of the P-numbers used in both figures is explained in Table F-1.

Note furthermore that both in Figure F-2 and Figure F-3:

1. all capital goods have been excluded.
2. only the diesel supply chain has been elaborated (the petrol chain has not been drawn).

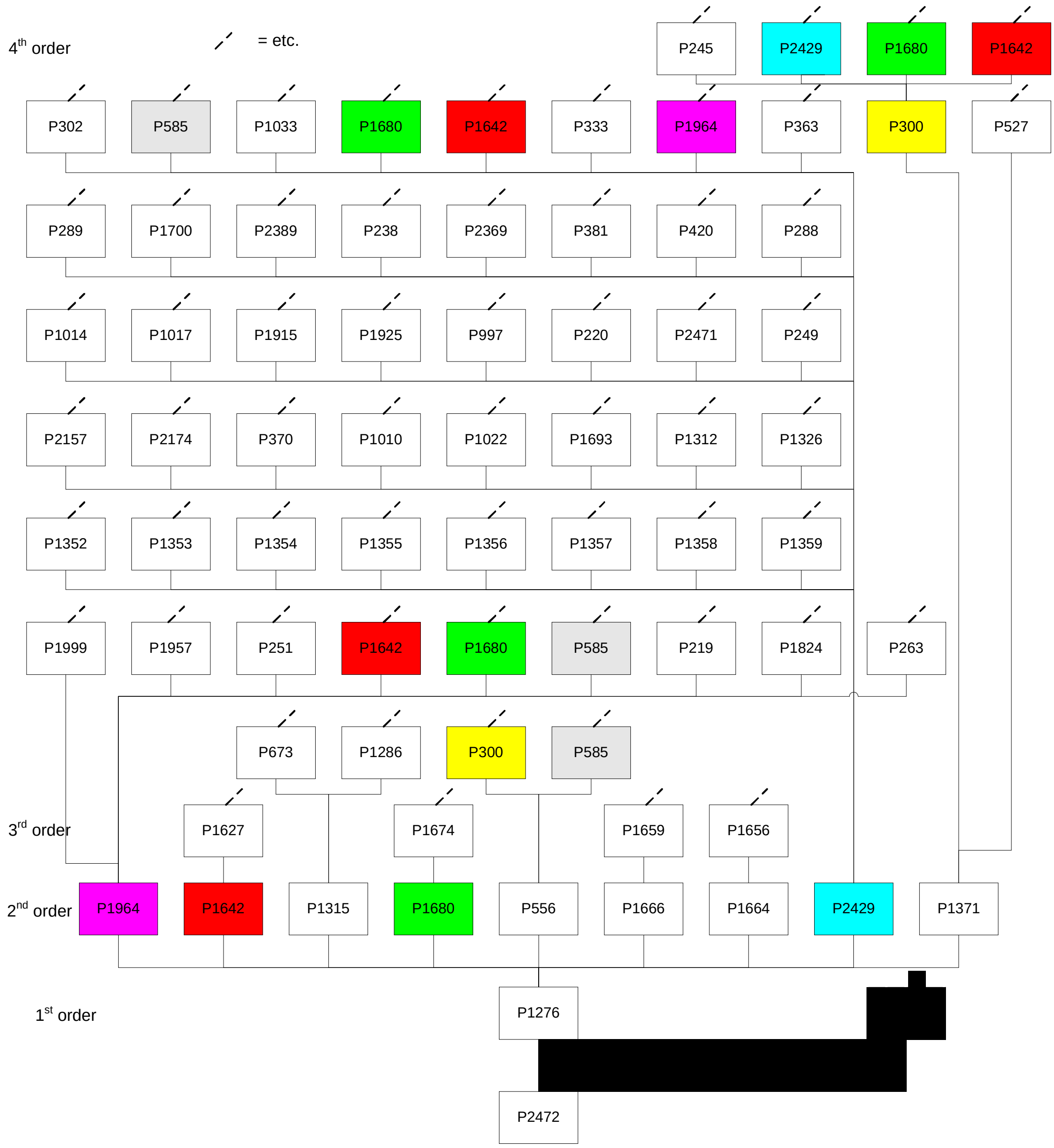

Figure F-2. Part of the flowchart for 1 km operation of an average Dutch passenger (diesel) car as modelled in ecoinvent v1.1 using specific car driving emission and fuel consumption data. Double processes are indicated in matching colours; all capital goods have been excluded from this flowchart; for practical reasons processes have only been included to the third level, and not on the basis of their individual contribution to a certain result (such as in SimaPro).

