BIOENERGY FOR EUROPE: WHICH ONES FIT BEST?

– A COMPARATIVE ANALYSIS FOR THE COMMUNITY –

Contract CT 98 3832

Final Report

The Research Group:

BLT	Bundesanstalt für Landtechnik (Austria)
CLM	Centrum voor Landbouw en Milieu (Netherlands)
CRES	Centre for Renewable Energy Sources (Greece)
CTI	Comitato Thermotecnico Italiano (Italy)
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Research funded in part by The European Commission
in the framework of the FAIR V Programme
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The Research Group:

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Executive summary

This report presents the methodology and the results of a project carried out in a co-operative task by eight European countries from 1998 to 2000. Its aim was to assess – by means of life cycle analyses – the environmental effects of various biofuels and to compare them against their fossil equivalents as well as against each other. The following institutes and countries participated in the project: BLT (Austria), TUD (Denmark), INRA (France), IFEU (Germany), CRES (Greece), CTI (Italy), CLM (The Netherlands) and FAT (Switzerland). The study was partially funded by the European Commission and by various ministries and institutes in the countries concerned. The main target groups of this report are intended to be decision makers in the European Commission directorates and in national ministries for agriculture, energy and the environment in each country involved. This summary comprises the following sections:

1 Background
2 Goals of the study
3 Design of the study
4 Results
5 Conclusions and recommendations

1 Background

The issue of bioenergy production has been discussed within the European Union over a number of years now under various different aspects, ranging from environmental questions to socio-economic ones. Many individual research projects have been carried out concerning the environmental consequences of increased bioenergy production and utilisation. What has been lacking so far however was a comprehensive international investigation of the effects of large scale bioenergy generation within the European Community considering recent ISO 14040–14043 standards. Furthermore, in order to implement a large scale promotion of bioenergy throughout Europe, it is necessary to establish first of all the economic as well as ecological costs and benefits involved, and secondly, to identify which sources of bioenergy, if any, are the most beneficial ones and the production of which ones is most feasible in each country.

2 Goals of the study

The present project provides – for the first time – a high quality decision base regarding the environmental effects of the production and utilisation of biofuels in Europe. It is designed to:

- show the environmental advantages and disadvantages of the different biofuels in the various countries involved and the EU, compared to corresponding fossil fuels by means of life cycle analyses
- make comparisons between biofuels within each country and the EU
- make comparisons between countries and the EU for each biofuel
- point out the most favourable biofuels in each country and the European Union respectively, with the help of life cycle analyses and a socio-economic and political analysis

Using state of the art methodology in life cycle analysis, comparisons were made between the respective participating countries with regard to each specific biofuel, as well as between different biofuels within each country. In addition, the specific socio-economic and political conditions in each country were taken into account.

3 Design of the study

Each of the organisations involved investigated the environmental effects of various biofuels. The results were then used to calculate average values for the European Union. The comparisons carried out in this project are listed below (**Table 1**).

Table 1 Investigated biofuels, their utilisation and fossil counterparts

Biofuel	Utilisation	Fossil fuel
Triticale	Co-firing for electricity	Hard coal
Willow	District heating	Light oil and natural gas
Miscanthus	District heating	Light oil and natural gas
Rape seed oil methyl ester (RME)	Transport	Fossil diesel fuel
Sunflower oil methyl ester (SME)	Transport	Fossil diesel fuel
ETBE from sugar beet	Transport	MTBE
Traditional firewood	Residential heating	Light oil and natural gas
Wheat straw	District heating	Light oil and natural gas
Biogas from swine excrements	Heat and electricity	Natural gas
Hemp	Gasification for electricity	Hard coal

All of these comparisons were calculated for the European Union with the exception of hemp, which was investigated by The Netherlands only, as a novel production chain.

The assessment of these biofuels was carried out using mainly published data in order to carry out complete life cycle assessments (LCA) of the biofuels and fossil fuels respectively. The different countries first identified the most relevant biofuels to be investigated. The environmental aspect of this study was done in correspondence with the LCA-standards ISO 14040 – 14043.

The biofuels were compared against conventional fossil fuels as well as other biofuels by means of full life cycle analyses based on life cycle inventories and impact assessments. All processes involved in producing and utilising a particular fuel were considered, which for the agriculturally produced biofuels included the production and application of fertiliser, pesticides, use of machinery etc. as well as so-called reference systems to take into account the alternative land use when no biofuel is cultivated.

4 Results

The results fall into four sections, namely *comparisons between biofuels and fossil fuels*, *comparisons among different biofuels* and *comparisons between the countries for each biofuel*. Finally, a *socio-economic analysis* was also carried out. For the environmental comparisons a range of parameters was assessed. These were aggregated into the following impact categories: use of fossil fuels, greenhouse effect, acidification, eutrophication, nitrous oxide and summer smog. In addition, the following categories were also assessed: human toxicity, ecotoxicity, persistent toxicity, ecosystem occupation and harmful rainfall. For these no quantitative results could be obtained within this project that were reliable enough for a sound scientific assessment. This was partly due to the lack of sufficiently developed methodology and partly to the lack of available data, given the scope of this study.

4.1 Biofuels versus fossil fuels

Regarding the categories for which reliable values were obtained, the results for the biofuel–fossil fuel comparisons are summarised in **Table 2**. The full results are given in the Chapters 4.1 (for Europe) and 7.1 (for each country). The main conclusions are generally similar between the various countries and Europe.

The advantage of the biofuels over the fossil fuels regarding the category use of fossil fuels is due to the fact that through the production and use of biofuels the utilisation of fossil fuels is reduced. The greenhouse effect is causally connected to the use of fossil fuels (which leads to the emission of greenhouse gases) and therefore gives very similar results, i.e. always to the advantage of the biofuels. In the case of eutrophication the biofuels compare unfavourably against their fossil equivalents in most cases, due to the utilisation of fertiliser and its inevitable partial escape into water bodies. Regarding human toxicity, depending on the comparison the results showed either very small differences or else were in favour of the fossil fuels. Due to a lack of data however, the results have a high uncertainty and should therefore not form a part of a final assessment.

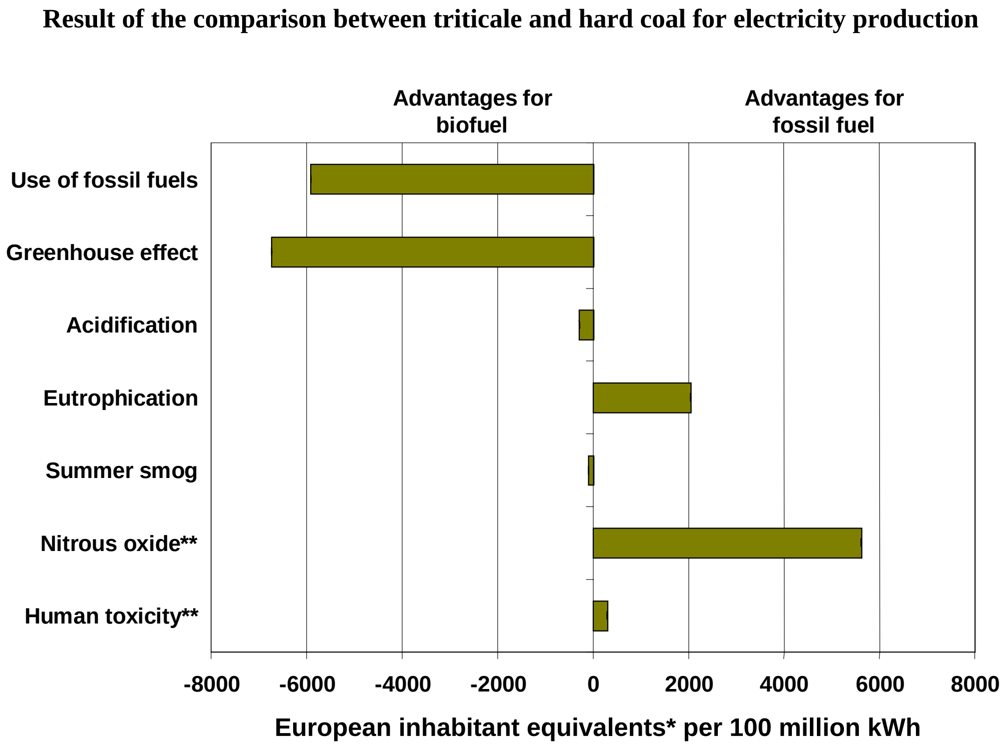
The category biodiversity and soil quality was assessed using four parameters, for two of which no results were obtainable due to a lack of suitable methodology and data. Regarding the parameter ecosystem occupation as a measure for life support functions of the soil, there appears to be a difference in the impacts of cereals, perennials, and other crops respectively. However, more research is needed to verify and explain this result. With respect to the parameter harmful rainfall as an indicator of erosion, perennial crops and cereals with short row intervals show lower erosion risks due to their higher degree of soil cover.

Furthermore, two parameters were investigated concerning toxicity towards humans and ecosystems, namely ecotoxicity and persistent toxicity. It was decided, however, not to include these results in the graphs because of a lack of data and more specifically inconsistencies in data quality for the two compared systems: for biofuels, pesticides were assessed on a very detailed level, whereas the same level of detail was not obtained for the fossil fuels. Due to these differences, it was not possible to draw any conclusions, but the data on biofuels serve as a good basis for further work on the subject.

Table 2 Results of the European comparisons between biofuels and fossil fuels

Biofuel	**Use of fossil fuels**	**Greenhouse effect**	**Acidification**	**Eutrophication**	**Summer smog**
Triticale	+	+	+/-	-	+
Willow	+	+	-	-	+
Miscanthus	+	+	-	-	+
Rape seed oil methyl ester (RME)	+	+	-	-	+/-
Sunflower oil methyl ester (SME)	+	+	-	+/-	+/-
ETBE from sugar beet	+	+	-	-	+/-
Traditional firewood	+	+	+/-	-	+
Wheat straw	+	+	-	-	+
Biogas from swine excrements	+	+	-	-	+
+ advantage for biofuel - advantage for fossil fuel +/- insignificant or ambiguous result					

Concerning the interpretation of these results, a final assessment in favour of or against a particular fuel cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required, which differ from person to person. Whether a specific biofuel is assessed as better or worse than its fossil equivalent depends upon the focus and priorities of the decision maker. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, then the biofuel will be better suited. If on the other hand other parameters are deemed to be most important, then depending on the specific results of the comparison in question, the fossil fuel might be preferred. Thus decision makers, political institutions, etc. are encouraged to carry out their own assessment on the basis of the results presented here, and – very importantly – to express their priorities by which they carry out the assessment. **Figure 1** shows an example of the results obtained for Europe – in this case for triticale.



*** How to interpret the diagram**

The figure shows the results of comparisons between complete life cycles where hard coal is substituted by triticale for electricity generation. The unit refers to an amount of one hundred million kWh of electricity. This is equivalent to the average electricity requirement of about 20,000 inhabitants of Europe in one year or a triticale production of about 5,500 ha/a. In this case for example the amount of fossil fuel saved is equal to the amount which nearly 6,000 European citizens would on average consume in one year (this is what is meant by “European inhabitant equivalents”).
See Chapter 4.2.1 for a discussion of the results.

Figure 1 Example of a result diagram

4.2 Biofuels versus biofuels

In this part those biofuels which fulfil the same purpose were compared against each other, for Europe and for each individual country (Chapters 4.2 and 7.1 respectively). The following issues were addressed: heat production, transport, efficiency of land use and impacts related to saved energy. The comparisons were carried out on the basis of the differences between the biofuels and their respective fossil equivalents with regard to the same environmental impact categories referred to in the previous section.

- Heat production: traditional firewood, Miscanthus, willow and wheat straw were compared against each other. Regarding the use of fossil fuels and the greenhouse effect there are no significant differences between any of the biofuels, but traditional firewood shows the most favourable values in all categories apart from summer smog (for which the results are too small however to be regarded as significant).
- Transport: RME, SME and ETBE were compared against each other. SME achieves the best results regarding the use of fossil fuels, the greenhouse effect and eutrophication, while RME achieves the lowest for most categories.
- Efficiency of land use: triticale, willow, Miscanthus, RME, SME and ETBE were compared against each other. In this case the impacts of each fuel produced on an equal amount of land area were as-

sessed. Triticale reveals by far the highest benefits regarding the categories use of fossil fuels, greenhouse effect and acidification. However, it has also the greatest disadvantages with respect to ozone depletion and eutrophication. RME and SME show the smallest advantages regarding the use of fossil fuels and the greenhouse effect.

- Impacts related to saved energy: here the comparison revealed the “side-effects” of each biofuel for every MJ saved through its use instead of the fossil fuel. All biofuels were compared against each other. The results here are very heterogeneous, depending on the biofuel and “side-effect” impact category respectively. For every MJ fossil energy saved, a reduction in greenhouse gas emissions also ensues for all biofuels. This effect is by far the greatest for biogas, followed by triticale, and is lowest for RME. On the other hand, for most of the biofuels a negative “side-effect” results compared to the fossil fuels regarding most other categories.

To summarise, no single biofuel can be regarded as “the best” for any of these issues. An evaluation must consider the different types of energy (for space heating, power production, transport fuel), the different levels of technological development (mature technology, demonstration or pilot stage, experimental) and additionally the subjective judgements of the individual decision maker regarding which of the impact categories is most important. Still the observations listed above can be useful in such a decision process. These results themselves can be regarded as very reliable, since generally the uncertainties of the data for the various biofuels are due to similar factors and therefore tend to cancel each other out in the comparison among each other.

4.3 Results of the comparisons between the countries for each biofuel

Here the results of each country for each biofuel were compared against each other. This was done with regard to the differences between the biofuels and their corresponding fossil fuels. For further details on this as well as the presentation of the result graphs the reader is referred to Chapter 7.2.

The results give a very heterogeneous picture: for certain biofuels and impact categories the differences between the countries are relatively small, while for others they are significantly large. The magnitude of the differences appears to be more dependent on the biofuel than the impact categories, thus for some chains, such as wheat straw, the values for all countries and with respect to most impact categories are relatively similar to the European average, while for other chains, e. g. biogas, the values differ significantly. It is noticeable that with the exception of biogas for all biofuels the parameters use of fossil fuels, greenhouse effect and human toxicity show very similar results between the countries, while for the other categories the differences tend to be larger.

Differences in yields also influence the results of the environmental analysis. The differences between countries are most profound with the perennial crops, which may be explained by differences in the scarce experiences with these crops and their cultivation. The influence of this variation in yields on the results is limited however, if (primary) energy is used as functional unit. The influence is larger when the analysis focuses on efficiency of land use.

4.4 Results of the socio-economic and political analyses

The purpose of these analyses was to complement the findings resulting from the environmental analysis. Their function was to show support, or lack of it, for the results of the environmental analysis, from a socio-economic and political point of view. It must be particularly emphasised that this part of the assessment is not a comprehensive one, as this would have exceeded the scope of this project by far. Also, in many cases the methodology was not advanced enough or insufficient reliable data could be obtained to enable an adequate assessment. This present assessment comprised three sectors: economic aspects, visual impact of landscape changes and political factors.

The first part is mainly quantitative. For the cost calculation the same input and yield figures were used as in the environmental analysis (Chapter 7), supplemented with price data from the literature. The second and third parts are qualitative and contain effects on landscape and an impression of policy and political arguments by each country in favour of or against certain biofuel chains.

Economic aspects

- Due to the lack of reliable data the economic analysis could only be carried out for forestry and the agricultural production of the biofuels. The processing and utilisation as well as the production of the fossil fuels and a final comparison could therefore not be carried out.
- The economic analysis of forestry and the agricultural production of the biofuels showed partly large differences between the various countries. This is due to differences in land prices, production costs, cultivation practices and yields. A cost assessment based on the production costs at farm gate level leads to the following ranking (based on useful energy as a reference unit): wheat straw is the most economic option (being a residue produced at low costs), followed by willow, Miscanthus and wood logs, then triticale and ETBE and finally rape seed and sunflower as the most expensive ones.

Visual impact of landscape changes

- The bright yellow flowers of rape seed and sunflowers are widely appreciated. However, in areas that are attractive without these flowers, their introduction may be seen as a disruption. Furthermore, especially with regard to sunflowers, the crop is not particularly sightly outside the flowering period, which only lasts for about a month.
- The positive contribution of perennials to the attractiveness of a landscape is due to their variation in structure; while the negative aspect lies in the fact that the same crop remains for many years and that in the later stages the crops may block the view as a result of their height. All in all the positive and negative aspects appear to balance each other out.
- The method to assess the impact of biofuels on landscape by the variation in structure and colour seems a valuable method that is relatively easy to carry out and for which data are readily available. However, the method needs improvement on aspects relating to objectivity and representativity.

Political factors

- In order to successfully introduce or increase the cultivation of energy crops, not only laws and directives are required but also the support from local authorities, e.g. environmental groups and farmers.
- An increased emphasis on extensification, nature development, new outlets and reduction of imports may have the result that land availability becomes the major limiting factor for energy crops.
- Despite the goal of opening up the energy market, there is no level playing field as yet. Major distortions are the differences in environmental regulations and in subsidies, giving fossil fuels advantages over renewables.
- With certain biofuels farmers experience three main constraints: poor farm economics, poor fit into cropping systems and poor logistics concerning harvest and post-harvest management.
- Within the liberalised energy market, temporary regulations are required to ensure the contribution of energy crops to the national CO_2-reductions.

5 Conclusions and recommendations

The objective of this study was to create a decision tool, based on reliable scientific data, with regard to the question of which biofuels or fossil fuels are ecologically the most suitable for specific purposes and countries within Europe. Within the scope of this project this goal has been partly successfully achieved:

- The LCA method has been adapted so that any energy carrier can be assessed (10 biofuels were investigated in this project).
- The calculation tool has been successfully implemented.
- The socio-economic analysis on the other hand was only partially successful.

One important outcome however is the realisation that with respect to certain environmental impact categories – i. e. toxicological impacts as well as biodiversity and soil quality – the data availability and current methodology is as yet not adequate for a reliable scientific assessment. Furthermore, the socio-economic and political analyses could not be carried out in sufficient depth to allow their inclusion in a final assessment. This was due to the relatively poor data availability and the resource limitations of this project. In all these subject areas it is urgently required to carry out or continue relevant work on the methodological developments.