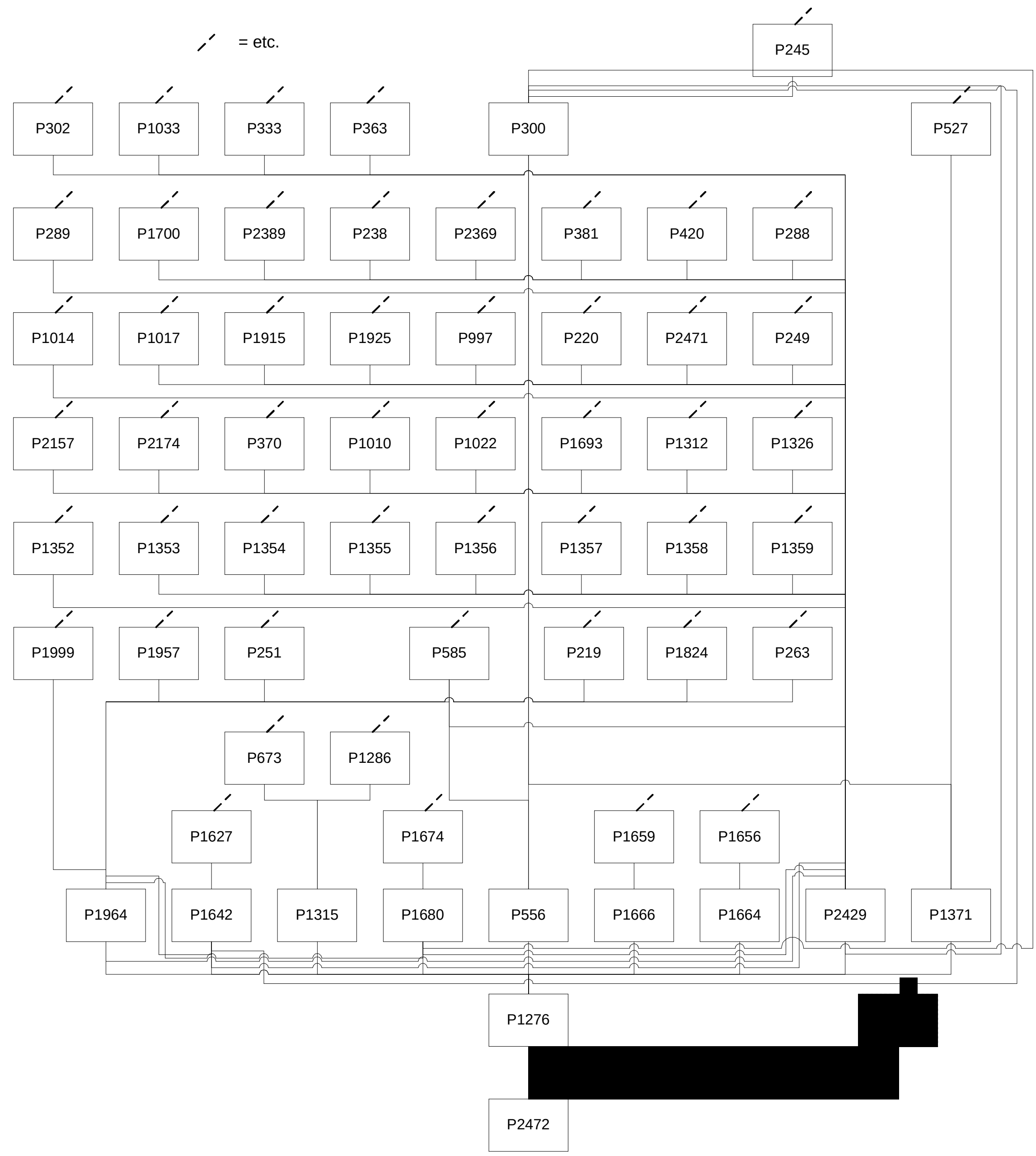

Figure F-3. **Same flowchart as drawn in Figure F-2 but with double processes included as recursion lines (loops).**

Table F-1. Explanation of P-numbers used in Figure F-2 and Figure F-3 (the third column indicates whether a process is a multi-output (MO) process or not) (Ecoinvent v1.1.; Ecofys bv).

P-no.	Process name	MO
(P219)	aluminium sulphate, powder, at plant(RER)	-
(P220)	ammonia, liquid, at regional storehouse(RER)	-
(P238)	chlorine, liquid, production mix, at plant(RER)	-
(P245)	fluorine, liquid, at plant(RER)	-
(P249)	hydrochloric acid, 30% in H2O, at plant(RER)	-
(P251)	hydrogen peroxide, 50% in H2O, at plant(RER)	-
(P263)	ozone, liquid, at plant(RER)	-
(P288)	sodium hydroxide, 50% in H2O, production mix, at plant(RER)	-
(P289)	sodium hypochlorite, 15% in H2O, at plant(RER)	-
(P300)	sodium silicate, furnace liquor, 37% in H2O, at plant(RER)	-
(P302)	sulphuric acid, liquid, at plant(RER)	-
(P333)	chemicals organic, at plant(GLO)	-
(P363)	lubricating oil, at plant(RER)	-
(P370)	methyl tert-butyl ether, at plant(RER)	-
(P381)	propylene glycol, liquid, at plant(RER)	-
(P420)	lime, hydrated, packed, at plant(CH)	-
(P527)	electricity, high voltage, production UCTE, at grid(UCTE)	-
(P556)	electricity, low voltage, production UCTE, at grid(UCTE)	-
(P585)	electricity, medium voltage, production UCTE, at grid(UCTE)	-
(P673)	electricity, low voltage, at grid(CH)	-
(P997)	iron sulphate, at plant(RER)	-
(P1010)	molybdenum, at regional storage(RER)	-
(P1014)	palladium, at regional storage(RER)	-
(P1017)	platinum, at regional storage(RER)	-
(P1022)	rhodium, at regional storage(RER)	-
(P1033)	zinc for coating, at regional storage(RER)	-
(P1276)	diesel, at regional storage(RER)	-
(P1286)	light fuel oil, at regional storage(CH)	-
(P1294)	petrol, two-stroke blend, at regional storage	-
(P1296)	petrol, unleaded, at regional storage(RER)	-
(P1312)	heavy fuel oil, burned in refinery furnace(RER)	-
(P1315)	light fuel oil, burned in boiler 100kW, non-modulating(CH)	-
(P1326)	refinery gas, burned in furnace(RER)	-
(P1352)	crude oil, production GB, at long distance transport(RER)	-
(P1353)	crude oil, production NG, at long distance transport(RER)	-
(P1354)	crude oil, production NL, at long distance transport(RER)	-
(P1355)	crude oil, production NO, at long distance transport(RER)	-
(P1356)	crude oil, production RAF, at long distance transport(RER)	-
(P1357)	crude oil, production RLA, at long distance transport(RER)	-
(P1358)	crude oil, production RME, at long distance transport(RER)	-
(P1359)	crude oil, production RU, at long distance transport(RER)	-
(P1371)	transport, crude oil pipeline, onshore(RER)	-
(P1627)	operation, lorry 32t(RER)	-
(P1642)	transport, lorry 32t(RER)	-
(P1656)	operation, barge tanker(RER)	-
(P1659)	operation, transoceanic tanker(OCE)	-
(P1664)	transport, barge tanker(RER)	-
(P1666)	transport, transoceanic tanker(OCE)	-
(P1674)	operation, freight train(RER)	-
(P1680)	transport, freight, rail(RER)	-
(P1693)	zeolite, powder, at plant(RER)	-
(P1700)	soap, at plant(RER)	-
(P1824)	disposal, wood untreated, 20% water, to municipal incineration(CH)	-
(P1915)	disposal, refinery sludge, 89.5% water, to sanitary landfill(CH)	-
(P1925)	disposal, catalytic converter NOx reduction, 0% water, to underground deposit(DE)	-
(P1957)	treatment, sewage, unpolluted, to wastewater treatment, class 3(CH)	-
(P1964)	tap water, at user(RER)	-
(P1999)	charcoal, at plant(GLO)	-
(P2157)	naphtha, at regional storage(RER)	-
(P2174)	refinery gas, burned in flare(GLO)	-