Regarding the *comparison between the various biofuels and fossil fuels* the most significant findings were as follows:

- Concerning the major goal of the target groups with respect to the promotion of biofuels – also defined in the “White Paper” of the European Commission – i. e. energy saving and greenhouse gas reduction, it can be concluded that bioenergy should be promoted.
- On the other hand there are certain negative impacts, the degree depending on the individual fuel.
- The relevance of these negative impacts cannot be directly assessed scientifically. There is a clear requirement for further research. Instruments for decision making should be tested or developed further, in addition to the current ones used in LCA.
- Every fuel has its particular advantages and disadvantages; the final decision of which fuel to prefer therefore remains with the ultimate decision maker.
- It was unfortunately not possible to reach many definitive conclusions on the socio-economic issue.
- The choice for a certain bioenergy chain cannot generally be regulated at EU level. The actual choice depends on how national authorities value the different environmental parameters. It also depends on the possibilities to adapt chains in such a way that environmental disadvantages are diminished in order to fit a certain energy crop into a specific region. The European Commission is therefore recommended to develop a set of criteria which can be used by authorities to assess whether a certain chain fits into their specific region.
- Some of the chains investigated here are fairly established, but others still require further research and development. The conclusions of this study are valid only for the chains investigated here. The results of can be used as a basis for further improvements. The detailed balance reveals the strengths and weaknesses of the different chains and can initiate further work.

Regarding the *comparison between the various biofuels*, a ranking according to their environmental performance is somewhat easier, e. g. regarding almost all environmental impacts, the solid biofuels such as triticale and traditional firewood generally achieve more favourable results than the liquid biofuels for the transportation sector. Still, however, here again no single biofuel can be regarded as “the best” for any of these issues because again the final decision depends upon the subjective judgements of the individual decision maker regarding which of the impact categories is most important.

As a further recommendation it should be pointed out that the respective disadvantages of the various biofuels may possibly change in the future due to further development of the production, conversion and combustion processes, utilisation of by-products etc. These disadvantages are not necessarily inherent characteristics of the biofuel production systems. Rather they are able to be reduced or even avoided altogether. For example, as a result of improved farming methods and technologies, the NH_3 emissions arising from agricultural processes may be reduced and yields may be increased, leading to lower environmental impacts per unit of useful energy. The exact potential for this depends on the specific biofuel however.

Thus while no definitive answer can be given here with regard to which biofuel or fossil fuel is the best, due to the fact that the final decision depends on subjective judgements, the results obtained in this project can be used as an important tool for decision makers.

1 Goals, target groups and general information

Background

The issue of bioenergy production has been discussed within the European Union over a number of years now under various different aspects, ranging from environmental questions to socio-economic ones. The public debate over issues such as the greenhouse effect, ozone layer depletion, acidification etc. led to various international agreements, as for example the Agenda 21 and the Kyoto Protocol, for the expressed purpose of decreasing global environmental impacts in general and greenhouse gas emissions in particular. In its White Paper for a Community Strategy and Action Plan "Energy for the future: renewable sources of energy" (European Commission 1997), the European Commission expressed its intention to contribute to the reduction of greenhouse gas emissions by aiming for a 12 % share of renewable energies compared to total energy consumption until the year 2010. Strategies for achieving this objective outlined in the White Paper stress the importance of biomass, which is likely to contribute most to an overall CO_2-reduction (**Table 1-1**).

Table 1-1 Estimated CO_2-reduction until 2010 (European Commission 1997)

	Biomass	Wind	Small hydro-power	Solar energy	Geo-thermal	Photo-voltaic	Total
Mio t/a	255	72	48	19	5	3	402
Percentage	63 %	18 %	12 %	5 %	1 %	1 %	100 %

Apart from environmental aspects, there are also socio-economic and political aspects to the production of bioenergy, especially with regard to agriculture. Under the Common Agricultural Policy (CAP) it has been agreed to curb surplus production of food within the Community by means of obligatory set-aside land. In this context the production of energy crops on such land can arguably help to maintain otherwise declining farm income.

In the light of these issues, many individual research projects have been carried out concerning the environmental consequences of increased bioenergy production and utilisation at national level, such as Biewenga and van der Bijl (The Netherlands 1996), Wolfensberger and Dinkel (Switzerland 1997) and Reinhardt and Zemanek (Germany 2000). What has been lacking so far however is a comprehensive international investigation of the effects of large scale bioenergy generation within the European Community considering recent ISO 14040 – 14043 standards on environmental life cycle assessment. Furthermore, in order to implement a large scale promotion of bioenergy throughout Europe, it is necessary to establish first of all the economic as well as ecological costs and benefits involved, and secondly, to identify which sources of bioenergy, if any, are the most beneficial ones and the production of which ones is most feasible in each country.

Goals of the study

The present project provides – for the first time – a high quality decision base regarding the environmental effects of the production and utilisation of biofuels in Europe. It is designed to:

- show the environmental advantages and disadvantages of the different biofuels in the various countries involved and the EU, compared to corresponding fossil fuels by means of life cycle analyses
- make comparisons between biofuels within each country and the EU
- make comparisons between countries and the EU for each biofuel
- point out the most favourable biofuels in each country and the European Union respectively, with the help of life cycle analyses and a socio-economic and political analysis

Target group

The main target groups of this study are intended to be relevant decision makers in the European Commission directorates and in national ministries for agriculture, energy and the environment in each country involved. The results may furthermore be relevant to other European countries and organisations as well as other national ministries interested in the aspects of the subject covered here.

Since the project was aimed to produce results on a European level, the emphasis was laid on results relating to whole countries rather than individual regions within countries.

General information on the project

The project was partially funded by the European Community over a period of 2 years (1998–2000) within the framework of the FAIR V program. The remaining funds were provided by various institutions within each respective country. The work carried out by CLM was co-financed by the Dutch Ministry of Agriculture, Nature Management and Fisheries, the Ministry of Housing, Spatial Planning and the Environment, and the Netherlands Agency for Energy and Environment (NOVEM). The contributions of FAT were fully supported by the Swiss Federal Office for Education and Science.

This is a co-operative project involving seven of the EU member states as well as Switzerland, each represented by a relevant scientific institute. These are:

Austria: BLT – Federal Institute for Agricultural Engineering
Denmark: TUD – Technical University of Denmark
France: INRA – National Institute of Agronomic Research
Germany: IFEU – Institute for Energy and Environmental Research Heidelberg (project co-ordinator)
Greece: CRES – Centre for Renewable Energy Sources
Italy: CTI – Italian Thermotechnical Committee
Netherlands: CLM – Centre for Agriculture and Environment
Switzerland: FAL – Swiss Federal Research Station for Agroecology and Agriculture (since Oct. 1999)
FAT – Swiss Federal Research Station for Agricultural Economics and Engineering

The addresses of these institutes can be found in Annex 7.4.

Biofuels under concern

Ten biofuels were investigated that are either cultivated or stem from agricultural or forestry residues. They are listed below. For the various countries different ones of these were investigated. For details see Chapter 2.

- Triticale for co-firing for electricity
- Willow for district heating
- Miscanthus for district heating
- Rape seed oil methyl ester (RME) for transportation
- Sunflower oil methyl ester (SME) for transportation
- ETBE from sugar beet for transportation
- Traditional firewood for residential heating
- Wheat straw for district heating
- Biogas from swine excrements for heat and electricity
- Hemp gasification for electricity

Design of the study

The assessment of the biofuels investigated was carried out using available data in order to carry out complete life cycle analyses (LCA) of the biofuels and fossil fuels respectively. The different countries first identified the most relevant specific biofuels to be investigated. The environmental aspect of this study was done in correspondence with the LCA-standards ISO 14040 – 14043. In agreement with all project partners, a critical external review in accordance with these standards was not carried out.

The biofuels were compared against conventional fossil fuels as well as other biofuels by means of full life cycle analyses based on life cycle inventories and impact assessments. The procedure consisted of the following steps:

- **Preparatory assessment:** this identified all quantifiable results of impact categories and environmental parameters that were scientifically reliable enough to qualify for further assessment.
- **Comparison between biofuels and fossil fuels:** here all biofuels investigated by the respective country and the EU were compared against equivalent types of fossil fuels, e. g. rape seed oil methyl ester (RME) versus conventional diesel.
- **Comparison among different biofuels:** this involved a comparison of all relevant biofuels against each other in order to establish which ones perform best with regard to which parameters and for which purpose (e. g. transportation or heat).
- **Socio-economic and political analyses:** in order to complement the detailed ecological analysis, in this step socio-economic and political analyses were carried out on the basis of a general overview without a claim for completeness. These included e. g. an analysis of the costs involved in producing each biofuel as well as an estimate of the visual impact on the landscape.
- **Conclusions:** these were given in different ways according to the nature of the results. The country specific results were considered as well as the European ones. Specific recommendations for “the one best fuel” could not be made.

The life cycle comparisons considered all processes involved in producing and utilising a particular fuel, which for the agriculturally produced biofuels included the production and application of fertiliser, pesticides, use of machinery etc. as well as so-called reference systems taking into account the use of land if no bioenergy crop is cultivated.

A range of environmental parameters was assessed. These were aggregated into the following impact categories/parameters:

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Nitrous oxide
- Human toxicity

Furthermore, the category biodiversity and soil quality was investigated on the basis of certain quantifiable indicators. The selection of environmental parameters and impact categories is described in Chapters 3.3 and 3.4 respectively.

The focus of this study was not the development of new methodological approaches. Instead, its aim was to provide – for the first time – a comprehensive report covering a wide range of environmental impacts for the most important biofuels for all participating countries of the Community. The conclusions are not intended to provide definitive decisions as to which fuels perform best in an absolute sense, since this is naturally open to subjective judgement, depending on which environmental or other aspects priority is given. The presentation of the results is designed to enable each decision maker to consult a scientifically reliable decision base regarding particular questions related to the substitution of fossil fuels by biofuels.

2 Biofuels under Study

Within Europe, there is a large variety of biofuels with the potential to replace equivalent fossil fuels. In each of the eight participating countries, there are different types of biofuels for which the economical, technical and ecological conditions are suitable with regard to their production.

Some crops can be grown in almost every country, others are being cultivated only in certain countries, due to climatic or cultural conditions. Thus for example wheat straw can be produced in all countries, while sunflowers cannot be cultivated very successfully in northern Europe and was therefore investigated by Greece, Italy and France but not by the other countries. In this chapter, the various production chains are introduced, providing information about:

- which countries investigated which fuels,
- which type of fossil fuel each biofuel was compared to and
- which function the respective fuel is to fulfil (e. g. heat, electricity or transport)

Finally it will be described how the individual comparisons were structured. Due to the limited scope of this report this will be done giving only an overview of the comparisons. For more detailed information on this subject see Annex 7.5.

2.1 Biofuels investigated by the participating countries

Within Europe there is obviously a large variety of climatic and other environmental conditions, which leads to the necessity to investigate different sources of biofuels in different countries, as they all have their particular ecological requirements. Apart from the environmental conditions, other factors such as technical and economic feasibility were taken into account in the choice of biofuel sources for the various countries. Thus only those production lines were considered for which the technology already exists at least in the form of prototypes. Secondly, all those sources of biofuel were excluded for which there was interest in less than three countries. A deliberate exception to this was the inclusion of hemp as a novel production line, which was considered by the Netherlands only. This however was not included in the European assessment. The choice of biofuel production lines for each country was based on expert judgements within each respective country. Due to the lack of objective criteria by which to decide on the question of which biofuels to include in the assessment, the respective country representatives based their choices on professional knowledge as well as communication with national ministries for agriculture, energy and the environment or other institutions where relevant.

Table 2-1 Biofuels investigated by each participating country

Biofuel	Austria	Denmark	France	Germany	Greece	Italy	Netherlands	Switzerland	EU
Cultivated solid biofuels									
Triticale	X	X	X	X					X
Willow		X		X			X		X
Miscanthus		X	X	X			X		X
Cultivated liquid biofuels									
Rape seed (RME)	X	X	X	X				X	X
Sunflower (SME)			X		X	X			X
Sugar beet (ETBE)			X	X			X		X
Biofuels from residues									
Trad. firewood	X					X		X	X
Wheat straw	X	X	X	X	X				X
Biogas	X	X			X	X	X	X	X
Novel production line									
Hemp							X		

The results of previous projects and reports were also taken into consideration in order to find the most adequate sources of biofuel to be assessed in each country. The results of these considerations are given in **Table 2-1**.

The various assessments carried out within each country were then combined in order to obtain average results for the European scenario. These are presented in the Chapters 4.2 and 4.3. The results for each individual country are found in Chapter 7.1 in the Annex. A summary is given in Chapter 4.4.

The comparisons between the biofuels and the fossil fuels depend partly on the intended use of the respective fuel. Thus whether a particular biofuel is compared to diesel fuel, light oil, hard coal or natural gas depends partly on whether it is to be used for transport, for producing heat or electricity. The nine biofuels were compared to the particular fossil fuels listed in **Table 2-2**.

Table 2-2 Investigated biofuels, their utilisation and fossil counterparts

Biofuel	Utilisation	Fossil fuel
Triticale	Co-firing for electricity	Hard coal
Willow	District heating	Light oil and natural gas
Miscanthus	District heating	Light oil and natural gas
Rape seed oil methyl ester (RME)	Transport	Fossil diesel fuel
Sunflower oil methyl ester (SME)	Transport	Fossil diesel fuel
ETBE from sugar beet	Transport	MTBE
Traditional firewood	Residential heating	Light oil and natural gas
Wheat straw	District heating	Light oil and natural gas
Biogas from swine excrements	Heat and electricity	Natural gas
Hemp	Gasification for electricity	Hard coal

The investigated chains differ with regard to the type of energy (i. e. heat, electricity, transportation) and the level of technological development. For space heating, different sources of renewable energy are available, bioenergy being one of them. For electricity generation, high quality fuels and/or expensive technologies are required.

The firewood chain is well established on the market. The technology for ETBE from biomass as an additive for gasoline is already relatively mature and the change from MTBE to ETBE is a feasible one. Due to the high iodine number the car industry avoids the use of sunflower oil methyl ester. Biogas from swine excrements for heat and power is on its way to market establishment. For heat production, willow has reached the pilot stage and wheat straw the slightly more advanced demonstration phase. No proven technology is available for heat from Miscanthus, but this can be expected by 2010. Electricity from triticale and hemp has not been produced yet and the development seems to be uncertain, as the same slagging and corrosion problems can be expected as is the case with straw.

2.2 Principles of the biofuel-fossil fuel comparisons

The comparisons between the various biofuels and their respective fossil counterparts were based on the principle of life cycle assessment (LCA). This involves an assessment of the environmental effects associated with the production as well as utilisation and/or disposal of a certain product. All processes involved are taken into consideration, i. e. “from cradle to grave”. With regard to biofuels from agricultural crops for example this includes the manufacture and application of fertiliser and pesticides, the fuel used in tractors and so on, through to processing and the combustion of the fuel. All these effects are then compared to those arising from the use of fossil fuels. This is done with regard to a number of environmental parameters such as greenhouse gas emissions, acidification, etc. **Figure 2-1** is an example of a schematic life cycle comparison between a biofuel and a fossil fuel. A more detailed description of the parameters involved, the methodology applied and other criteria used within an LCA is given in Chapter 3.

For every biofuel, the whole life cycle was analysed to a high degree of differentiation and in accordance with the ISO 14040 ff. standards. Likewise, the life cycles of the fossil fuels were investigated in detail. An example of a life cycle comparison showing the full details considered within the calculations in this project (e. g. how the system boundaries were chosen etc.) can be found in Chapter 3. Providing this information for all the life cycles investigated within this project would exceed the scope and the objective of this report, but the source for detailed information can be found in Annex 7.5. In this chapter, simplified representations are given of all the biofuel life cycles investigated in this project.

In the following sections the biofuel life cycles are described. They are grouped according to the nature of the production line of the fuels, i. e. whether they stem from solid cultivated raw materials such as Miscanthus, or liquid ones like rape seed oil, or else from residual materials from agriculture or forestry. Finally, the novel production line of hemp is given in a separate section. In all of these life cycle comparisons, the fossil fuels are represented on the left hand side of the diagram. On the right hand side the reference system is given. The reference system defines the indirect effects of the bioenergy production system, which are not covered by the comparison with the fossil fuel directly, such as the use of non-energetic co-products like fodder, which contribute to save conventional resources. It also defines what the land area that is used for biofuel production would be used for in the case of fossil fuel utilisation, i. e. an alternative land use. In this project it is generally taken to be fallow land, because this is considered to be the simplest and most realistic reference system. Furthermore, where relevant, additional environmental "credits" are indicated, which arise from any co-products and result in the potential saving of conventional resources and the effects of their utilisation.

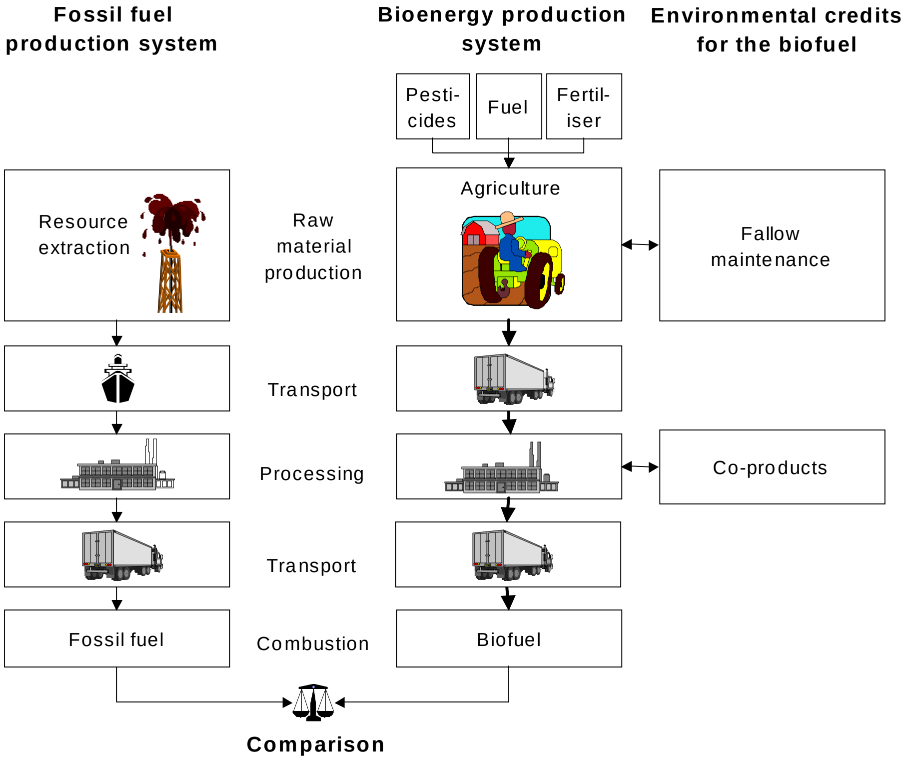


Figure 2-1 Simplified representation of a life cycle comparison between a fossil fuel and a biofuel

2.3 Life cycles of solid biofuels

2.3.1 Triticale (whole crops)

Figure 2-2 shows the life cycle of triticale compared to its corresponding fossil fuel, which is hard coal. The utilisation of the triticale is co-firing of the grain with hard coal for electricity production. The left hand side of the diagram shows the various steps of conventional fuel production, whereas the middle column represents the biofuel chain. On the right hand side the agricultural reference system is shown which is replaced by the triticale production. The maintenance of fallow land is no longer necessary, as instead triticale is cultivated. These factors are described in some more detail below.

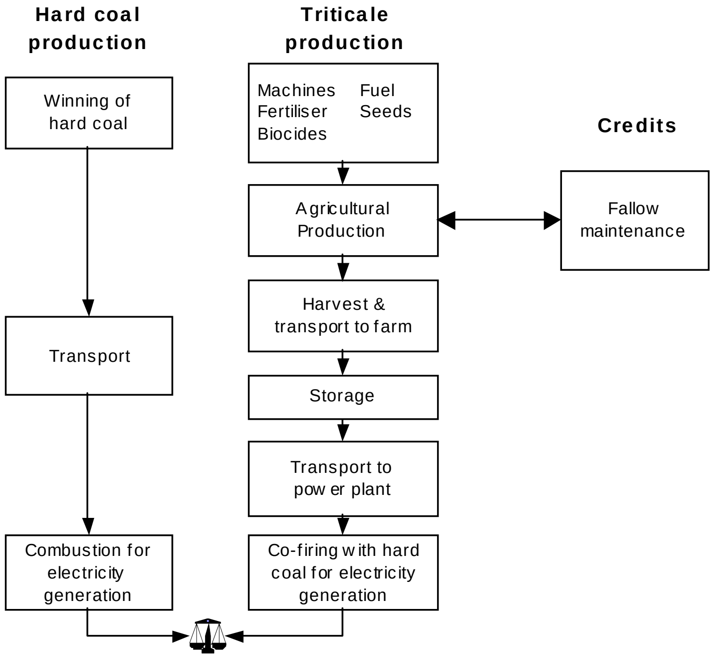


Figure 2-2 Schematic life cycle comparison of whole crops (triticale) versus hard coal

Details of the life cycle steps

Fossil fuel chain: The coal is exploited in USA, Canada, Australia and S. Africa (in equal shares) and transported to Europe using average distances. In Europe the coal is combusted for electricity generation. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: The production, application and partial leaching of agrochemicals such as chemical fertiliser and herbicides are taken into account, assuming good agricultural practice. No pest management is carried out. The use of tractors for field preparation, planting, harvest etc. is also included. The biomass is baled and transported to the farm for storage. From there it is transported to the combustion plant where it is co-fired with hard coal for electricity generation. The effects of the disposal of ash in a landfill site are also taken into account.

Utilisation: Both fuels are balanced with regard to combustion for electricity production on the basis of kWh electricity output.

2.3.2 Short rotation willow coppice

Figure 2-3 shows the life cycle of short rotation willow coppice (SRC) compared to two fossil fuels: light oil and natural gas. The utilisation of the willow is combustion of the chipped wood for district heating.

The left hand side of the diagram shows the various steps of conventional fuel production, whereas the middle column represents the biofuel chain. On the right hand side the agricultural reference system is shown which is replaced by the willow production. In this case maintenance of fallow land is no longer necessary, as instead willow is cultivated. These factors are described in some more detail below.

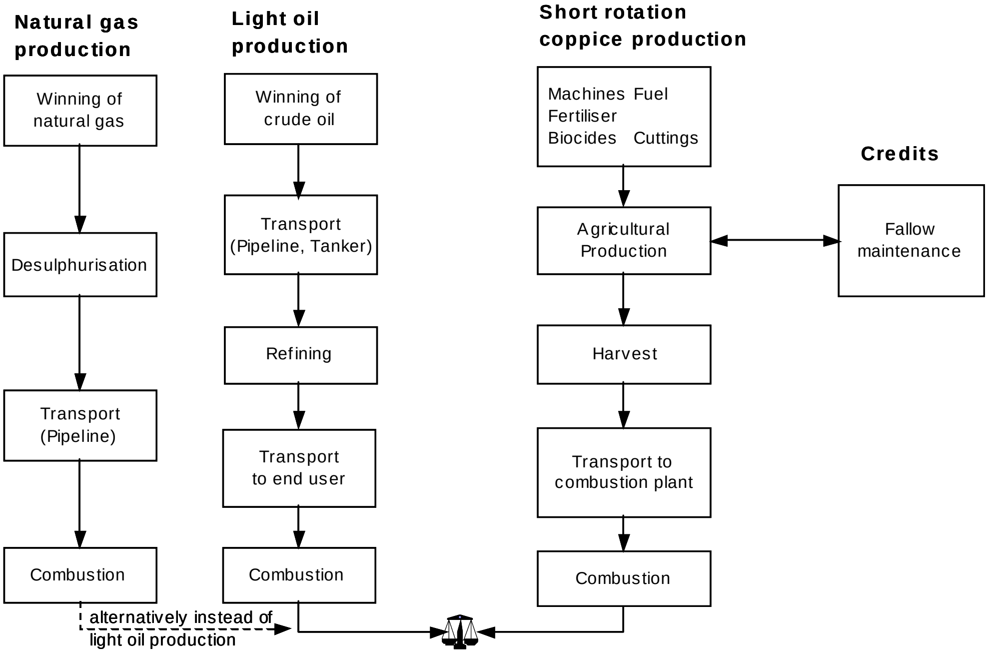


Figure 2-3 Schematic life cycle comparison of short rotation willow coppice (SRC) versus light oil and natural gas respectively

Details of the life cycle steps

Fossil fuel chain: The crude oil is extracted in OPEC-countries and transported to Europe using average distances. In Europe the oil is refined in order to produce light oil for combustion in heating plants. The alternative fossil fuel chain is that for natural gas. In this case the gas is exploited in Norway and the Confederation of Independent States (in equal shares) transported and compressed, processed and distributed to the end user. Combustion takes place in small-scale residential heating systems. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: The production, application and partial leaching of agrochemicals such as chemical fertiliser and herbicides are taken into account, assuming good agricultural practice. The use of tractors for field preparation, planting, harvest etc. is also included, as is the production and transport of the cuttings. The willow is left to grow for 4 years before the first harvest and is then harvested every 3 years until the field is ploughed again after 20 years. The impacts of harvest etc. are averaged over the lifetime of the crop in order to obtain annual values. The wood is chipped and the chips are finally stored and transported before combustion. The effects of the disposal of ash are also taken into account.

Utilisation: All three fuels are balanced with regard to combustion for district heating on the basis of MJ heat output.

2.3.3 Miscanthus

Figure 2-4 shows the life cycle of Miscanthus compared to two fossil fuels: light oil and natural gas. The utilisation of the Miscanthus is combustion for district heating.

The left hand side of the diagram shows the various steps of conventional fuel production, whereas the middle column represents the biofuel chain. On the right hand side the agricultural reference system is shown which is replaced by the Miscanthus production. In this case maintenance of fallow land is no longer necessary, as instead Miscanthus is cultivated. These factors are described in some more detail below.

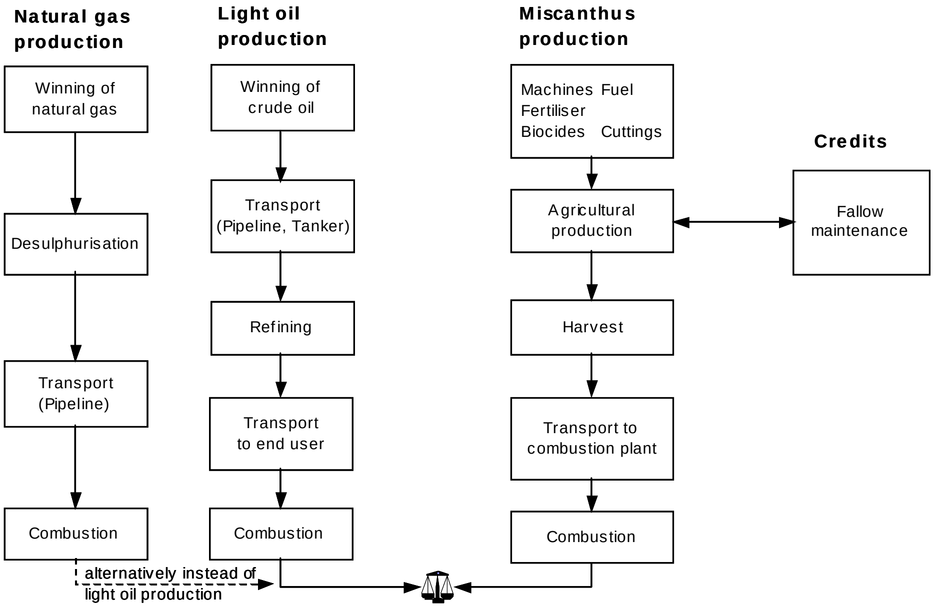


Figure 2-4 Schematic life cycle comparison of Miscanthus versus light oil and natural gas respectively

Details of the life cycle steps

Fossil fuel chain: The crude oil is extracted in OPEC-countries and transported to Europe using average distances. In Europe the oil is refined in order to produce light oil for combustion in heating plants. The alternative fossil fuel chain is that for natural gas. In this case the gas is exploited in Norway and the Confederation of Independent States (in equal shares) transported and compressed, processed and distributed to the end user. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: The production, application and partial leaching of agrochemicals such as chemical fertiliser and herbicides are taken into account, assuming good agricultural practice. The use of tractors for field preparation, planting, harvest etc. is also included, as is the production and transport of the cuttings. The Miscanthus is left to grow for 2 years before the first harvest and is then harvested every year until the field is ploughed again after 16 years. Weed control is only required in the first year and fertilising starts in the second year. The impacts of these processes are averaged over the lifetime of the crop in order to obtain annual values. The crop is chopped and transported to the combustion plant where it is burnt and the ash is disposed of in a landfill.

Utilisation: All three fuels are balanced with regard to combustion for district heating on the basis of MJ heat output.

2.4 Life cycles of liquid biofuels

2.4.1 Rape seed oil methyl ester (RME)

Figure 2-5 shows the life cycle of rape seed oil methyl ester (RME) compared to its corresponding fossil fuel, which is conventional diesel fuel for utilisation in transport vehicles. The raw material for RME is rape seed oil. The left hand side of the diagram shows the various steps of conventional fuel production, whereas the middle column represents the biofuel chain. On the right hand side the equivalent conventional processes are shown which are being replaced as a consequence of the biodiesel production – i. e. these can be regarded as “credits” because the environmental effects arising through them can be “saved”. For example maintenance of fallow land is no longer necessary, as instead rape seed is cultivated.

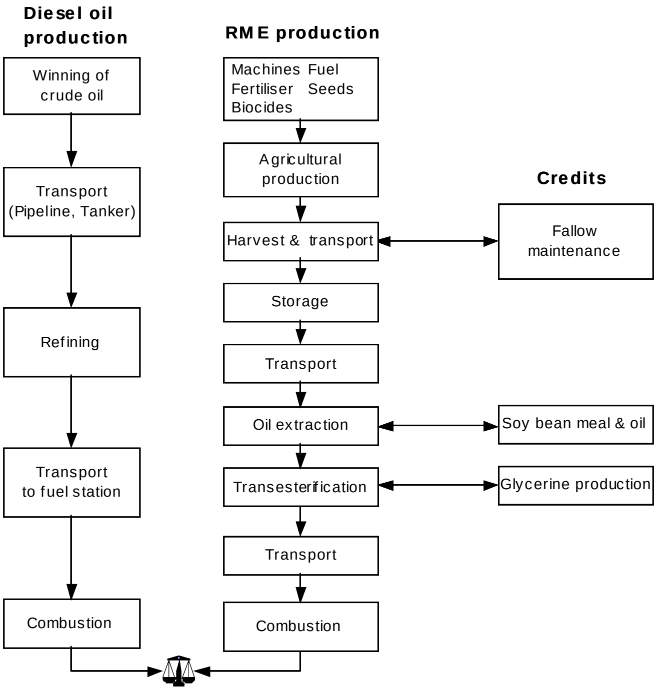


Figure 2-5 Schematic life cycle comparison of rape seed oil methyl ester (RME) versus diesel oil

Details of the life cycle steps

Fossil fuel chain: The crude oil is extracted in OPEC-countries and transported to Europe using average distances. In Europe the oil is refined in order to produce standard diesel fuel for combustion in transport vehicles. Then again the fuel undergoes transport until it has reached the filling station. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: The production, application and partial leaching of agrochemicals such as chemical fertiliser and herbicides are taken into account, assuming good agricultural practice. The use of tractors for field preparation, sowing, harvest etc. is also included, as is the production and transport of the seeds. The oil is extracted from the harvested seeds, producing rape seed meal as a co-product. Both the oil and the meal substitute soy bean oil and meal from production in Brazil. The oil is refined and undergoes transesterification with the use of potassiumhydroxid, methanol and acid – the production and disposal of which are all taken into account. The transesterification process leads to glycerine as a further co-product, substituting conventional glycerine production. Finally, the crude rape seed oil methyl ester is purified, distributed and combusted.

Utilisation: The comparison is based on the utilisation of both types of fuel in a passenger car according to the EURO-4 emission standard obligatory up from 2005. The reference unit is one kilometre of distance driven.

2.4.2 Sunflower oil methyl ester (SME)

Figure 2-6 shows the life cycle of sunflower oil methyl ester (SME) compared to its corresponding fossil fuel, which is conventional diesel oil for utilisation in transport vehicles. The raw material for SME is sunflower oil. The left hand side of the diagram shows the various steps of conventional fuel production, whereas the middle column represents the biofuel chain. On the right hand side the equivalent conventional processes are shown which are being replaced as a consequence of the biodiesel production – i. e. these can be regarded as "credits" because the environmental effects arising through them can be "saved". For example maintenance of fallow land is no longer necessary, as instead rape seed is cultivated.

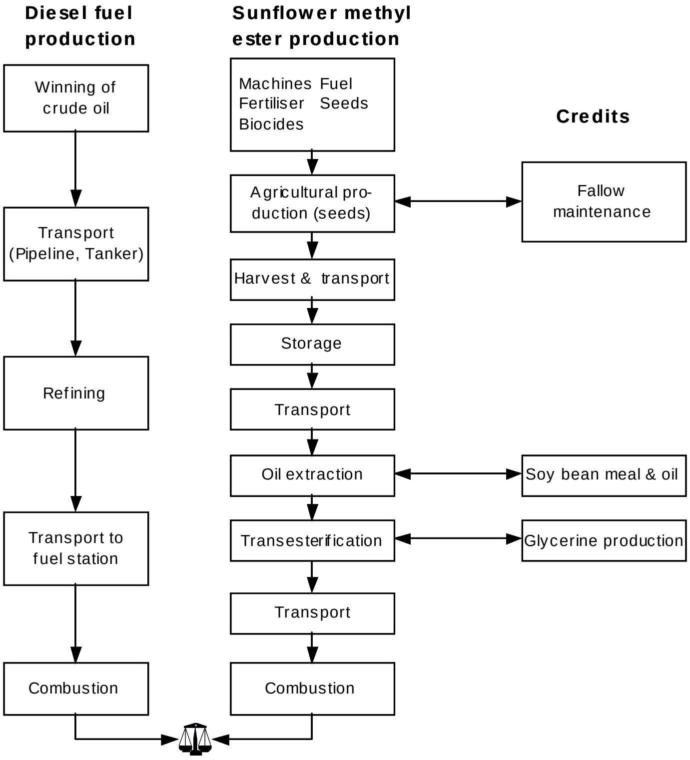


Figure 2-6 Schematic life cycle comparison of sunflower oil methyl ester (SME) versus diesel oil

Details of the life cycle steps

Fossil fuel chain: The crude oil is extracted in OPEC-countries and transported to Europe using average distances. In Europe the oil is refined in order to produce standard diesel fuel for combustion in transport vehicles. Then again the fuel undergoes transport until it has reached the filling station. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: The production, application and partial leaching of agrochemicals such as chemical fertiliser and herbicides are taken into account, assuming good agricultural practice. The use of tractors for field preparation, sowing, harvest etc. is also included, as is the production and transport of the seeds. The harvested seeds are transported and stored. Then they are transported to the oil mill where the hulls are removed and used for electricity generation. The oil is extracted from the seeds and the meal which is obtained as a co-product is used for animal feed, substituting soy bean meal. The oil is refined and undergoes transesterification. The transesterification process leads to glycerine as a further co-product, substituting conventional glycerine production. Finally, the crude sunflower oil methyl ester is purified, distributed and used for combustion in diesel engines.

Utilisation: The comparison is based on the utilisation of both types of fuel in a passenger car according to the EURO-4 emission standard obligatory up from 2005. The reference unit is one kilometre of distance driven.

2.4.3 ETBE from sugar beet

Figure 2-7 shows the life cycle of ETBE (ethyl-tertiary-butyl-ether). The corresponding fossil fuel is MTBE for utilisation in transport vehicles. ETBE is produced from sugar beets. The left hand side of the diagram shows the various steps of conventional fuel production, whereas the middle column represents the biofuel chain. On the right hand side processes are shown which are counted as “credits” for the biofuel system. Thus for example the maintenance of fallow land is no longer necessary, as instead sugar beet is cultivated. These factors are described in some more detail below.

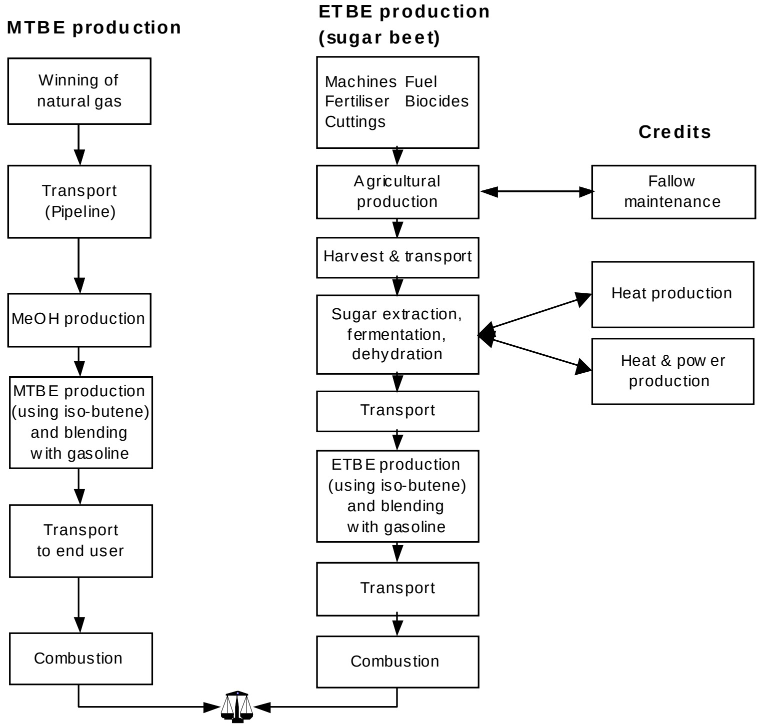


Figure 2-7 Schematic life cycle comparison of ETBE versus MTBE

Details of the life cycle steps

Fossil fuel chain: MTBE is produced from oil and natural gas. The crude oil and natural gas are exploited and transported to Europe, where the oil is refined to produce iso-butene (besides other fuels) and the gas is used to produce methanol. These two are processed to obtain MTBE, which is blended with gasoline for combustion in car engines. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: The production, application and partial leaching of agrochemicals such as chemical fertiliser and herbicides are taken into account, assuming good agricultural practice. The use of tractors for field preparation, sowing, harvest etc. is also included, as is the production and transport of the seeds. The beets are harvested and transported, while the leaves are left in the field. The sugar is extracted from the beets and fermented to produce ethanol, which is distilled and dehydrated. The remaining slop is fermented to give biogas for heat production and the chips are used for heat and power production, substituting conventional heat and power production. The ethanol is transported to the refinery and ETBE is produced from this and iso-butene. Finally it is blended with gasoline for combustion in car engines.