Table F-1 c'd. **Explanation of P-numbers used in Figure F-2 and Figure F-3 (the third column indicates whether a process is a multi-output (MO) process or not) (Ecoinvent v1.1.; Ecofys bv).**

(P2369)	air separation, cryogenic; multi-output process of argon, nitrogen and oxygen	+
(P2389)	nickel production, sulphidic ore, primary; multi-output process of nickel and copper	+
(P2429)	crude oil, in refinery; multi-output process refinery	+
(P2471)	soda production, solvay process, at plant; multi-output process of soda powder and calcium chloride	+
(P2472)	operation, average Dutch passenger diesel car (Ecofys)(NL)	-

The total number of processes linked to the "operation, average Dutch passenger diesel car (Ecofys)(NL)" process excluding capital goods, amounts to 1183. Including capital goods the number amounts to 1584. In Figure F-2 and Figure F-3, only 66 processes are presented (total number in Figure F-2 is 76 but as discussed above, some processes appear more than once in this Figure).

Just as a learning result, we have calculated the influence of capital goods for the fossil fuel chains modelled in this quick scan. The impact assessment (characterisation) results for his comparison are shown in Table F-2.

Table F-2. **Comparison of the characterisation results for the "operation, average Dutch passenger diesel car (Ecofys)(NL)" taking capital goods into account, and for the " operation, average Dutch passenger diesel car (Ecofys)(NL)" excluding capital good from the analysis (according to default Ecoinvent allocation).**

	incl. infrastructure (I)	excl. infrastructure (E)	Unit	Capital goods % in total infrastructure value (I-E/E)
Abiotic depletion	0,00118	0,00116	kg antimony eq.	2%
Global warming GWP100	0,184	0,18	kg CO_2 eq.	2%
Ozone layer depletion ODP steady state	2,29E-08	2,26E-08	kg CFC-11 eq.	1%
Human toxicity HTP inf.	0,0077	0,00633	kg 1,4-dichlorobenzene eq.	18%
Freshwater aquatic ecotoxicity FAETP inf.	0,00156	0,000789	kg 1,4-dichlorobenzene eq.	49%
Marine aquatic ecotoxicity MAETP inf	7,84	5,55	kg 1,4-dichlorobenzene eq.	29%
Terrestrial ecotoxicity TETP inf	0,000171	0,0000633	kg 1,4-dichlorobenzene eq.	63%
Photochemical ozone creation (high NOx)	0,000101	0,0000941	kg ethylene eq.	7%
Acidification (incl. fate, average Europe total)	0,000449	0,000416	kg SO_2 eq.	7%
Eutrophication (fate not incl.)	0,0000495	0,0000443	kg PO_4 eq.	11%

Until now it was generally assumed that the contribution of capital goods to the characterisation result of an average LCA-study would not exceed 1-2%. From Table F-2, however, it appears that the contribution of capital good may be between 1% and almost 65%, depending on the impact category. The difference of the human toxicity scores is, for example, mainly due to heavy metal emissions associated to the life cycle of metal construction compounds. On an inventory level the differences may be even larger and some emissions may even completely be caused by capital goods (for practical reasons, the inventory results have not been included in this report).

As these results are quite surprising, further double-checks, contribution analyses and interpretation analyses should be made; time is, however, unfortunately lacking to perform such analyses as part of this quick scan.

F.4 Multi-output processes and allocation scenarios selected

In order to make the quick scan focusing on different allocation scenarios for fossil fuels chains a feasible task, the allocation scenarios calculated have been limited to the following three:

1. Economic value (economic allocation): in this scenario calculations are performed on the basis of the proceeds (quantity produced times price per quantity) of the valuable outputs of the MO process.
2. Common physical parameter (physical allocation): in this scenario calculations are performed on the basis of a common physical parameter of the valuable out puts of the MO process. In this quick scan, the common physical parameter will be mass (kg) or energy (MJ). If for a specific MO process a common physical parameter cannot be determined or derived, economic allocation will be applied again for that process.
3. Ecoinvent default: in this scenario the allocations are taken as currently implemented in the Ecoinvent v1.1 database by its designers;

As mentioned earlier, it is not possible to apply "system enlargement" to the refinery, which is the main multi-output process of the fossil fuel chains. Therefore, this allocation scenario has not been elaborated any further in this quick scan on fossil fuels.

For collecting data on prices it is important to determine which price data exactly is strived for. Based on Guinée et al. (2002), the following price data are the preferred ones ("ideal situation"):

1. FOB prices (Free On Board), this are the prices at the gate excluding transport, insurance and taxes.
2. Average prices over the last 3 years, or an average price for the short term future (futures market ('termijnmarkt') prices)[13].
3. All prices are expressed or calculated in one currency according to exchange rates for a given period or point in time, e.g. € according to the average exchange rates of February 2005.

As prices are often confidential data, it may also be useful to work with relative proceeds. In terms of proceeds, one then doesn't have to give exact data but may give the relevant ratios. These ratios, however, should reflect the exact amount-ratios as produced according to the ecoinvent v1.1 data for that process, and that may again raise a problem in practice as ecoinvent data often reflect averages, which cannot be found in practice in exactly the same qualities and quantities.

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[13] Rather not 'on the spot' prices (= e.g., oil prices in Rotterdam harbor) as these depend too much on local and daily fluctuations (e.g., oil prices may locally significantly increase when blizzards are forecasted).

There are 54 MO processes linked to both the passenger car and the diesel system in the ecoinvent v1.1 database. Within this quick scan, it is impossible to run the three allocation scenarios for all 54 MO processes and to collect price data for these etc. Therefore, contribution analyses have first been performed on the passenger car results using the default ecoinvent allocation determining which MO processes contribute most to one of the environmental impact categories of the characterisation (abiotic depletion, global warming, etc.). This has resulted to a selection of seven MO processes that have been further analysed with the three allocation scenarios mentioned above:

Table F-3. Multi output processes that were analysed with different allocation scenarios.

Label	Name
(P2390)	platinum group metal production, primary(ZA)
(P2391)	platinum group metal production, primary(RU)
(P2422)	combined offshore gas and oil production(NO)
(P2429)	crude oil, in refinery(RER)
(P2430)	combined gas and oil production(NG)
(P2431)	combined offshore gas and oil production(GB)
(P2432)	municipal solid waste to municipal incineration(CH)

ZA = South Africa; RU = Russian Federation; NO = Norway; RER = Europe; NG = Nigeria; GB = United Kingdom; CH = Switzerland

For these seven MO processes the three allocation scenarios have been calculated. We have tried to collect the price data through the stakeholders of the 'Biofuels project' but unfortunately without result. For now, data have been collected through public sources as the CBS statistics and all kinds of relevant websites. However, the data collected in this way don't fully match the preferred ones as explained above. It could therefore be considered to perform a sensitivity analysis for price data, if time is left for this at the end of the project. The price data used for the economic allocation scenarios and the sources used for this are presented in annexed Table F-7.

F.5 Results

Below, results of this quick scan will be presented in terms of:

- allocation factors (determining the part of economic inputs, resource extractions, emissions etc. that is allocated to each of the valuable outputs of a MO process) for each of the three allocation scenarios;
- impact assessment (characterisation) results for each of the three allocation scenarios;

for 1 km driving (operation of an average Dutch passenger diesel/petrol car) using the ecoinvent v1.1 database.

Table F-4. Allocation factors (expressed in %) for selected multi-output processes for three different allocation scenarios.

Economic outflows	economic allocation	mass/energy allocation	ecoinvent allocation
Process = (P2390) platinum group metal production, primary(ZA)			
palladium, primary, at refinery(ZA)	7,2%	0,1%	19,7%
platinum, primary, at refinery(ZA)	82,1%	0,3%	69,1%
rhodium, primary, at refinery(ZA)	0,0%	0,0%	7,6%
copper, primary, from platinum group metal production(ZA)	1,4%	41,3%	2,1%
nickel, primary, from platinum group metal production(ZA)	9,2%	58,3%	1,5%
Process = (P2391) platinum group metal production, primary(RU)			
palladium, primary, at refinery(RU)	7,7%	0,0%	31,4%
platinum, primary, at refinery(RU)	12,7%	0,0%	16,0%
rhodium, primary, at refinery(RU)	0,0%	0,0%	2,8%
copper, primary, from platinum group metal production(RU)	18,6%	58,1%	29,0%
nickel, primary, from platinum group metal production(RU)	61,0%	41,9%	20,9%
Process = (P2422) combined offshore gas and oil production(NO)			
natural gas, at production offshore(NO)	14,8%	20,5%	20,7%
crude oil, at production offshore(NO)	85,2%	79,5%	79,3%
Process = (P2429) crude oil, in refinery(RER)			
naphtha, at refinery(RER)	8,1%	6,5%	6,5%
heavy fuel oil, at refinery(RER)	*9,8%*	*16,8%*	*16,8%*
petroleum coke, at refinery(RER)	0,0%	0,0%	0,0%
secondary sulphur, at refinery(RER)	0,1%	0,5%	0,5%
propane/ butane, at refinery(RER)	2,3%	2,7%	2,7%
bitumen, at refinery(RER)	0,0%	0,1%	0,1%
diesel, at refinery(RER)	*14,1%*	*9,6%*	*9,6%*
kerosene, at refinery(RER)	3,7%	6,4%	6,4%
light fuel oil, at refinery(RER)	26,9%	25,6%	25,6%
petrol, unleaded, at refinery(RER)	*27,1%*	*20,6%*	*20,5%*
refinery gas, at refinery(RER)	7,4%	11,2%	11,2%
electricity, at refinery(RER)	0,5%	0,0%	0,0%
Process = (P2430) combined gas and oil production(NG)			
crude oil, at production(NG)	93,4%	90,5%	90,4%
natural gas, at production(NG)	6,6%	9,5%	9,6%
Process = (P2431) combined offshore gas and oil production(GB)			
natural gas, at production offshore(GB)	27,0%	35,4%	35,7%
crude oil, at production offshore(GB)	73,0%	64,6%	64,3%
Process = (P2432) municipal solid waste to municipal incineration(CH)			
disposal, municipal solid waste, 22.9% water, to municipal incineration(CH)	65,4%	65,4%	100,0%
electricity from waste, at municipal waste incineration plant(CH)	11,0%	11,0%	0,0%
heat from waste, at municipal waste incineration plant(CH)	23,6%	23,6%	0,0%

The results above show that different allocation methods may result in quite diverging sets of allocation factors. The most significant differences are found for the "(P2390) platinum group metal production, primary" MO process. Here, mass allocation or economic allocation changes the allocation factors for platinum from 0,003 to more than 0,8 (!). Also for other processes there are changes, but these are not so significant.

Finally note that Ecoinvent didn't allocate any impacts to the co-production of electricity and heat in process "(P2432) municipal solid waste to municipal incineration".

Environmental impacts of average Dutch passenger diesel car for three different allocation scenarios

The impact assessment (characterisation) results in Table F-5 show that although at the process level allocation factors may differ significantly (up to 300), the total results only differ modestly (1-2; see last two columns). There is no general rule between these two. They depend on the scaling factor and the environmental impact related to the resource extractions and emissions of a particular multi-output process and its upstream processes in the total system analysed. For example, if the *(P2390) platinum group metal production, primary (ZA)* process quantitatively only plays a very marginal role in the operation of an average Dutch passenger diesel car, then a huge difference in allocation factors will only give a minor change in the total result. However, if a very hazardous chemical emission is involved in that process, the change in the total result may again be more significant.