Utilisation: The comparison is based on the utilisation of both types of fuel in a passenger car according to the EURO-4 emission standard obligatory up from 2005. The reference unit is one kilometre of distance driven.

2.5 Life cycles of biofuels from residues

2.5.1 Traditional firewood

Figure 2-8 shows the life cycle of traditional firewood from forestry residues in form of wood logs. A comparison was carried out with two fossil fuels: light oil and natural gas. The utilisation of the firewood is for residential heat production.

The left hand side of the diagram shows the various steps of conventional fuel production, whereas the right hand column represents the biofuel chain. These factors are described in some more detail below.

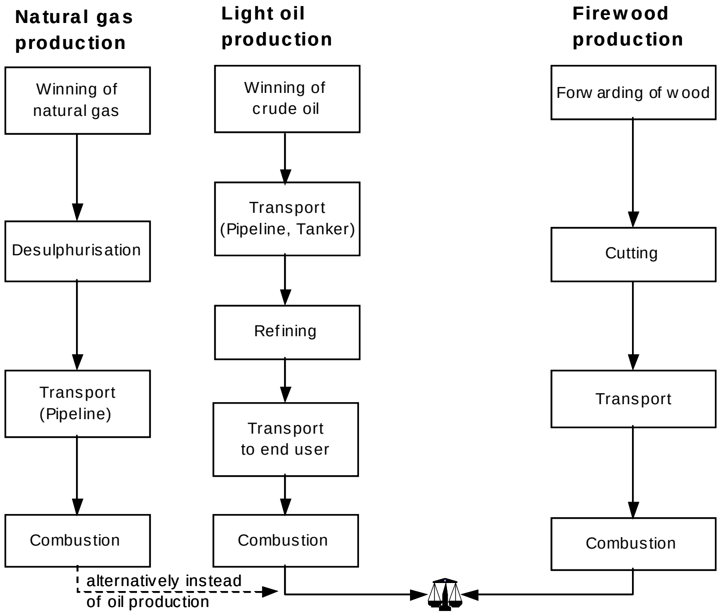


Figure 2-8 Schematic life cycle comparison of firewood for heat production versus light oil and natural gas respectively

Details of the life cycle steps

Fossil fuel chain: The crude oil is extracted in OPEC-countries and transported to Europe using average distances. In Europe the oil is refined in order to produce light oil for combustion in heating plants. The alternative fossil fuel chain is that for natural gas. In this case the gas is exploited in Norway and the Confederation of Independent States (in equal shares) transported and compressed, processed and distributed to the end user. Combustion takes place in small-scale residential heating systems. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: Since firewood is a residue of forestry, there are no credits to be taken into account. The reference system in this case is to leave the wood in the forest. Therefore only the additional processes associated with firewood production are considered: the wood is forwarded to a storage place, cut and transported to the end user.

Utilisation: All three fuels are balanced with regard to combustion for residential heating on the basis of MJ heat output.

2.5.2 Wheat straw

Figure 2-9 shows the life cycle of wheat straw from crop residues. A comparison was carried out with two fossil fuels: light oil and natural gas. The utilisation of the wheat straw is combustion for district heating.

The left hand side of the diagram shows the various steps of conventional fuel production, whereas the right hand column represents the biofuel chain. These factors are described in some more detail below.

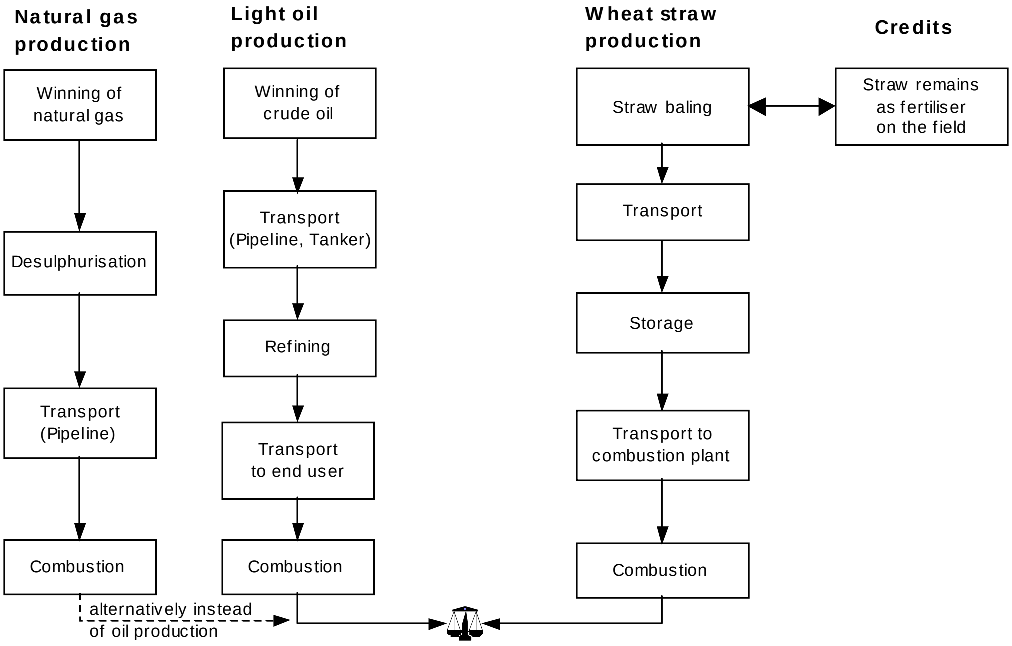


Figure 2-9 Schematic life cycle comparison of wheat straw for heat production versus light oil and natural gas respectively

Details of the life cycle steps

Fossil fuel chain: The crude oil is extracted in OPEC-countries and transported to Europe using average distances. In Europe the oil is refined in order to produce light oil for combustion in heating plants. The alternative fossil fuel chain is that for natural gas. In this case the gas is exploited in Norway and the Confederation of Independent States (in equal shares), transported and compressed, processed and distributed to the end user. Combustion takes place in small-scale residential heating systems. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: Since wheat straw is a co-product of grain production, the effects of agricultural production are not taken into account. The reference system is to leave the straw in the field as a fertiliser. Only the additional processes associated with wheat straw utilisation are considered, such as baling, storage and transport. The disposal of the ash is also taken into account.

Utilisation: All three fuels are balanced with regard to combustion for residential heating on the basis of MJ heat output.

2.5.3 Biogas from swine excrements

Figure 2-10 shows the life cycle of biogas from swine excrements. The utilisation of the biogas is for energy production (both heat and electricity). The corresponding conventional energy source is natural gas.

The left hand side of the diagram shows the various steps of conventional fuel production, whereas the right hand column represents the biofuel chain. In the case of the biofuel production the fermented slurry can be sprayed onto the field as fertiliser as would happen in the case of fossil fuel production. The difference in the environmental impact would in this case be mainly due to transport.

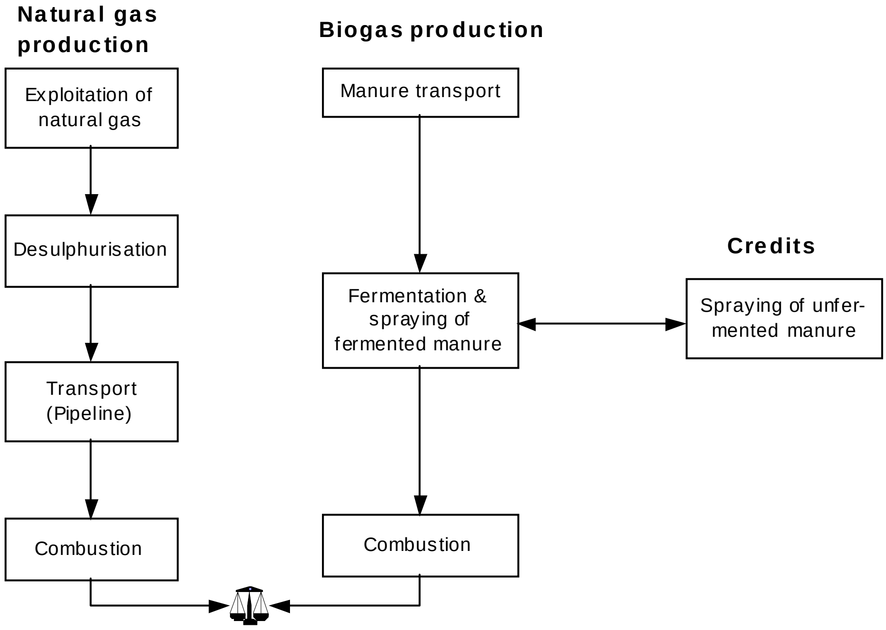


Figure 2-10 Schematic life cycle comparison of biogas from swine excrements versus energy production from natural gas

Details of the life cycle steps

Fossil fuel chain: Natural gas is assumed to be extracted in Norway and the Confederation of Independent States respectively and transported from there with shares of 50 % each. It is then processed and transported to the combustion plants. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: Since swine manure is a by-product of food production, the agricultural effects are in this case not taken into account. The reference system in this case is the utilisation of the manure as a fertiliser. Therefore only the additional processes associated with biogas production are considered, such as its fermentation. The spraying of the fermented slurry as manure and associated differences in transportation are also considered.

Utilisation: Both fuels are balanced with regard to combustion in a combined heat and power plant on the basis of MJ heat output.

2.6 Novel production line: electricity from hemp

Figure 2-11 shows the life cycle of power from hemp. The corresponding fossil fuel is hard coal. The utilisation of the hemp is the gasification and combustion of the stems for electricity production. The left hand side of the diagram shows the various steps of conventional fuel production, whereas the middle column represents the biofuel chain. On the right hand side the agricultural reference system is shown which is replaced by the hemp production. In this case the maintenance of fallow land is no longer necessary, as instead hemp is cultivated. These factors are described in some more detail below.

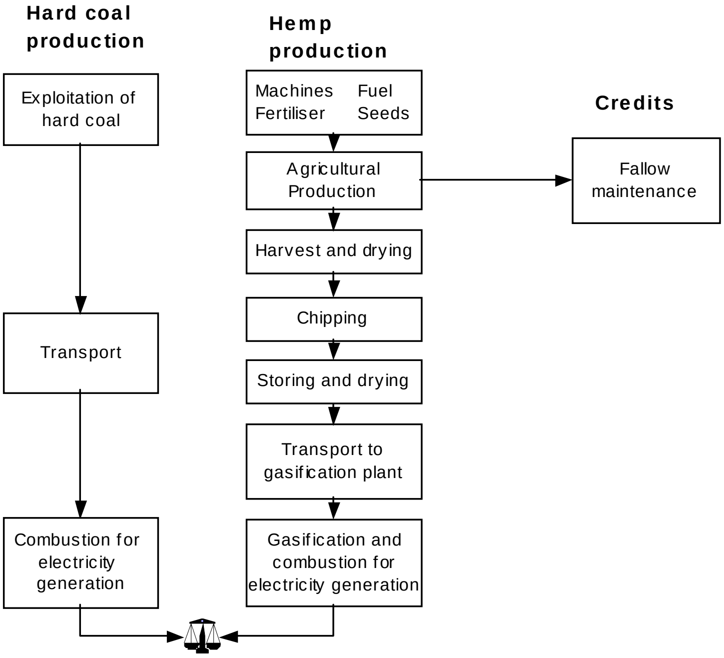


Figure 2-11 Schematic life cycle comparison of hemp versus hard coal

Details of the life cycle steps

Fossil fuel chain: The coal is exploited in USA, Canada, Australia and S. Africa (in equal shares) and transported to Europe using average distances. In Europe it is combusted for electricity generation. These assumptions are based on expert judgements and are considered to represent the marginal technology.

Biofuel chain: The production, application and partial leaching of agrochemicals such as chemical fertiliser and herbicides are taken into account, assuming good agricultural practice. No plant protection measures are carried out. The use of tractors for field preparation, planting, harvest etc. is included. The stems are dried in the field, chipped and transported to the gasification plant where they are stored before gasification and combustion for electricity production. The effects of the disposal of ash are also taken into account.

Utilisation: Both fuels are balanced with regard to combustion (with prior gasification in the case of hemp) for electricity generation on the basis of kWh electricity output.

3 Life cycle assessment of biofuels: methods and tools

3.1 Life cycle assessment – an overview

Life cycle assessment (LCA) is an environmental assessment methodology which analyses all resource requirements (energy, water, etc.) and material flows (inputs and outputs, co-products, emissions, etc.) of a product system. Fields of application are product development and improvement, strategic planning, marketing and public policy making. LCA is one of several environmental management techniques. It typically does not address the economic or social aspects of a product. Generally, the information obtained from an LCA should be used as part of a much more comprehensive decision process or used to understand the broad or general trade-offs involved. Comparing the results of different LCA studies is only possible if the assumptions and context of each study are the same. In addition to an LCA, in this project a socio-economic and political analysis has also been carried out.

LCA is performed according to the principle summarised by the expression “from cradle to grave”, i. e. all previous stages of the input production up to the extraction of the natural resources on the one hand and all subsequent stages of an output after it goes out of the system on the other hand are included. The calculated results are expressed in terms of a measure reflecting the usefulness of the product system (the so-called functional unit).

LCA distinguishes itself from other environmental evaluation methods by its holistic character. Errors of interpretation due to a partial environmental analysis should be avoided. LCA is still the only international standardised method to assess environmental performances of product systems (ISO 14040 up to 14043). There is a general consensus to aggregate the environmental impacts of the emissions and the resource use into scientifically sound impact categories (like energy resources, greenhouse potential, eutrophication etc.). On the other hand, there is no general agreement on a further aggregation of the impact categories, and each LCA has to present its own interpretation scheme. The categories soil quality, biodiversity and landscape are often neglected and methodological development is still required for a proper inclusion.

An LCA is structured into four phases (see also **Figure 3-1**):

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Interpretation

These will each be described in brief in the sections below.

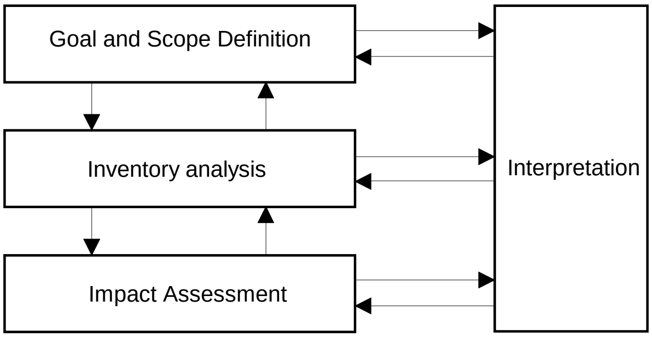


Figure 3-1 Components of a product life cycle assessment according to EN ISO 1997

For all phases of the LCA, the ISO norm stresses the importance of an objective, transparent and complete reporting. Methodological decisions as well as data collection must be completely transparent. For this reason all methodological procedures as well as all basic data used in this study were clearly and comprehensively documented. Furthermore all intermediate calculations and all result tables were included in the documentation. Further information on this can be found in Annex 7.5.

Goal and scope definition

In this first phase all the assumptions made are defined and the framework of the LCA, including methodological aspects, is set up. The main points covered in this step are:

- the goal of the LCA; reasons for carrying out the study
- the target group
- the function(s) of the investigated systems
- the functional unit
- the system boundaries, i.e. the level of detail considered, the time frame etc.
- allocation procedures
- the choice of the types of impact and the methodology to be used for impact assessment and subsequent interpretation
- requirements on data quality
- consistency of the comparison (if applicable)
- type of critical review (if applicable)

Inventory analysis

In the inventory analysis all inputs and outputs are first quantified (according to mass, volume etc.) and then expressed in terms of the functional unit. For practical reasons, efforts are focused on the investigated product system – the main life cycle – for which data must be collected. For common input data, standardised information can be used. In some extreme cases, inputs or outputs of small environmental importance may be neglected.

In a second step, all resources and emissions linked with the material flows are quantified. Regarding the emissions, as well those directly occurring in the product system (for example nitrate leaching by rape seed cropping) as those linked with the input production (for example nitrous oxide while producing the electricity needed for the manufacture of mineral fertilisers) are quantified.

Impact assessment

In the inventory analysis, numerous parameters may be investigated regarding emissions to the environment (e. g. CO_2, CH_4, N_2O etc.) or types of resource utilisation (e. g. fossil fuels) as discussed in Chapter 3.4.2. In the impact assessment phase, these are first aggregated into up to fifteen impact categories according to scientific criteria (also given in the tables mentioned above). For example, carbon dioxide and methane emissions are aggregated to a single figure reflecting their impact on global warming. Each impact category corresponds to an important environmental problem (eutrophication, depletion of non renewable energy resources, ozone depletion, etc.). There is no standardised list of impact categories. The latter are to be chosen and defined on the basis of their relevance to the investigated product system and the level of scientific knowledge.

In a second step, the results of each impact category can be normalised, i. e. referred to national data in order to assess their country specific relevance compared to the national total impact. This method is optional and has in this project been applied to the results for Europe and certain individual countries (see also Chapter 3.4.4 on “Normalisation”). Because of a very weak scientific soundness, the next optional step – the weighting – which consists of attributing different weights to impact categories according to their fundamental environmental relevance is not performed here.

Interpretation

In the interpretation phase, all results of the first three stages are verified and qualified with the help of different controlling tools. In the present study, two tools are used:

- Uncertainty analysis of the MonteCarlo type in order to assess the propagation of the numerical uncertainty of all the data used (described in Chapter 3.3.2)

- Sensitivity analysis to assess the influence of some methodological assumptions (for example an allocation procedure) on the results (described in Chapter 3.3.3).

In this study, these elements are discussed within the context of the inventory analysis (Chapter 3.3). The interpretation phase concentrates in this case on the comparison of the fossil fuels versus the biofuels and the biofuels among each other (see Chapter 3.5). This includes a description of how the presentation of the results is structured and how they should be interpreted.

The following chapter deals with the main methodological aspects of the study. When some elements of the method are reported in other parts of the report for more convenience, there will be an indication at the beginning of the corresponding chapter. In order to keep the text length to an appropriate size, it will be focused on the specificities of the present study. For more detailed aspects, the reader is referred to the literature quoted.

3.2 Scope definition of the investigated biofuels

The main aspects of the goal and scope definition phase are described hereafter. For the goal of the study, the reasons for carrying it out as well as the intended target groups, the reader is referred to Chapter 1.

3.2.1 Functions of the production systems

ISO 14040 defines the function as the performance of a production system in a life cycle assessment. Since agriculture and forestry are multi-purpose, their products can fulfil several functions. The following criteria were considered in order to determine the functions relevant in this project:

- Goals and scope of the study
- Motivation of the target groups when promoting biofuels
- Motivation of the direct actors when implementing biofuels.

From most people’s point of view, the primary purpose of the investigated biofuels is providing renewable energy. This function implies the comparison with fossil fuels and is the main motivation for the target groups coming from the field of energy and the environment. As the consumption of the energy is included in the product system because of its ecological relevance, the correct function is “provision of useful energy”. This is the primary function used in this study.

In some cases, two additional functions (so-called secondary functions) may also be fulfilled by biofuels:

- The function “treatment of agricultural and forestry residues” is relevant because biofuel production not only provides energy but can also improve the properties of the considered biomass significantly (e.g. by combustion). Moreover, in many cases the treatment results in a higher income for the farmer and less problems with the disposal of a residue. This function is only analysed when the biofuel production contributes to a significant improvement of the considered biomass.
- The functions “preservation of land under agricultural practice for social and food security reasons” was chosen from the farmers’ and agricultural sector’s view. Energy crops fulfil this function as well. This function is the point of interest for the target group agricultural ministries and concerns only the agricultural energy crops. (Note: there was no conclusive agreement on this by all institutes involved. However, this affected neither the methodologies chosen, nor the system boundaries and other definitions, nor the results.)

To sum up, the main function for all biofuels is the provision of useful energy and the reference system used for the comparison fulfils the same function with fossil fuels. In some specific cases, secondary functions must be considered. The procedure described in § 5.2.2 of the ISO Norm 14041 of associated reference systems is applied to take them correctly into account. An associate reference system complements the reference system used for the comparison in order to ensure the equivalence of the systems compared (in this case biofuels and fossil fuels). For the function “treatment of agricultural and forestry residues”, the associate reference system is the alternative way of handling the biomass. For the function “preservation of land under agricultural practice for social and food security reasons”, an agricultural reference system is considered as associate reference system (see also the representations of life cycle comparisons in Chapter 2).

As already discussed in Gaillard (1996) or Biewenga and van der Bijl (1996) and practised in several studies on biofuels, this way is equivalent to a procedure of avoiding allocation with help of a system expansion (see Chapter 3.2.4), where what it is called here a secondary function would be in reality a co-product. There is no objective reason to theoretically prefer one or the other way of presentation – also because the exact nature of the biofuel under investigation plays a role – and that the end result is the same for the two theoretical options. The economic aspects of the secondary functions are not considered within this part of the discussion. They are dealt with in Chapter 5.2.

The detailed list of the functions considered for each investigated biofuel chain and the corresponding reference systems used for the comparisons are given in the Chapters 2.3 to 2.6.

3.2.2 Functional and reference units

The functional unit expresses the performance of a system and serves as a reference unit for environmental impacts. The chosen functional unit of 1 MJ useful energy is based on the main function "provision of useful energy". Since however the various biofuels fulfil different specific purposes – such as heat production, electricity production or transportation – the results can also be expressed in terms of units that express such functions. Table 3-1 below lists such reference units as they are used for the European results and a number of individual countries within this project. For further explanations of these units see also Chapter 3.4.4.

Table 3-1 Functional units for each biofuel chain under concern

Biofuel	Functional unit
Triticale for co-firing for electricity	1 kWh electricity
Willow for district heating	1 MJ heat
Miscanthus for district heating	1 MJ heat
RME for transportation	1 km distance driven
SME for transportation	1 km distance driven
ETBE for transportation	1 km distance driven
Traditional firewood for residential heating	1 MJ heat
Wheat straw for district heating	1 MJ heat
Biogas from swine excrements	1 MJ useful energy (heat and electricity)*
Hemp gasification for electricity	1 kWh electricity

*during biogas combustion in a CHP (combined heat and power) plant, electricity is produced alongside with heat. In this study the total energy production has been balanced.

For the comparison of different biofuels among each other, two further reference units were used, namely "ha of land" for the comparison with regard to efficiency of land utilisation and "MJ of energy saved" with regard to the saving of energy resources respectively (see Chapter 4.2).

Units of the secondary functions "treatment of agricultural and forestry residues" and "preservation of land under agricultural practice for social and food security reasons" are kg respectively ha.

For the inventory analysis, when collecting, validating and presenting the data for the unit processes dealing with biomass production, the unit ha is much more practical than the functional unit MJ. The energy yield of the investigated biofuel chain is used in order to convert the results into the chosen functional unit.

3.2.3 System boundaries and unit processes

For the determination of the system boundaries a standard procedure was defined and applied to all investigated chains (biofuel production systems as well as reference systems used for the comparison) regarding the initial definition and inclusion of the unit processes, the standardisation of the input processes and the level of detail.

Fundamentally, all processes of the life cycle of the investigated products (biofuel and fossil fuel) are involved in the scope of the study. The following exceptions were made:

- Human labour
- Inputs whose mass is negligibly low compared to the total input mass, provided that they have no well-known environmental impact (for example pesticides were always analysed).

In short, the boundaries of the product system contain all unit processes needed for the provision of useful energy in form of biofuel or fossil fuel, including waste management. These unit processes are analysed in detail in accordance with the ISO Norm 14041. In this way, a chain contains various unit processes whose quantification is specific for each country.

Standardised process units for all countries and product systems under study were considered for items which are not specific to the biofuel chains (for example provision of energy, provision of raw materials, production of inputs and transport to the product system). Construction of machinery and other infrastructure directly used for the product systems are included in the corresponding unit processes.

A list of relevant resources and emissions was drawn up (see Tables 3-2 and 3-3 in Chapter 3.4.3) depending on the environmental relevance, the presence of corresponding impact assessment coefficients and the data availability. Background depositions of heavy metals and nitrogen on agricultural fields are included to calculate the corresponding field emissions. Concerning global warming, CO_2 from the atmosphere and the CO_2 storage effect are not taken into account. Regarding the non-inclusion of certain impact assessment categories, see Chapter 3.4.1. **Figure 3-2** shows the level of differentiation at which the various elements of the systems were considered.

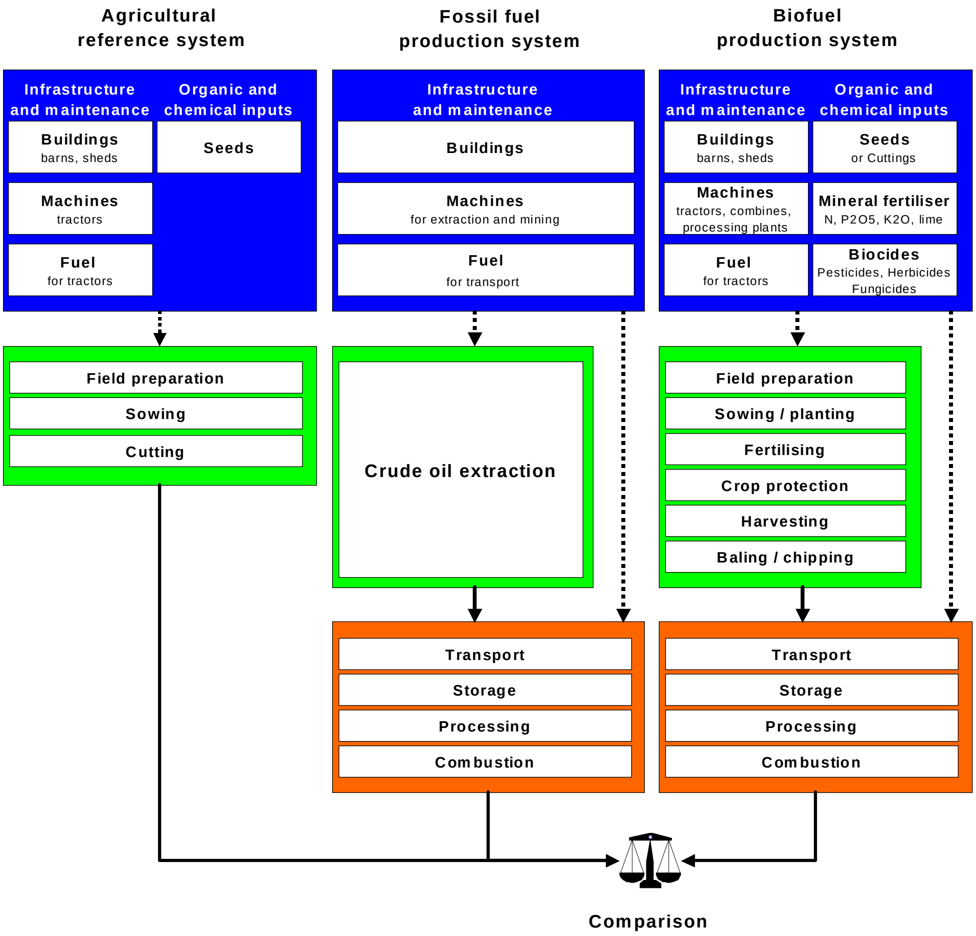


Figure 3-2 Schematic representation of a life cycle comparison showing the level of detail considered. The example chosen here is that of oil from fossil resources and a cultivated biofuel.

With regard to agricultural production, soil can be regarded as playing two distinct roles: on the one hand, it belongs to the investigated product system, comparable to a factory in an industrial process. On the other hand, soil is part of the environment and therefore an alteration of its quality should be assessed in an LCA. In this study, only those alterations were considered, which are observed between the beginning and the end of the cropping period (time related system boundaries). So for example the effects of emissions of pollutants which stay in the soil after cropping must be assessed. The difficulties encountered in the development of the impact category soil quality (see Chapter 3.4) did not allow a more profound way of handling this issue.

3.2.4 Treatment of by-products and allocation procedures

The system comparisons carried out here are made on the basis of a certain main function, i. e. the provision of energy. However, in a complex system like agriculture or forestry, other processes can fulfil secondary functions and products. Thus for example in the case of RME production from rape seed, glycerine is also being produced. In order to allow a meaningful comparison between diesel fuel and RME, this has to be taken into account. One way of doing this is by the method of allocation.

The aim of allocation is to take into account to which extent a product of a multi-output process is responsible for the total of the environmental interventions of this process. For the following unit processes allocation procedures are required:

- Coupled products not directly investigated in this study, respectively secondary functions of the biofuels not considered in the reference systems: extracted rape seed meal, P-fertiliser, glycerine, extracted sunflower meal, sugar beet chips and slop (leftover of the fermentation of sugar beet)
- Coupled products under study: traditional firewood and wheat straw
- Special inputs from other systems: liquid swine manure for biogas
- Inputs shared between several systems: machinery and buildings.

According to ISO 14041, allocation should be avoided wherever possible. If allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way which reflects the underlying physical relationship between them.

Avoiding allocation

Although ISO 14040 states that the whole life cycle shall be studied, it is however possible to avoid allocation by omitting certain stages of the life cycle if this does not change the outcome (ISO 14041). Those unit processes that are of equal quality and quantity both in the energy chain and the reference system are therefore left out in this study. With regard to the fuel chains listed below, the following products and processes are not included in the analysed systems:

- Traditional firewood: recreation, protection, conservation, forest residues, wood for construction, forest establishment and maintenance, felling and debranching
- Wheat straw: grain, wheat growing, harvest
- Liquid swine manure: products from livestock keeping.

For the following allocation cases, system expansion is used:

- Glycerine: with petrochemically produced glycerine (Reinhardt and Zemanek 2000)
- P-fertiliser: with mineral fertiliser on the basis of the plant available nutrient content
- Extracted rape seed meal: it is used as protein component in livestock feed and substitutes soy meal. In the procedure described below (Weidema 1999) no more allocation between soy meal and its by-product soy oil is needed. The system expansion is based on the preconditions that

  a) soy meal is the marginal protein fodder and rape seed oil is the marginal edible oil on the market
  b) rape seed contains 40 % oil and 20 % raw protein in the dry matter and that soy bean contains 17 % oil and 34 % raw protein in the dry matter
  c) the raw protein and the oil in both rape seed and soy bean are substitutable in the marginal application

  Per 5 kg rape seed produced an additional production of 1.66 kg rape seed is added. Then a system expansion with 3.91 kg soy bean is made (see Figure 3-3).

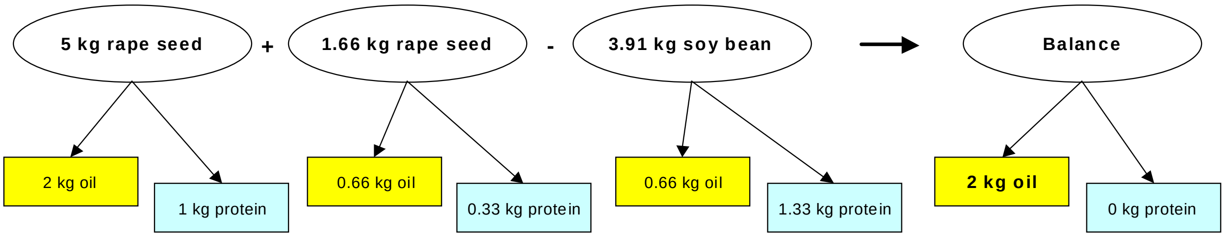


Figure 3-3 System expansion for rape seed with the purpose of avoiding allocation regarding soy bean oil and protein

- Extracted sunflower meal: the system expansion is performed according to the same principle as for extracted rape seed meal. Yet per 4.33 kg sunflower produced the production of 1.66 kg of rape seed is added. Then a system expansion with 3.91 kg soy bean is made.
- Regarding sugar beet, a system expansion is likewise carried out, considering the following processes: after sugar extraction the chips are used for the production of electricity and heat (system expansion with natural gas). The remaining slop is used for the production of heat only.

Allocation according to physical relationship

For the following items, it was not possible to avoid an allocation procedure:

- For tractors, allocation according to the hours of work compared to the total work hours of life is made (Audsley et al. 1997; Wolfensberger and Dinkel 1997). Other machines (ploughs etc.) are allocated according to the units worked compared to units worked during the machines life (Gaillard et al. 1997).
- For agricultural buildings allocation according to the space of the machine occupied compared to the total space of the building on the basis of machine working hours is performed (see Annex 7.5 for the equation).

3.2.5 Data specifications

Time related coverage

This project intends to cover the second half of the first decade of the 21st century with reference to the year 2010. The duration of the agricultural reference systems is considered in accordance with the growing time of the energy crop.

Geographical coverage

The results are valid only for the involved countries and the EU respectively. All the unit processes for the product systems and the outputs to technosphere and environment are specific to the individual countries, whereas all inputs from technosphere are European standard processes.

Technological coverage

In general, a specific product can be produced by means of various technologies. This is true for most of the steps of the life cycles under study here (biogen and fossil, in agriculture and industry). Because of the future reference year chosen, the study should be based on

- today’s best available technologies (BAT) and
- future technologies with a high probability of introduction.

The exact specifications, particularly efficiency and emissions, were obtained from the respective sources used or expert judgements based on these were used. Such expert judgements took into consideration particularly general developments within existing concepts without consideration of technical details.

European Chains

The European chains were calculated in two steps, based on the national results. In the first step, for those countries not participating in the project (or in a certain chain) the most appropriate country was selected for which the chain was calculated and the results were adopted. The main criteria were similarities in soil and climatic conditions. For example, the impacts of the life cycle of RME in the Netherlands were estimated based on the results for Denmark and Germany (50 % each). In the second step, the European impacts were calculated by weighting the national impacts according to the shares of the individual countries with regard to the European agricultural area. For SME (considered only for the south of Europe), traditional firewood and biogas (similar in all countries) the non-weighted means were used. (See Annex 7.5 for information on the data for the European chains.)

For data sources, consistency and representativeness see the following Chapter 3.3.1. For information on data uncertainty see Chapter 3.3.4.

3.2.6 Assumptions, limitations and review

Two major assumptions must be considered when interpreting the results:

- the allocation procedures, especially when co-products are dealt with by system expansion: depending on the substituted system chosen, the resulting emissions (accounted as a bonus) can reach several orders of magnitude of the total of the emissions calculated for the other process units of the investigated chain.
- the cut-off rules, especially each time when process units of the life cycle of the product were not considered because they are the same for the biofuel and the reference chains. The calculated difference between these two chains cannot be referred to the absolute value of the total chain in order to assess its respective relevance.

No critical review according to ISO 14040 was performed.

3.3 Inventory analysis

3.3.1 Data acquisition and quality

In theory, thousands of environmental parameters can be balanced within a life cycle analysis, depending on the priorities of the particular study or project. Thus it is necessary to select certain parameters that are of particular relevance. This choice has to be made in accordance with the aggregation methods in the impact assessment. The inventory parameters considered in this project are listed in Chapter 3.4.3.

In order to collect data for all these parameters in a standardised way for all countries involved, detailed data collection guidelines were required. These included for example the following conventions:

- for CO_2 only fossil sources were considered, i. e. no organic ones, since these are part of the global cycle and therefore do not add to the greenhouse effect
- the total carbon content of the combusted fuels was expressed in terms of CO_2 rather than a mix of CO_2 and other substances such as diesel particles etc.
- all NO_x were expressed in terms of NO_2.

For the purpose of this study the data were partly projected onto the reference year 2010. The input data were primarily obtained from the literature. Main sources were recent studies on related issues and agricultural handbooks (e. g. Borken et al. 1999, Ecoinvent 1996, Patyk and Reinhardt 1997). For certain parameters information was obtained from plant manufacturers and users. These data were partly modified by expert judgements in order to take into account future developments, particularly regarding increases in efficiency and emission reductions. Regarding the future reference year obviously estimates had to be used for representative specifications of plants and processes that are anticipated to be used then. Every institute involved was responsible for its own data inputs, but these data were exchanged and discussed and validated by the project co-ordinator. Therefore the database can be largely regarded as being homogenous.