Table F-5. Results for 1 km driving with an average Dutch passenger *diesel* car.

category	unit	economic allocation	mass allocation	ecoinvent allocation	ratio econ / ecoinvent alloc	ratio mass / ecoinvent alloc
abiotic depletion	kg antimony eq.	1,66E-03	1,25E-03	1,18E-03	**1,41**	1,06
global warming GWP100	kg CO2 eq.	1,99E-01	1,87E-01	1,84E-01	1,08	1,02
ozone layer depletion ODP steady state	kg CFC-11 eq.	3,35E-08	2,38E-08	2,29E-08	**1,46**	1,04
human toxicity HTP inf.	kg 1,4-dichlorobenzene eq.	1,12E-02	8,14E-03	7,76E-03	**1,44**	1,05
Freshwater aquatic ecotoxicity FAETP inf.	kg 1,4-dichlorobenzene eq.	2,30E-03	1,63E-03	1,57E-03	**1,46**	1,04
Marine aquatic ecotoxicity MAETP inf	kg 1,4-dichlorobenzene eq.	1,11E+01	7,78E+00	7,86E+00	**1,41**	0,99
Terrestrial ecotoxicity TETP inf	kg 1,4-dichlorobenzene eq.	2,62E-04	1,87E-04	1,72E-04	**1,52**	1,09
photochemical ozone creation (high NOx)	kg ethylene eq.	1,32E-04	1,02E-04	1,01E-04	**1,31**	1,01
acidification (incl. fate, average Europe total, A&B)	kg SO2 eq.	6,31E-04	4,83E-04	4,49E-04	**1,41**	1,08
eutrophication (fate not incl.)	kg PO4--- eq.	5,66E-05	5,07E-05	4,95E-05	1,14	1,02

The importance of the multi-output processes in the "operation, average Dutch passenger diesel car (Ecofys)(NL)" system analysed can be analysed by performing so-called contribution analyses. These analyses show the main contributing processes and inventory items (resource uses and emissions) for a specific impact category. In Annex 2, the different contributions for the three allocation scenarios on these three impact categories is shown. The annexed Figure F-5 through Figure F-9 show that the MO-processes are relevant contributors for the impact categories abiotic depletion, ozone layer depletion, human toxicity, photochemical ozone creation and acidification. This doesn't fully explain, however, the ratio differences identified in the last two columns of the table above. For example, one would have expected that MO-processes would also be visible as contributors to the impact category "marine aquatic ecotoxicity". This, however, appears not to be the case (see Figure F-4). The main contributors are P1362 and P1363, which model water emissions of the discharge of produced water from platforms for the combined extraction of oil and gas to the marine environment. These processes are directly linked to MO-process P2431 and P2430 respectively, and thus also change significantly with the three allocation scenarios, thus also significantly influencing the final results.

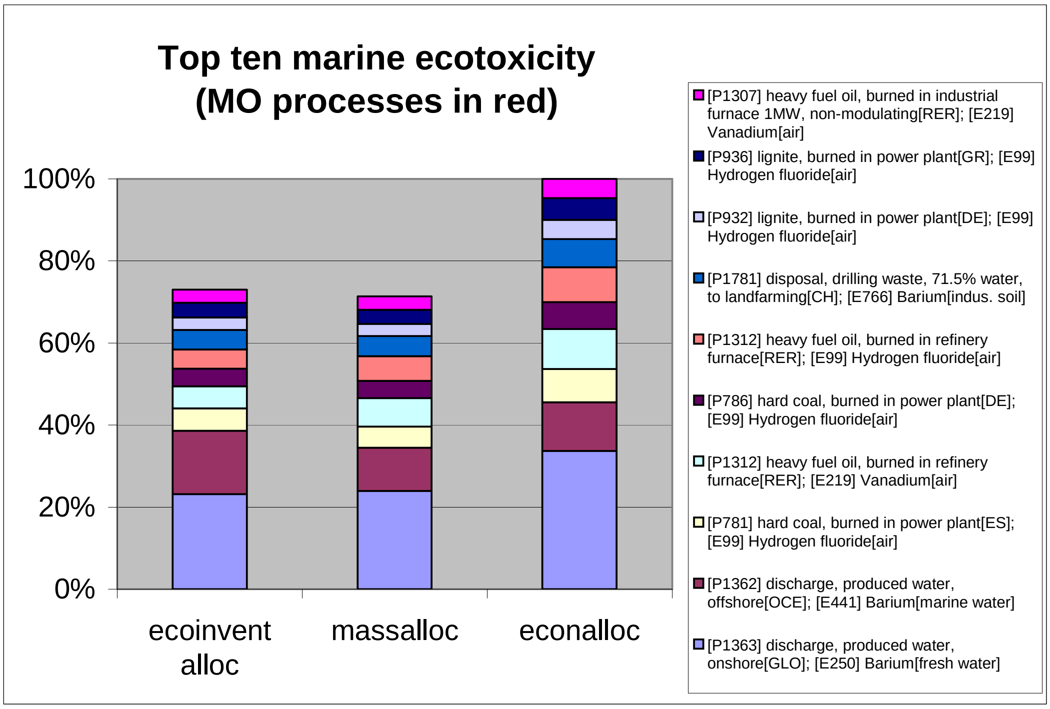

Figure F-4. Top ten contributing process interventions to marine aquatic ecotoxicity.

Environmental impacts of average Dutch passenger petrol car for three different allocation scenarios

For the results on driving a petrol car (see Table F-6) the same discussion is applicable as for the results of the passenger diesel car.

Table F-6. Results for 1 km driving with an average Dutch passenger *petrol* car.

Category	Unit	economic allocation	mass allocation	ecoinvent allocation	ratio econ / ecoinvent alloc	ratio mass / ecoinvent alloc
Abiotic depletion	kg antimony eq.	1,93E-03	1,36E-03	1,39E-03	**1,39**	0,98
Global warming GWP100	kg CO2 eq.	2,23E-01	2,08E-01	2,16E-01	1,03	0,96
Ozone layer depletion ODP steady state	kg CFC-11 eq.	3,91E-08	2,60E-08	2,61E-08	**1,50**	1,00
Human toxicity HTP inf.	kg 1,4-dichlorobenzene eq.	1,33E-02	9,19E-03	1,10E-02	**1,21**	0,84
Freshwater aquatic ecotoxicity FAETP inf.	kg 1,4-dichlorobenzene eq.	2,67E-03	1,77E-03	2,15E-03	**1,24**	0,82
Marine aquatic ecotoxicity MAETP inf	kg 1,4-dichlorobenzene eq.	1,28E+01	8,48E+00	1,05E+01	**1,22**	0,81
Terrestrial ecotoxicity TETP inf	kg 1,4-dichlorobenzene eq.	3,05E-04	2,03E-04	2,34E-04	**1,30**	0,87
Photochemical ozone creation (high NOx)	kg ethylene eq.	1,89E-04	1,49E-04	1,58E-04	**1,20**	0,94
Acidification (incl. fate, average Europe total, A&B)	kg SO2 eq.	6,97E-04	4,99E-04	5,90E-04	1,18	0,85
Eutrophication (fate not incl.)	kg PO4--- eq.	5,62E-05	4,82E-05	5,03E-05	1,12	0,96