For impact categories such as erosion or soil compaction the situation is generally more difficult. Within an LCIA these categories can usually only be described by very simplified models.

For the purpose of this project country specific input data were required, particularly with regard to agricultural production. Different climatic conditions, soil quality and topography for example are likely to lead to different dry matter yields. For other parts of the life cycles of bioenergy carriers on the other hand, equal conditions can be assumed for all participating countries – or at least this can be expected for the future. These processes are listed below:

- supply of conventional energy carriers
- fertiliser production
- use of agricultural machinery (fuel consumption and emissions per hour)
- transportation (fuel consumption and emissions per km)
- supply of the machines and plants („infrastructure“)

For the description of these processes, uniform data sets are used without regional differentiation. The essential rules for data collection and generation respectively, as well as relevant conversion factors, were compiled in the data collection guidelines (see Annex 7.5). These included methods of obtaining relevant data for the following factors:

1. Agriculture: fertiliser application, yields, mechanical work, field emissions (N_2O, NO_x, NH_3, phosphate, nitrate, heavy metals, pesticides)
2. Conversion and use: data for energy consumption and emissions of various substances to water and atmosphere (e.g. CO_2, SO_2, CH_4, HCl, NH_3, heavy metals)
3. Biodiversity and soil quality: ecosystem occupation, soil quantity, harmful rainfall
4. Normalisation

For the complete data collection guidelines used for this project see Annex 7.5.

The data required for the description of the life cycles of bioenergy carriers and their fossil counterparts show significant, in parts even extreme differences regarding availability and scientific reliability. Naturally, this has also an effect on the reliability and accuracy of the results. Using “technical” parameters only, as for example the diesel requirement for ploughing one hectare, or the NO_x emissions from the production of one kWh electricity, the following ranking can be carried out:

- The largest available amount and highest quality of data is that for the energy consumption of plants and machines working in accordance with established procedures. For individual sectors such as the mineral oil industry or electricity production, reliable mean values can be deduced from official statistics. These mean values can, if necessary, be used as a basis for updates as well as an assessment of marginal technology.
- The emission data for those pollutants, like for example CO_2 and SO_2, whose values are calculated on the basis of the content of the relevant substance in the consumed resource, show comparable quality.
- The reliability of data regarding “standard” pollutants, whose emission values are rather limited with respect to technical processes in many countries, is somewhat lower. This is true e. g. for NO_x or NMHC, where the emission values often depend on the particular conditions for each process.
- The reliability of data regarding limited and non-limited emissions of trace elements as well as certain other limited emissions (BaP, dioxins, heavy metals) is generally very low.

The following ranking refers to sectors: the highest quality data come from the conventional energy industry, followed by the transport and raw material industry. Regarding the conversion of bioenergy carriers the data can show significant uncertainty, as is generally true for new technologies. In extreme cases basic data may be completely missing.

For all input parameters CV (coefficient of variance) were calculated or estimated. With these data MonteCarlo calculations were made (the results of which however are not represented in the end result diagrams; see Chapter 4.1.3 for further information on this). On the level of the final results the differences between the countries can be interpreted as an *approximate* measure of the uncertainties. (These differences are to be regarded as the variability *exclusively* between the various countries only if each input value can be given with an uncertainty value of zero.)

The significant uncertainties are derived from estimates of CVs (coefficients of variance) for input data and “MonteCarlo”-calculations.

3.3.2 Data format

For the first run of data collection and exchange for validation and calculation, the data were stored in the so-called SPOLD format (SPOLD: Society for Promotion of Life Cycle Assessment Development). Each unit process of each chain was stored in a separate file (e. g. harvesting of rape seed in Denmark). The SPOLD format is an approach for standardising the storage and exchange of life cycle inventory data. The data are divided into eight classes of inputs and outputs from and to nature and technosphere. The format allows a comprehensive documentation of data origin, time and geographic reference, cut off criteria etc. The SPOLD files can be exported to Microsoft Excel®. In order to accelerate the subsequent validation and calculation steps, consolidated Excel files were prepared from those related to the SPOLD files. These had the structure mentioned above (one file for each chain in all participating countries with defined lines and columns for all inputs and outputs of all unit processes).

3.3.3 Calculation tools

The present project required two different kinds of tools in order to store and to handle the great amount of data collected for each country and for each chain under study. For these purposes two software tools were used:

- Microsoft Excel®: for the calculation of the inventories
- Palisade @Risk®: for the statistical analysis and the assessment of the quality of data based on a MonteCarlo simulation.

A specific calculation tool was developed using Microsoft Excel®. After the first run of calculation it was modified in order to speed up validation procedures and the statistical simulation.
The calculation tool allows for each chain:

- an aggregation of the emissions and the resource depletion relevant to each input data of each process unit into one "process system" (representing the whole chain). The structure of the inventory is based on the SPOLD data format that consists of eight categories of input and output data:

    1. Input from technosphere – materials and fuels
    2. Input from technosphere – electricity and heat
    3. Input from nature
    4. Output to technosphere – products and by-products
    5. Output to technosphere – waste
    6. Output to nature – air
    7. Output to nature – water
    8. Output to nature – soil

- taking into account the uncertainty of data. Each data collected is characterised by a coefficient of variance (standardised for each category of data). The uncertainty of data is handled by a specific software tool (Palisade @Risk®) which, using appropriate formulas, calculates the mean, the minimum, the maximum and the standard deviation values of each data stored in the spreadsheet according to a log-normal distribution and using a MonteCarlo simulation model.

Two kinds of data sets were used for the calculation of the inventories:

- base data in form of standardised input data (grams of emissions and MJ of energy depletion relevant to the supply and use of machinery, buildings, plants, chemicals, etc.)
- country specific data (hours per hectare of machinery use, cubic meters of storage buildings, kg of chemicals per hectare used in the process).

For energy crops, the calculations were carried out as follows. The first data processing consisted of the conversion of base data into specific values per hectare (the relevant reference unit for these chains), using the country specific data and taking into account default values set for some items (i. e. average speed of tractors, calorific values of fuels). The results of the first calculation are expressed as "*g of emissions per hectare*" and "*MJ of energy per hectare*" for each of the process units into which the chain under study is split.

The second step consisted of the sum of impacts relevant to each process unit in order to obtain the total amount of impacts per hectare for the whole chain. The third step consisted of subtracting from the main chain the impacts due to the corresponding agricultural reference system (calculated in the same way as the main chain). The final results were converted in order to express all the impacts in the relevant functional unit (MJ or kWh of useful energy respectively). This step takes into account the energy production of the main chain. For the European results and certain individual countries the last calculation step consisted of a “normalisation" procedure (see Chapter 3.4.4).

For the fossil fuels the calculations were carried out in an equivalent fashion, likewise taking into account all process units and including all aspects of resource acquisition, processing and utilisation. The results for the fossil fuel chains were then *subtracted* from those for the biofuel chains, so that a negative figure indicates an environmental advantage for the biofuel (because it implies that the impacts of the biofuel are smaller than those of the fossil fuel) and vice versa, i. e. a positive figure indicates an advantage of the fossil fuel.

3.3.4 Completeness, consistency and sensitivity analysis

The completeness and consistency of the results are naturally directly dependent on the completeness and consistency of the input data. Therefore a close scrutiny of such data is essential. The input data can be divided into the following groups with regard to their generation and validation:

Basic processes

The following data were balanced and checked by means of comparisons with data from the literature and with regard to their plausibility:

- data for all fossil energy carriers
- data for those basic processes of bioenergy carrier chains that were not country specific – such as fertiliser and pesticide production or emissions and time specific energy demand of agricultural machines.

Country specific input data

The data were generated on a country specific basis, i. e. the representatives of each participating country were responsible for its specific data generation. For certain parameters, particularly those related to agriculture, significant differences were to be expected between the individual countries. Thus for example on small fields with steep slopes like in Austria and Switzerland, smaller machines are required than on larger and more level fields like in Germany – and smaller machines require a higher specific time input than larger ones.

The completeness of the data was checked by means of a comparison with the instructions for the life cycle descriptions. With regard to consistency, spreads were estimated on the basis of expert judgements, which leave much scope for country specific differences and should therefore not be transgressed.

Validation took place in several steps: In the first step missing data as well as extreme values for parameters with large spreads were simply recorded and the respective partners were asked for a thorough check and supplement or modification of the data. In the next round, default values were suggested which were either accepted or modified by the countries involved. This step was repeated with narrower spreads and finished with the acceptation of the input data sets. Here it was obvious that the last step did not lead to a decrease of the spreads. This means that the – in some cases very large – differences for certain parameters have to be regarded as real.

Inhabitant equivalents

These data were largely obtained from the literature or previous projects funded by the various ministries. Due to the small number of sources – which meant little scope for subsequent improvements – only one validation round was carried out. For several parameters, particularly with regard to toxicity, data are missing completely. Furthermore, the reliability of available figures for inhabitant equivalents tends to be lower than those for life cycle specific data.

Sensitivity analysis

Three types of sensitivity analysis were carried out, which are described in further detail in Chapter 4.1.3:

- *Data uncertainty analysis:* The uncertainties of the results of the individual life cycles were estimated from the mean as well as extreme values of the results of all the countries involved in the respective comparisons. The ratios minimum to mean and maximum to mean respectively were considered representative of the life cycles for the respective countries.
- *Different system boundaries:* The influence of various credits and agricultural reference systems was investigated through their inclusion or exclusion in the calculations.
- *Different life cycle comparisons:* A further type of sensitivity analysis consisted of the comparison of four biofuels (firewood, Miscanthus, willow and straw) with light oil as well as natural gas, showing the influence of the choice of comparison on the environmental performance of those biofuels.

3.4 Impact assessment

3.4.1 Selection of the impact assessment categories

After the collection of data describing the energy systems, it can now be assessed to what extent the processes contribute to environmental problems. For this project, focus is set on the following impact categories (for detailed descriptions see Chapter 3.4.2):

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Ozone depletion by nitrous oxide
- Human toxicity

The following impact categories have partly been investigated to a certain extent:

- Depletion of abiotic resources
- Ecotoxicity
- Persistent toxicity
- Biodiversity and soil quality

The following sections explain to what extent these four categories have been investigated, which methods were used and to what extent they have been included in the impact assessment.

Depletion of abiotic resources

Different methodologies exist for assessing the use of abiotic resources in LCA, but in this study, besides the use of the energy content of finite energy carriers, the only depletion of abiotic resources with special relevance for energy supply and agriculture might be the use of water in countries where it is limited. The reason for this is that experience from previous projects (Reinhardt et al. 1999) has shown that with regard to the biofuels investigated here no scarce resources are utilised to a significant extent.

In this study, ground water consumption for irrigation is only included in the inventory in areas where water is depleted. Evaporation of water from plants, which could possibly lead to increased ground water consumption, was not considered. However for the countries concerned (Italy and Greece) energy crops are likely to be cultivated on non-irrigated marginal land, therefore for all countries, only the depletion of energy resources as explained in Chapter 3.4.2 is considered.

Ecotoxicity and persistent toxicity

Toxic substances emitted to the atmosphere, aquatic recipients or soil potentially contribute to ecotoxicity and/or human toxicity (Wenzel et al. 1997 and Hauschild and Wenzel 1998). The health of an ecosystem may be affected in different sectors: the air, the soil or in the aquatic environment, where the impact may be acute or chronic.

The toxic properties of each individual substance depend on a large number of different factors concerning the substance itself, the quantity emitted and the circumstances under which it is emitted and converted in the environment. In contrast to the situation pertaining to many of the other impact categories, there are no common internationally accepted equivalence factors for toxic substances. However, there is general agreement that the developed methodology shall be based on an integrated quantification of the environmental fate and the inherent toxicity potential of the substance (Udo de Haes 1996). These criteria are fulfilled by the EDIP-method (Wenzel et al. 1997) and this method is advantageous because a large amount of effect factors were available and new factors could be calculated within the expertise in the project.

Since the number of toxicity potentials is larger than the number of the rest of the environmental potentials there is a risk of focusing too much on toxicity compared to the other potentials. Thus it has been decided to aggregate the potentials into three impacts (human toxicity, persistent toxicity and ecotoxicity), representing different geographical scales and time horizons. Persistent toxicity is an aggregated parameter of ecotoxicity and human toxicity on a regional scale. It also represents the long-term effects.

The toxicological impact of a substance is measured in relation to how many m^3 of the environmental medium (air, water or soil) will bring the emission to a level with no toxic effect. Generally the PNEC (predicted no effect concentration) value is used. For humans a similar value is used: HRC (human reference concentration) which is the highest concentration of the substance in the inhaled air expected to give no effect on humans on life-long inhalation under standard conditions. For the water and soil compartment, HRD (human reference dose) is used. This is based on no effect on humans on daily digestion.

Ecotoxicity and persistent toxicity were calculated within this project but due to high uncertainty it was decided not to show the results in the graphs presented in Chapter 4. The reason for the uncertainty was mainly due to lack of information and the uncertainty inherent in the method.

Biodiversity and soil quality

The issues of biodiversity and soil quality are extremely difficult to assess quantitatively and so far no standardised methodology has been developed for LCA. There are many possible approaches to choose from and parameters to consider. Within this project, four of these have been investigated:

- Ecosystem occupation as an indicator of loss of biodiversity
- Ecosystem occupation as a measure for life support functions of the soil
- Harmful rainfall as an indicator of erosion
- Soil compaction

Ecosystem occupation as an indicator of loss of biodiversity: only few quantitative methodological approaches for the assessment of biodiversity are available. They must still be validated and are often not practicable because of the data requirement. However, it is important to determine the impact on biodiversity in the overall evaluation of chains and crops for bioenergy, if one aims for sustainable agricultural and forest production. Therefore biodiversity has to be taken into account, even if it appears not to be quantifiable. Biodiversity, or biological diversity, according to UNEP (1998) means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. The methodology in this study is based on Lindeijer et al. (1998) and looks at the impact on the number of species in the area that is used for energy production (see Annex 7.5). Unfortunately, most data required were not available for many countries under concern. Therefore this parameter could not be assessed successfully.

Ecosystem occupation as a measure for life support functions of the soil: soil quality is an important element of life support functions. A soil with a good quality is able on the one hand to maintain a diversified and active biological activity and a typical soil structure for the site, and on the other hand to guarantee sufficient, good and safe products for man and animals in high crop yields for its type and climate. Cowell (1998) defines changes of organic matter as one factor concerning soil suitable for inclusion in an LCA. An indicator close to organic matter added to the soil is the free net primary biomass productivity. This is simply the total biomass dry matter grown on one hectare in a year, minus the biomass removed from the field in harvest. Lindeijer et al. (1998) have proposed to use free net primary biomass productivity as an indicator for the potential of nature development, as it expresses the amount of biomass free for development of higher species. The complete formula for ecosystem occupation as a measure for life support is listed in the external annex (see Annex 7.5). This method “ecosystem occupation as a measure for life support functionality” is used in this study. Tentative calculations have been carried out with this method. Since the results obtained for this parameter show significant qualitative differences compared to those for the impact categories described in Chapter 3.4.2, they are presented separately in Chapter 4.2.10.

Harmful rainfall as an indicator of erosion: especially in areas with mountains the risk of erosion is high. The quantity of eroded soil can be measured, but should in most cases (due to lack of data) be calculated with the (revised) Universal Soil Loss Equation. (For details on this equation see Annex 7.5). Most factors in the formula are fixed for a certain location, at least on a short-term basis. Two factors are different between crops: the rainfall factor R and the crop management factor C. In this project, values for C and R per crop stage were collected and multiplied (R*C) which gives the amount of harmful rainfall. Finally the harmful rainfall data per crop stage are summed up to give one result per energy crop. This indicator is also suggested by Cowell (1998). It should be noted however, that according to Wolfensberger & Dinkel (1997) the factor C is the central one, which may lead to different results than those obtained in this study. Since the results obtained for this parameter show significant qualitative differences compared to those for the impact categories described in Chapter 3.4.2, they are presented separately in Chapter 4.2.10.

Soil compaction: again, Cowell (1998) suggests this parameter as a factor to be considered in an environmental assessment. Soil compaction by the use of machines is an important problem in agriculture. Compaction is related to the weight of tractors and machinery, tyre width and tyre pressure, as well as soil humidity. Available formulae are incomplete, e.g. they do not include the clay and water content. The best would be to use the most complete method (Wolfensberger & Dinkel 1997).

Due to the large additional data acquisition required, it was not possible to collect data for all countries. Therefore finally no scores were calculated for soil compaction in this study.

3.4.2 Description of the impact categories

There is a fairly stable consensus upon how to treat some of these environmental impacts in life cycle assessments. This is especially the case for global warming or acidification. For others, such as the toxicological impacts, there exists a diversity of methods. Only methodologies specially used in this project are reported hereafter. The coefficients used are given in Chapter 3.4.3.

Use of fossil fuels

Contrary to the more general category of abiotic resources, the methodologies are in relative agreement for the energy resources. In this project, the finite energy carriers are characterised through their lower calorific value, because it represents the amount of energy that is practically derived from the fuel in most plants.

Greenhouse effect

The Intergovernmental Panel on Climate Change (IPCC) has developed an equivalence factor system, which expresses the various climate-forcing substances in the same reference unit, i. e. CO_2-equivalents (Houghton et al., 1995). This procedure is based on expert judgements of scientists world wide and has gained international acceptance.

The IPCC provides values for three different time horizons: 20, 100 and 500 years. For this project, the 100- and the 500-year time horizons were chosen. The characterisation factors used for calculating these are given in Table 3.2 in Chapter 3.4.3. In the results, only the values for the 500-year time horizon are given.

Acidification

Heijungs et al. (1992) suggest an equivalence factor system, which expresses the various substances in one reference unit, i. e. SO2-equivalents, according to their efficiency in reducing the ecosystem's acid neutralising capacity. This is called the Acidifying Potential (AP). This procedure is based upon simple assumptions about the chemical formations that the substances usually form. The characterisation factors used for calculating the results are given in Table 3.2 in Chapter 3.4.3.

Eutrophication

Heijungs (1992) and Hauschild and Wenzel (1998) suggest an equivalence factor system, where the nitrogen- and phosphorus-related problems can be assessed individually and aggregated by either assessing the total emission of N, P, or using a reference unit NO3-equivalents in proportion to the average N/P-relationship in biomass. The characterisation factors used for calculating the results are given in Table 3.2 in Chapter 3.4.3.

Summer smog

The potential contribution to photochemical ozone creation from a substance is described by its Photochemical Ozone Creation Potential (POCP). This is calculated on the basis of knowledge about the types of reactions that the substance undergoes with other substances present in the troposphere, and the rate at which the various reactions proceed.

The POCP-values vary between regions with high or low concentrations of NO_x (see Hauschild and Wenzel, 1998). Low NO_x is most relevant for Scandinavia, whereas high NO_x values are more relevant in the rest of Europe. Therefore, characterisation factors for high NO_x conditions are used as worst-case default.

Ozone depletion by nitrous oxide

The first concept for this impact category was introduced by Wuebbles (1988) and further developed by the World Meteorological Organisation (WMO), which has compiled an equivalence factor system that expresses the various substances in the reference unit "CFC11-equivalents" (WMO 1995). This is called the Ozone Depletion Potential (ODP). The procedure for its calculation is based on expert judgements of scientists world wide and has gained international acceptance. But, since in the processes studied in the present project, N_2O is the only one substance contributing to a change of the stratospheric ozone layer, the assessment regarding ozone depletion has been performed on the basis of the inventory analysis, i. e. the parameter N_2O only.

It must be noted that it is scientifically proven that N_2O has a twofold influence on the ozone layer (ozone depletion through direct and indirect processes; ozone formation through a direct process), but it is not yet established whether this leads to a net increase or decrease (Reinhardt and Zemanek 2000). Taking this fact into account, only the balance of the parameter N_2O is given in this study, without linking it directly with ozone depletion.

Human toxicity

Toxic substances emitted to the environment also contribute to human toxicity. The distribution of human toxicity between air, water and soil follow the same principles as discussed briefly for ecotoxicity above (Chapter 3.4.1). The impact upon human health depends largely upon where the emission takes place (to air, water or soil), and whether humans are exposed through air, soil, surface water or groundwater.

The values for the human toxicity category tend to be rather uncertain. The reason for this is that it is extremely difficult to obtain reliable input data (emission and characterisation factors) for all toxicity parameters of relevance. Furthermore, within the scientific community the methodology on the assessment of toxicity is still being discussed.

3.4.3 Parameters and coefficients used

The different emitted substances can be aggregated by the use of an equivalence factor system according to the efficiency of the substances with regard to the environmental impact categories. In **Table 3-2** the characterisation factors used for the calculations are shown. For the characterisation factors regarding human toxicological impact potentials see Annex 7.5.

Table 3-2 Characterisation factors for non-toxicological impact potential categories (see text for references).

Substance name	**Formula**	**Global warming potential (g CO_2-eq./g)**		**Acidification potential (g SO_2-eq./g)**	**Nutrient enrichment potential (g NO_3-eq./g)**	**POCP**[4] **(g C_2H_4-eq./g)**
		100-year	500-year			
Ammonia	NH_3	-	-	1.88	3.64	-
Ammonium	NH_4^+	-	-	-	3.44	-
Benzene	C_6H_6	-	-	-	-	0.2
Carbon monoxide	CO	2	2	-	-	0.03
Carbon dioxide[1]	CO_2	1	1	-	-	-
Hexane	C_6H_{14}	-	-	-	-	0.4
Hydrochloric acid	HCl	-	-	0.88	-	-
Methane	CH_4	25	8	-	-	0.007
Nitrate	NO_3^-	-	-	-	1	-
Nitrogen oxide[2]	NO_x			0.70	1.35	-
Nitrous oxide	N_2O	320	180			
Non-methane volatile organic compounds[3]	NMVOC	3	3	-	-	0.5
Phosphate	PO_4^{3-}	-	-	-	10.45	-
Sulphur dioxide	SO_2	-	-	1		-

[1] Includes only CO_2 of petrochemical origin

[2] NO_X is calculated as NO_2.

[3] The NMVOC cover a range of substances, and the present characterisation factors only represent estimates of average values.

[4] Photochemical ozone creation potential

3.4.4 Normalisation – a preparation for interpretation

According to the ISO norm 14040, the impact assessment phase must include the assigning of data to impact categories (classification) and the modelling of the inventory data within the impact categories (characterisation). These two steps were described in the Chapters 3.4.2 and 3.4.3.

Further elements, like normalisation, ranking, grouping and weighting, are optional. They are used to express the results in different ways, which can make the interpretation easier with respect to certain objectives. While normalisation simply expresses the data using a different reference unit, ranking and grouping also involve subjective value choices.

There is no specific rule when it makes sense to use normalisation. It is largely a matter of individual choice and personal preference. In this project, some countries applied normalisation as explained below. No other optional element has been used.

Normalisation enables the decision maker to assess the environmental impact of a certain fuel regarding a particular parameter *relative* to the general environmental situation. Thus the “specific contribution” of the individual ecological parameters can be expressed in terms of the “equivalent value per capita”, as has been done in certain cases in this project: of the 8 participating partner countries, some chose to present their results as LCIA parameters without normalisation, and others chose to use normalisation, which led to two distinct forms of data presentation. The choice of each country is indicated in **Table 3-3**. It also shows that the results for all of Europe were decided to be presented in the normalised form. They are included in the main body of the text, while all country specific results can be found in the Annex. 2010 was chosen as the reference year.

Table 3-3 Country specific choice regarding presentation of results

LCIA results without normalisation	Normalised LCIA results
France	Austria
Greece	Denmark
The Netherlands	Germany
Switzerland	Italy
	Europe (EU)

Those countries using normalisation chose a reference unit that appears fairly complicated, but the underlying principle is relatively simple and allows an appropriate way of assessing the relative impact of the respective biofuel with regard to the different parameters: what is being expressed is the specific environmental impact of the respective fuel relative to the environmental impact of an average inhabitant of the country concerned. The derived unit is therefore “inhabitant equivalent per functional unit”. For example, the parameter “Use of fossil fuels” would be expressed in the following way for normalised results:

> **If biofuel B replaces an equivalent amount of fossil fuel F, then the amount of fossil fuel saved would be equivalent to the average consumption of X inhabitants per year.**

This way, it is possible to compare the relative effect of using a certain fuel with regard to different parameters.

In order to express the results most meaningfully, it may be desirable to chose a unit generally used with regard to the utility of the fuel – thus for example a fuel used for transportation might best be expressed in terms of inhabitant equivalents per km of distance covered by a car. Furthermore, it might be necessary to chose a different order of magnitude than the functional unit is expressed in, so that the results are given in figures that are easy to comprehend (e. g. 300 inhabitant equivalents per GJ rather than 0.3 inhabitant equivalents per MJ). Thus the results would be expressed in derived functional units. This has been done with regard to the normalised results presented in this project, in order to further facilitate their interpretation.

3.5 Interpretation

3.5.1 General procedure

The assessment of the environmental impacts of biofuels within this study involves two distinct parts: firstly, to compare the biofuels against those fossil fuels which fulfil equivalent purposes, e. g. conventional diesel versus biodiesel for transport. These comparisons are based on complete life cycle analyses according to the ISO 14040 – 14043 standards. The procedure for this is explained in Chapter 3.5.2.

Secondly, the biofuels were compared against each other, based on the results of their comparisons against the respective fossil fuels. This is a complex task because the environmental performance of any biofuel depends partly on the objective of its use. Thus for example one biofuel might be most efficient when the goal is to produce heat, but another might be better suited for producing electricity. Therefore, the comparison between the various biofuels was carried out in the light of four different questions (see Chapter 4.3).

It is important to acknowledge that while the calculations of the quantitative results regarding individual environmental parameters can be carried out with scientific objectivity, with regard to the overall comparisons no objective final conclusions can be drawn. These depend on the particular objective of the decision maker. Thus all fuels investigated here have advantages regarding certain environmental parameters and disadvantages with respect to others. For instance, the results of the project generally show that the cultivable biofuels like rape seed and triticale tend to perform better than fossil fuels with regard to emissions of CO_2 and equivalent greenhouse gases, but the nitrogen and SO_2 emissions are much higher for these due to agricultural production. It is therefore up to the particular decision maker which parameter to assign a higher ecological importance.

Regarding the procedure for the assessments, first the relevant LCI and parameters and LCIA categories were chosen according to the impact assessment procedure outlined in Chapter 3.4. Following the calculations of the values for these parameters, the results were processed graphically, described verbally and compared against each other. The assessments were carried out on a country specific basis as well as for the whole EU (see **Table 2-1** in Chapter 2.1).

3.5.2 Interpretation concept: biofuels versus fossil fuels

First, the various biofuels investigated by each participating country were compared against their fossil counterparts on the basis of complete LCAs with regard to the parameters chosen in the impact assessment. The quantitative results were obtained using the functional unit (MJ of heat, electricity, or heat value in the fuels – depending on which form of energy the particular biofuel was intended to produce). Therefore the result e. g. for the comparison between biofuel B and fossil fuel F with regard to the parameter “Use of fossil fuels” would be expressed in the following way:

> **If biofuel B replaces an equivalent amount of fossil fuel F, then X MJ of fossil energy resources would be saved for every MJ of biofuel consumed.**

This was then expressed in diagrammatic form. In this way, it is possible to compare the results for a certain fuel with regard to each impact category with those of other fuels regarding the same parameter.

Concluding Interpretation

An interpretation in the sense of a concluding interpretation will not be carried out here. This is the responsibility of the user or decision maker, because for this purpose, definite subjective assessment criteria are required – as for example the decision regarding the importance of the environmental impact categories and LCI parameters respectively. It is commonly accepted that these cannot be defined scientifically and may differ from person to person. Thus the results presented here may serve as a tool for any decision maker to arrive at his or her own conclusions, depending on the particular objective. For instance, if saving the greatest amount of abiotic resources is aimed for, a different fuel may be optimal than if the objective is to reduce greenhouse gas emissions, and yet another fuel might be chosen if human toxicity is the main issue. Such decisions cannot be made within this study. However, by presenting the results in a clear and comprehensible way and by discussing the quantitative results, an attempt was made to provide a scientifically sound foundation for such decisions.

3.5.3 Interpretation concept: Biofuels versus Biofuels

The purpose of this part is to examine which biofuels should be preferred to others (it is not subject of the study to compare the fossil fuels among themselves). For those countries that did not normalise the results (see **Table 3-3**), this has already been included in the comparison of biofuels versus fossil fuels.

For the group of countries that did normalise their results, the normalisation procedure is as for the comparison biofuels versus fossil fuels described above.

The comparisons between the biofuels are based on the individual comparisons between each biofuel and its equivalent fossil fuel. For instance, if RME is compared to ETBE, what is actually compared are the respective advantages or disadvantages of RME versus diesel oil and ETBE versus gasoline.

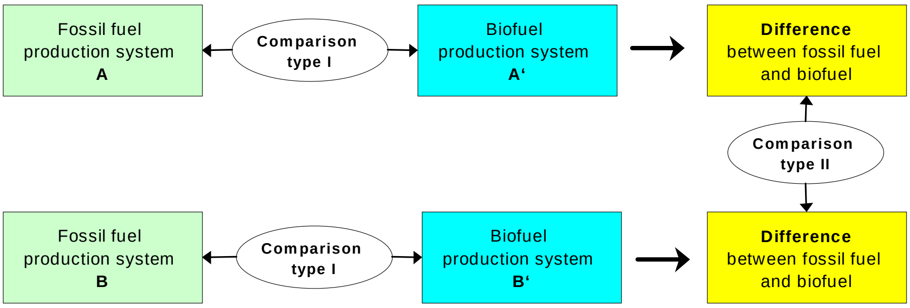


Figure 3-5 Schematic representation of the types of comparisons carried out in this project

Selection of biofuels to be compared

With regard to the comparison of the various bioenergy carriers among themselves, it is necessary first of all to identify those biofuels which are to be compared, because it is only sensible to compare all bioenergy carriers with each other under certain conditions. If for example the question is whether or not it is ecologically advantageous to cultivate energy crops, then a comparison between RME and residues such as swine excrements or wheat straw is not adequate. It is similarly irrelevant to compare wood chips with bioethanol and RME if the question is if and how conventional fuels for transportation can best be substituted by biofuels.

Thus depending on the question, different sets of biofuels should be compared against each other. For instance, if the question is which bioenergy carrier should be produced, the efficiency of production with regard to the land area is of foremost interest. If on the other hand the question were the production of which biofuel would save the greatest amount of fossil fuels, then the sum of all fossil fuels would form the basis of the assessment.

Apart from the choice of which bioenergy carriers are to be compared with each other, the reference unit regarding the quantitative results is to be defined for the description and interpretation of the results. These are generally derived directly from the question itself. Four questions have been defined in this context, which are being addressed by different countries. Hence in this assessment step it is first of all necessary to identify the comparisons between biofuels for the different countries, with respect to the individual questions.

Therefore, ultimately all potential bioenergy carriers to be compared must be identified and grouped together for every question and every geographical coverage. In **Table 3-4** the comparisons to be made between the bioenergy carriers with regard to each country are marked, i. e. in this project 24 groups of different bioenergy carriers are compared among each other.

Table 3-4 Questions to be answered by each country concerning the comparison between the biofuels

Objective	Austria	Denmark	France	Germany	Greece	Italy	Netherlands	Switzerland	EU
Heat	X	X	(X)	X			X		X
Transport			(X)	X					X
Land use	X	X	(X)	X			(X)		X
Resources	X	X	(X)	X	(X)	X	(X)	(X)	X

Heat: Which bioenergy is the most ecological if the aim is to produce heat?
Transport: Which bioenergy is the most ecological if the aim is to produce fuel for transportation?
Land use: Which bioenergy is the most ecological if the aim is to make most efficient use of the available land?
Resources: Which bioenergy is the most ecological if the aim is to save conventional energy carriers?
(X) = Interpretation not carried out separately

Concluding Interpretation

As with the comparison biofuels versus fossil fuels, no final interpretation was carried out here, other than answering the five questions addressed. But even with regard to these questions, the answers cannot be taken to be absolute. The reason for this is that the term “the most ecological” still depends on the parameters which are given priority. Again, the discussion of the results in Chapter 4 is intended to aid the interpretation of the quantitative data and to enable every decision maker to reach his or her own conclusions on a sound scientific basis.

4 Environmental results: presentation, discussion and interpretation

In this chapter the following groups of results are presented:

- comparisons between biofuels and fossil fuels investigated on the European level
- comparisons between different biofuels regarding special objectives on the European level
- country specific life cycle comparisons (summary of Chapter 7.1)
- comparisons between the countries for each biofuel (summary of Chapter 7.2)

Before the result discussion, in the following introduction information will be given on various aspects of the result presentation.

4.1 Introduction

In this chapter the most important definitions documented in the previous chapters are summarised. Furthermore, presentation criteria, the types of sensitivity analyses carried out and the chosen form of result presentation will be explained.

4.1.1 Life cycles under study

As explained in Chapter 2, each biofuel investigated was compared to its fossil counterpart by means of complete life cycle analyses. The biofuels under study and their fossil counterparts are listed below.

Table 4-1 Life cycle comparisons and the countries that investigated them

Life cycle comparison	Countries involved
Traditional firewood vs. light oil for residential heating	Austria, Italy, Switzerland
Triticale vs. coal for electricity production	Austria, Denmark, France, Germany
Miscanthus vs. light oil / natural gas for district heat production	Denmark, France, Germany, Netherlands
Willow vs. light oil / natural gas for district heat production	Denmark, Germany, Netherlands
Wheat straw vs. light oil / natural gas for district heat production	Austria, Denmark, France, Germany, Greece
Biogas from swine excrements vs. natural gas for combined heat and power production	Austria, Denmark, Greece, Italy, Netherlands, Switzerland
Rape seed oil methyl ester vs. diesel fuel for transportation	Austria, Denmark, France, Germany, Switzerland
Sunflower oil methyl ester vs. diesel fuel for transportation	France, Greece, Italy
ETBE from sugar beet vs. MTBE for transportation	France, Germany, Netherlands

All intermediate calculations and all result tables regarding the European chains are documented in the external annex. Further information on this can be found in Annex 7.5.

4.1.2 Impacts under study and presentation criteria

The environmental impact categories that were considered in the analyses were discussed in the Chapters 3.3 and 3.4. They are listed in **Table 4-2**.

In the presentation of the results the following observations have already been considered: with regard to the parameter greenhouse effect, the differences in the results for the 100 year and 500 year time horizon respectively were smaller than their uncertainties. Therefore only the 500-year values are presented here.

The effect of nitrous oxide is uncertain as explained in Chapter 3.4.2, due to the fact that N_2O has both ozone depletion as well as ozone forming properties and the net effect is not yet scientifically proven. In the graphs a higher N_2O emission is indicated as a disadvantage however.

The values for the human toxicity category tend to be rather uncertain. The reason for this is that it is extremely difficult to obtain reliable input data (emission and characterisation factors) for all toxicity parameters of relevance. Furthermore, within the scientific community the methodology on the assessment of toxicity is still being discussed.

The category biodiversity and soil quality is discussed qualitatively in Chapter 4.2.10 and is not included in the graphs of the following sections since they are extremely difficult to quantify.

Table 4-2 Environmental impact categories and data quality

Impact category	Data quality
Use of fossil fuels	good data quality; quantitative results presented in the graphs
Greenhouse effect	good data quality; quantitative results presented in the graphs
Acidification	medium data quality; quantitative results presented in the graphs
Eutrophication	medium data quality; quantitative results presented in the graphs
Summer smog	medium data quality; quantitative results presented in the graphs
Nitrous oxide	poor data quality; quantitative results presented in the graphs
Human toxicity	poor data quality; quantitative results presented in the graphs
Biodiversity and soil quality	very poor data quality; results discussed qualitatively

The actual presentation of the results is different regarding the various questions as well as the individual countries and the EU. They are described in detail within the respective chapters.

4.1.3 Sensitivity analyses

Three types of sensitivity analyses were carried out:

I Data uncertainty analysis
II Different system boundaries
III Different life cycle comparisons

These are discussed in turn in the following sections.

I Data uncertainty analysis

While in the calculations minimum-maximum evaluations were carried out, the results for these are not included in the graphs. Two types of methods were used for calculating the ranges: first the minimum and maximum values were calculated using the MonteCarlo method based on standard deviation values. However, it was found that the extreme values using this method are so large/small that a clear presentation including the mean values was not possible.

The second method employed was simply to use the minimum and maximum values from the individual countries involved and to calculate average minimum and maximum values from these. As shown in **Figure 4-1**, this method leads to a clear presentation and also indicates the reliability of the country specific data, as it implies that the results of the various countries are reasonably similar at least regarding the order of magnitude – as should be expected. However, the validity of this method in terms of indicating the range of input data may be questioned. Therefore it was decided to leave the minimum-maximum evaluations out of the general results.

II Different system boundaries

Concerning different system boundaries, within LCA also described as “different allocation procedures”, two types of sensitivity analyses were carried out.

Influence of various credits: during the production of three of the biofuels investigated here, namely RME, SME, and ETBE certain co-products are also produced. Therefore the environmental effects of their equivalent conventional products are considered as credits for the respective biofuel life cycles. In order to show the potential influence of these credits on the final result, in **Figure 4-2** the results of the complete life cycle of RME are given as examples – in one case including the credits and in the other case excluding them. Credits are given for the agricultural reference system (for details see the next paragraph), rape seed meal, and glycerine. The result of this comparison indicates that significant differences may result. This shows firstly that it is necessary to include the co-products adequately in the life cycle analyses (in accordance with the principle “from cradle to grave”) as it is done here. Secondly, the results presented here may only be interpreted in the light of the system boundaries (and credits considered) used within this study.