F.6 Conclusions

The following conclusions can be drawn from this quick scan LCA on three different allocation scenarios for the passenger car fossil fuel chain using the ecoinvent v1.1 database:

- Capital goods may play a much more important role in (fossil fuel) LCA-studies than thought before.
- Different allocation methods can cause significantly different results at the level of allocation factors and thus also at the level of environmental impacts allocated to the derived single-output processes.
- Although at the process level allocation factors and environmental impacts may differ significantly (up 300), the aggregated results only differ modestly (1-2). This is due to the fact that the total result depends on the scaling factor and the environmental impact related to the resource extractions and emissions of a particular multi-output process and its upstream processes in the total system analysed, or in other words, it depends on the importance of that particular MO-process in the whole passenger car system. These scaling factors and impacts were relatively small for the seven MO processes in this quick scan.
- This quick scan is one of the first studies calculating different allocation scenarios and has been very instructive to the authors (and hopefully also to the stakeholders of this biofuel project).

It is important to note that we have made no efforts to assess the representativeness and the general quality of the contents of the ecoinvent v1.1 database. For this exercise, we have taken it as it is. As far as we could judge, the ecoinvent v1.1 process reflects process data from 2000 and later, and from the documentation it appears that the decrease of sulphur in diesel/gasoline has been included in de database data (see minutes of Workshop 3, January 11, 2005).

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2. Ecoinvent reports: see http://www.ecoinvent.ch/en/publikationen.htm#ecoinvent%20reports

Table F-7. Price data used for the economic allocation scenario.

Process	Economic outflow	Price	Density
Platinum group metal production, primary (ZA)	Palladium, primary, at refinery(ZA)	4500 €/kg [1]	
	Platinum, primary, at refinery(ZA)	21650 €/kg [1]	
	Rhodium, primary, at refinery(ZA)	37,21 €/kg [2]	
	Copper, primary, from platinum group metal production(ZA)	2,47 €/kg [3]	
	Nickel, primary, from platinum group metal production(ZA)	11,23 €/kg [3]	
Platinum group metal production, primary (RU)	Palladium, primary, at refinery (RU)	4500 €/kg [1]	
	Platinum, primary, at refinery (RU)	21650 €/kg [1]	
	Rhodium, primary, at refinery (RU)	37,21 €/kg [1]	
	Copper, primary, from platinum group metal production (RU)	2,47 €/kg [3]	
	Nickel, primary, from platinum group metal production (RU)	11,23 €/kg [3]	
Combined offshore gas and oil production (NO)	Natural gas, at production offshore (NO)	0,14 €/m^3_{NTP} [4]	0,83 kg/m^3 [5]
	Crude oil, at production offshore (NO)	0,25 €/kg [6]	780,00 g/l [7]
Crude oil, in refinery (RER)	Naphtha, at refinery (RER)	0,32 €/kg	
	Heavy fuel oil, at refinery (RER)	0,15 €/kg	
	Petroleum coke, at refinery (RER)	0,01 €/kg	
	Secondary sulphur, at refinery (RER)	0,05 €/kg [8]	
	Propane/ butane, at refinery (RER)	0,22 €/kg	
	Bitumen, at refinery (RER)	0,12 €/kg [9]	780,00 g/l [10]
	Diesel, at refinery (RER)	0,38 €/kg [11]	0,84 kg/l [12]
	Kerosene, at refinery (RER)	0,15 €/kg	
	Light fuel oil, at refinery (RER)	0,27 €/kg	
	Petrol, unleaded, at refinery (RER)	0,34 €/kg [13]	0,72 kg/l [14]
	Refinery gas, at refinery (RER)	0,17 €/kg [15]	
	Electricity, at refinery (RER)	0,06 €/kWh	
Combined gas and oil production (NG)	Crude oil, at production (NG)	0,25 €/kg [6]	780,00 g/l [7]
	Natural gas, at production (NG)	0,14 €/m^3_{NTP} [4]	0,83 kg/m^3 [5]
Combined offshore gas and oil production (GB)	Natural gas, at production offshore (GB)	0,14 €/m^3_{NTP} [4]	0,83 kg/m^3 [5]
	Crude oil, at production offshore (GB)	0,25 €/kg [6]	780,00 g/l [7]
Municipal solid waste to municipal incineration (CH)	Disposal, municipal solid waste, 22.9% water, to municipal incineration (CH)	0,10 €/kg [16]	
	Electricity from waste, at municipal waste incineration plant (CH)	0,06 €/kWh	
	Heat from waste, at municipal waste incineration plant (CH)	0,02 €/MJ [17]	

1) http://www.edelmetaalkoersen.edelshop.nl/
2) http://www.taxfreegold.co.uk/rhodiumpricesusdollars.html
3) http://www.kitcometals.com/charts/Copper.html
4) NL price 2004.
5) BINAS table 12a
6) Http://statline.cbs.nl; fossil oil world market.
7) http://www.trimetal.nl/NR/rdonlyres/D18A7DB7-A438-4B81-B199-28241B911F14/0/AuberacMSDS.pdf
8) http://www.icislor.com/il_shared/Samples/SubPage152.asp
9) http://news.tradingcharts.com/futures/3/8/63354383.html
10) Assumption: density of bitumen equals that of oil.
11) 0,37 €/l excise deducted from sell price at gas station.
12) http://www.emis.vito.be/AFSS/fiches/Technieken/gebruik_als_biobrandstof.pdf
13) 0,68 €/l excise deducted from sell price at gas station.
14) Binas tabel 11; T=293 K
15) Assumption: 50 % of natural gas price
16) http://www.rivm.nl/milieuennatuurcompendium/nl/i-nl-0428-04.html
17) Assumption: waste heat costs as much as waste electricity per MJ.

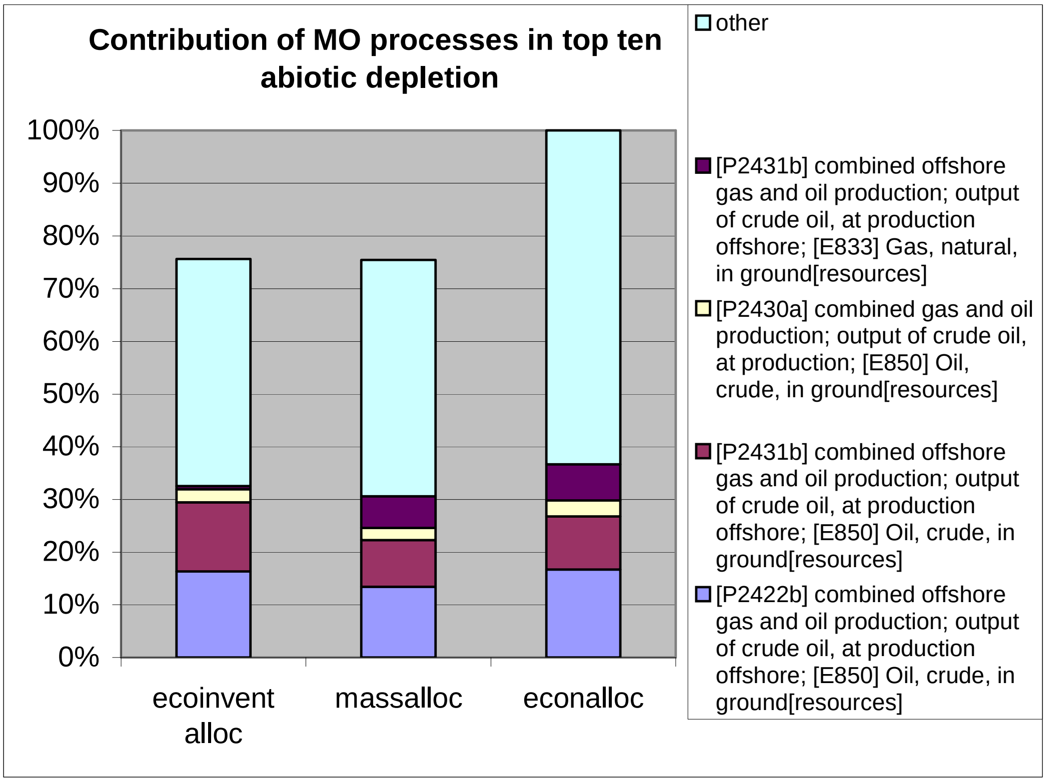

Figure F-5. Contribution analyses for the "operation, average Dutch passenger diesel car (Ecofys)(NL)" system, focusing on the role of the MO-processes in the top ten contributors for Abiotic depletion.

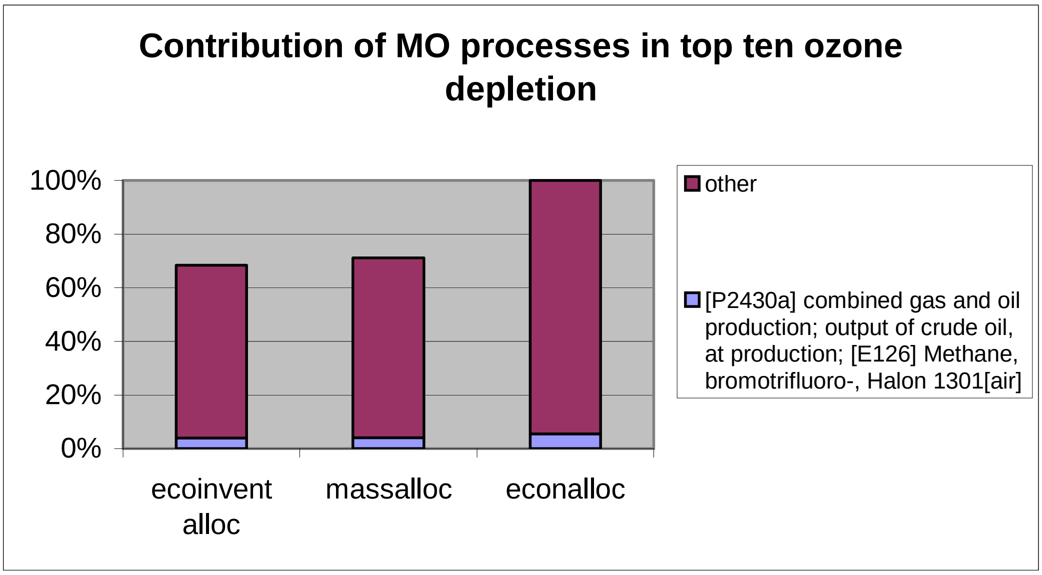

Figure F-6. Contribution analyses for the "operation, average Dutch passenger diesel car (Ecofys)(NL)" system, focusing on the role of the MO-processes in the top ten contributors for ozone layer depletion.

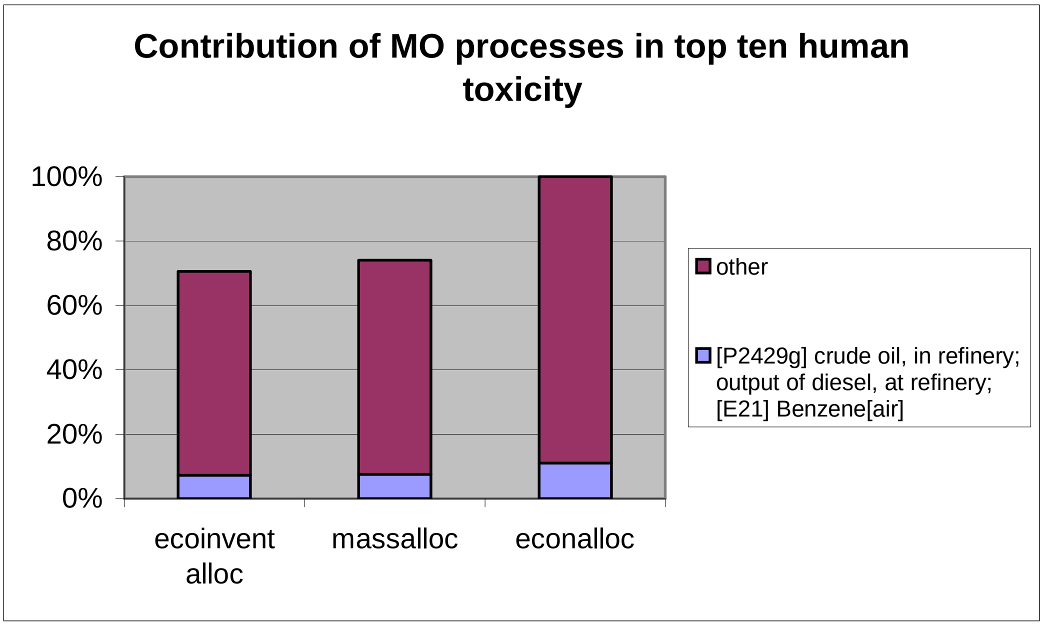

Figure F-7. Contribution analyses for the "operation, average Dutch passenger diesel car (Ecofys)(NL)" system, focusing on the role of the MO-processes in the top ten contributors for human toxicity.

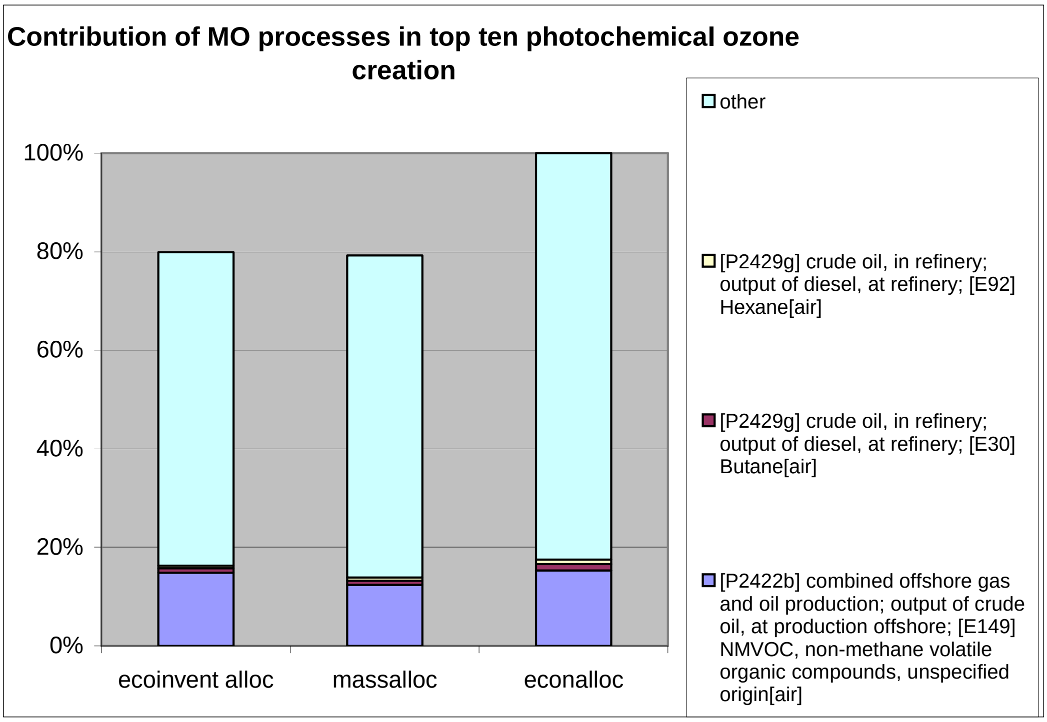

Figure F-8. Contribution analyses for the "operation, average Dutch passenger diesel car (Ecofys)(NL)" system, focusing on the role of the MO-processes in the top ten contributors for photochemical ozone creation.

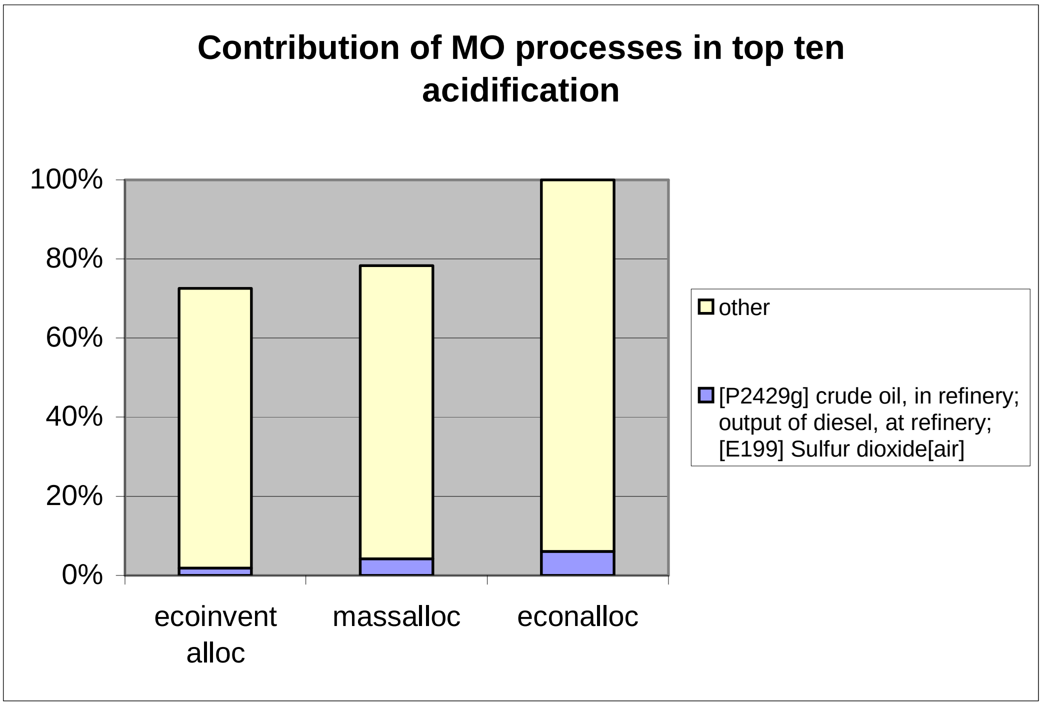

Figure F-9. Contribution analyses for the "operation, average Dutch passenger diesel car (Ecofys)(NL)" system, focusing on the role of the MO-processes in the top ten contributors for acidification.

GAVE-programme

This publication has been produced by the GAVE programme. GAVE stands for Gaseous and Liquid Climate-Neutral Energy Carriers, and is a programme that aims to accelerate the development and introduction of climate-neutral fuels into the Dutch transport sector.

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