Influence of agricultural reference systems: in the calculations of the life cycles of the bioenergy carriers, so-called agricultural reference systems are included (in the form of credits) as described in Chapter 3.2.1. These define the type of land use that would be applied if no bioenergy carriers were to be produced. **Figure 4-3** shows the influence of the agricultural reference system on the final result of various life cycle comparisons between biofuels and their corresponding fossil fuels. In each case the result is given with and without the agricultural reference system. Concerning the biofuels shown in the graph, it must be noted that the ratio for the ETBE values is similar to that of the others, but the absolute numbers differ by an order of magnitude, whereas the residues straw and wood show no difference at all as there is no direct change of the agricultural land use.

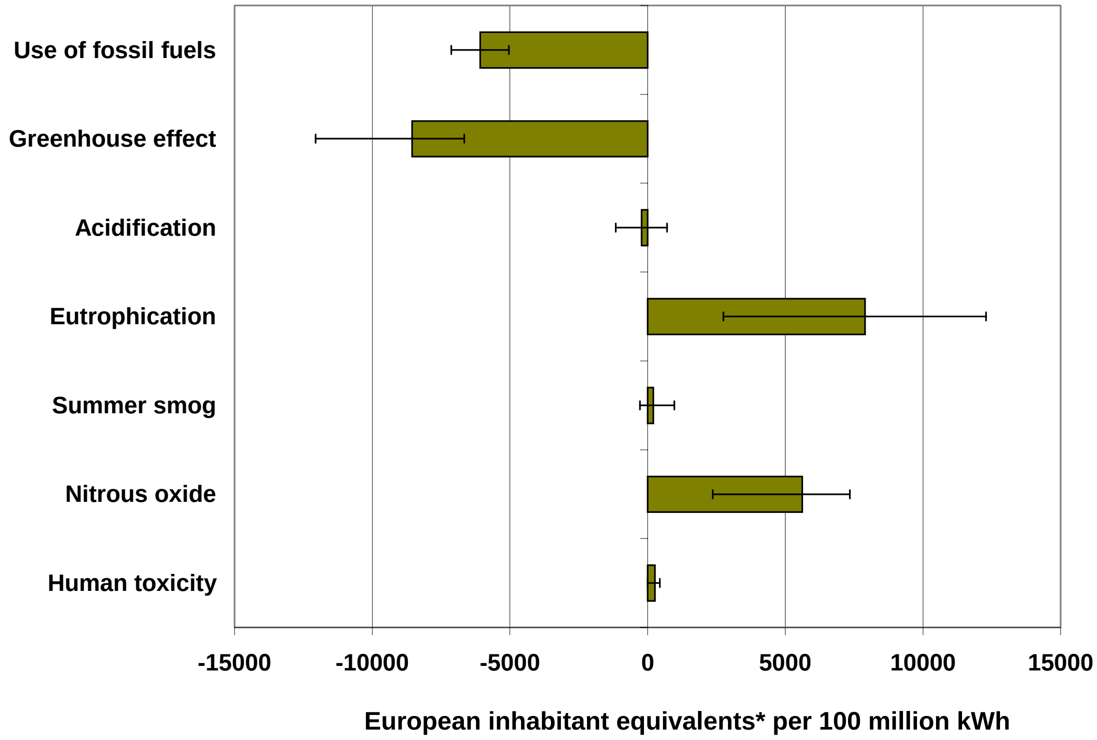


Figure 4-1 Exemplary data uncertainty analysis for triticale (based on unweighted averages)

Concerning the different environmental parameters under concern, the greatest differences of the results are associated with the parameter use of fossil fuels (besides eutrophication as this depends strongly on country specific differences in agricultural practices and conditions). The other parameters show smaller or even much smaller differences. Therefore, use of fossil fuels was chosen for the graph to show the largest occurring differences.

The graph indicates that in the cases considered here the agricultural reference system influences the results concerning the production and use of biofuels to a certain degree. But it does not significantly influence the overall results when the biofuel is compared with its fossil counterpart. That means that the chosen reference system does not significantly affect the results. However, it should be noted that the consideration of other agricultural reference systems might lead to completely different results, due to various factors such as transport processes or the cultivation of virgin land (Jungk & Reinhardt 2000).

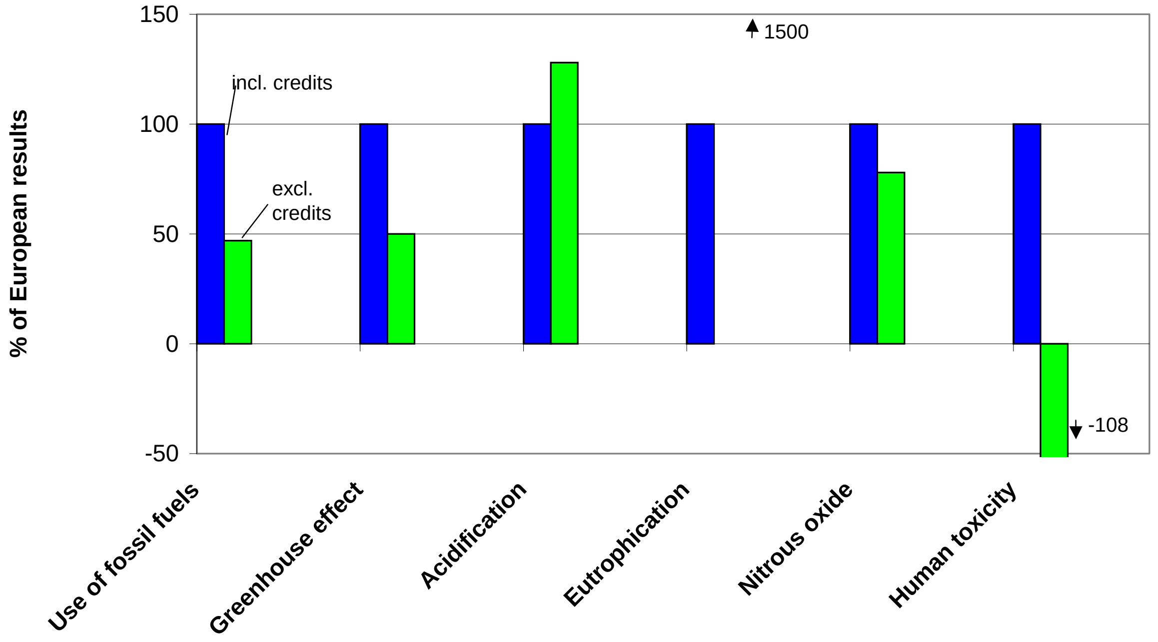


Figure 4-2 The influence of different system boundaries on the results for RME

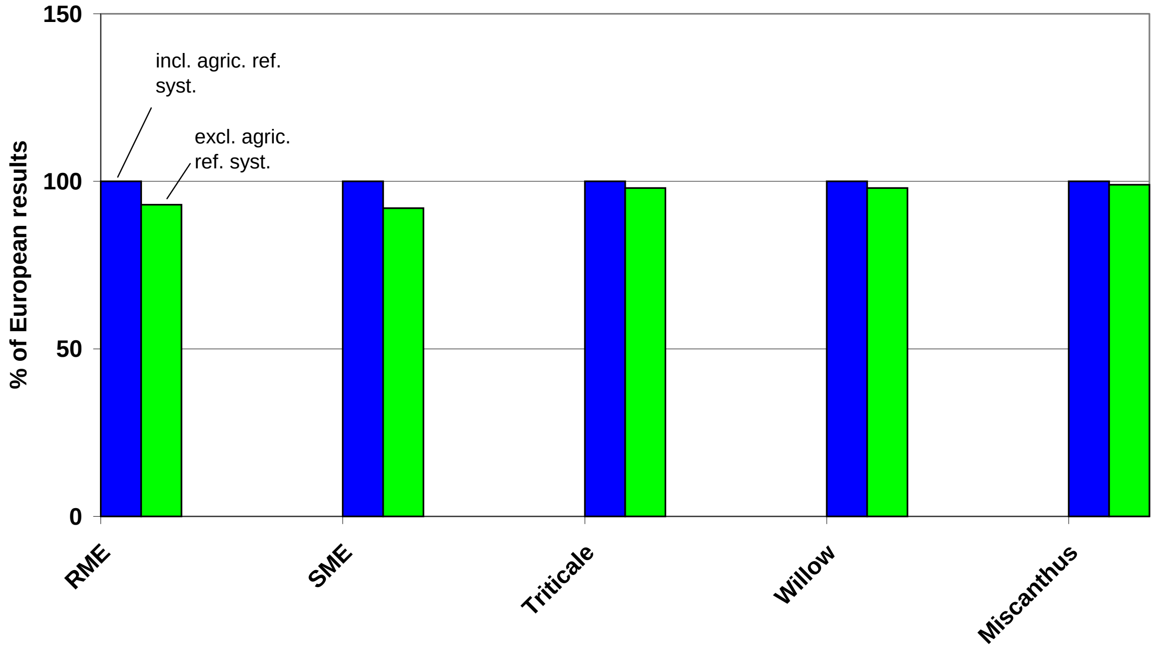


Figure 4-3 The influence of the agricultural reference system on the results for various biofuels regarding the parameter use of fossil fuels

III Different life cycle comparisons

As described in Chapter 3.3, the biofuels firewood, Miscanthus, willow and straw were compared with light oil as well as natural gas, in order to show the influence of the choice of comparison on the environmental performance of those biofuels. This is incorporated in the graphs of the respective biofuels.

4.1.4 The criteria of result description

For most of the comparisons described in the following sections the “remarks and conclusions” are more or less limited to a description of the results and explanations of differences shown in the graphs. There are certain differences between the country specific results (see Chapters 4.4 and 7.1), but in no case was it possible to recommend “the best biofuel”.

Some results are described as “non-significant”. This refers to a possible reversal of signs if the uncertainties are very large. Therefore, these assessments are not based on the magnitude of the values shown in the graphs given in “inhabitant equivalents”, but rather on the magnitude of the *relative differences biofuel-fossil fuel related to the fossil fuel (bio-fossil / fossil)* without normalisation. (The results of the life cycle comparisons biofuel-fossil fuel presented as relative differences are documented in Chapter 7.2.).

Further assessments in favour of or against the biofuels (or fossil fuels) besides those which are given in the respective paragraphs of 4.2, 4.3 and 4.5 cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. Thus decision makers, political institutions, etc. are encouraged to carry out their own assessment on the basis of the results presented here, and – very importantly – to express their priorities by which they carry out the assessment.

4.2 European results: biofuels compared to fossil fuels

The quantitative results of the European chains are presented in the form of bar diagrams, with the impact assessment parameters on the left hand side. In the calculations of the results, the impact figures of the fossil fuels have been subtracted from those of the biofuels, so that negative figures indicate environmental advantages of the biofuels and vice versa. In the graphs therefore the bars on the left hand side of the diagram indicate advantages of the biofuels while those on the right represent advantages of the fossil fuels.

As explained in Chapter 3.5.2 normalised figures have been used. For each graph an example is given of how exactly to interpret it.

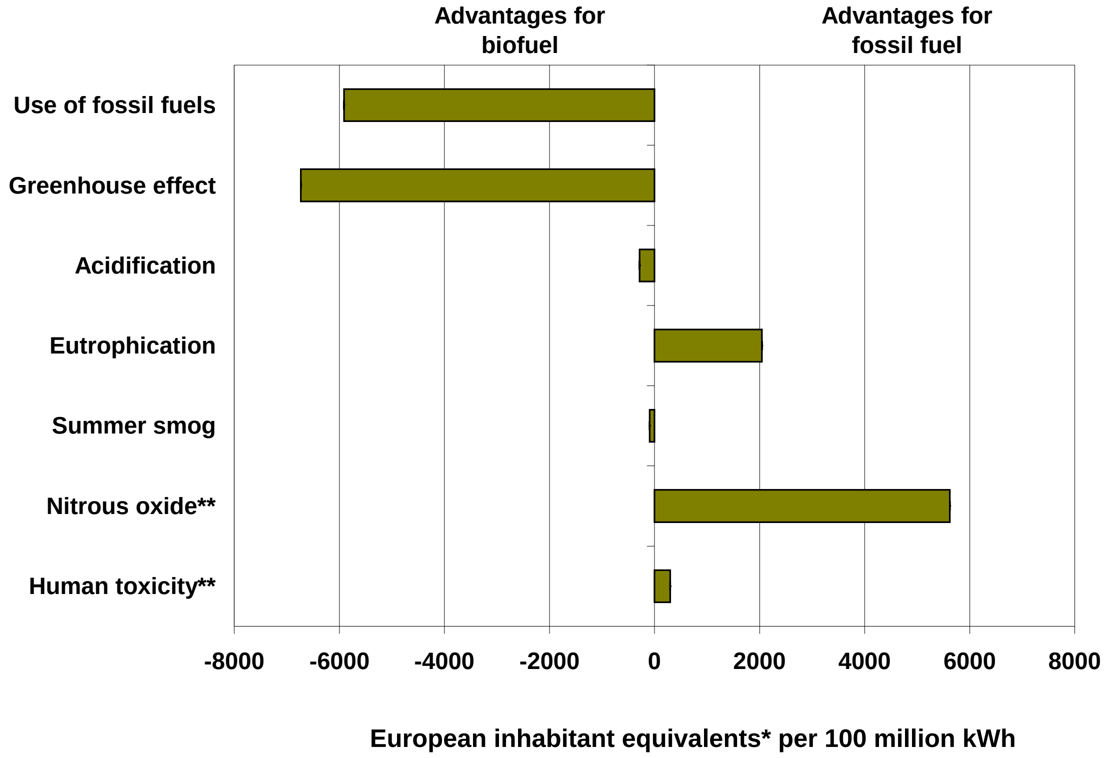
As mentioned in the previous section, some results are described as “non-significant”. This refers to a possible reversal of signs if the uncertainties are very large. Therefore, these assessments are not based on the magnitude of the values shown in the graphs given in “inhabitant equivalents”, but rather on the magnitude of the *relative differences biofuel-fossil fuel related to the fossil fuel (bio-fossil / fossil)* without normalisation. (The results of the life cycle comparisons biofuel-fossil fuel presented as relative differences are documented in Chapter 7.2.). Thus it is possible for small values to have a high certainty regarding the sign (positive/negative), whereas some larger ones may have a relatively high uncertainty.

Further assessments in favour of or against the biofuels (or fossil fuels) besides those which are given in the respective paragraphs of 4.2, 4.3 and 4.5 cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. Thus decision makers, political institutions, etc. are encouraged to carry out their own assessment on the basis of the results presented here, and – very importantly – to express their priorities by which they carry out the assessment.

The category biodiversity and soil quality is discussed qualitatively in Chapter 4.1.10 and is not included in the graphs of the following sections since they are extremely difficult to quantify.

For further information on the result presentation, the parameters used and sensitivity analysis see Chapter 4.1 and for more detailed information Chapter 3.

4.2.1 Triticale versus hard coal for electricity production



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where hard coal is substituted by triticale for electricity generation. The unit refers to an amount of one hundred million kWh of electricity. This is equivalent to the average electricity requirement of about 20,000 inhabitants of Europe in one year or a triticale production of about 5,500 ha/a. In this case for example the amount of fossil fuel saved is equal to the amount which nearly 6,000 European citizens would on average consume in one year (this is what is meant by “European inhabitant equivalents”).

Remarks and conclusions

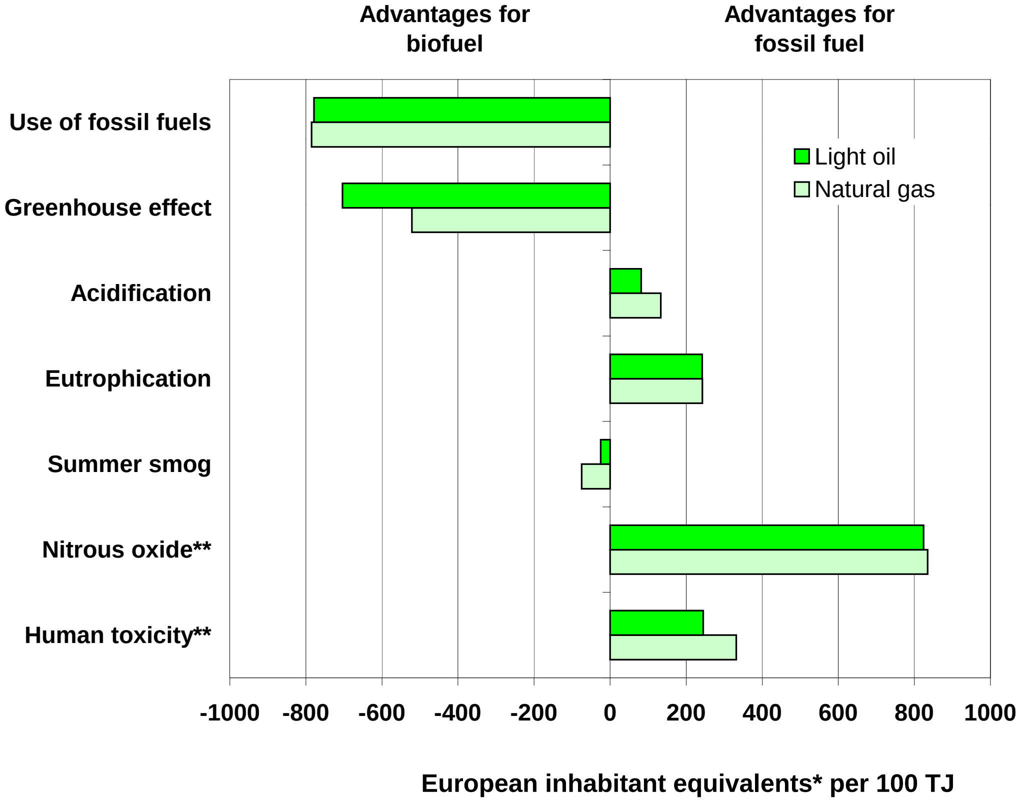
The results show that both triticale as well as hard coal have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect and summer smog (small)
- Advantages of the fossil fuel: eutrophication
- Low or no significance: acidification

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against triticale or hard coal cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.2 Willow versus light oil / natural gas for district heat production



*** How to interpret the diagram**

The figure shows the results of comparisons between complete life cycles where light oil and natural gas respectively are substituted by willow for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 4,000 inhabitants of Europe in one year or a willow production of about 900 ha/a. In this case for example the amount of fossil fuel saved if willow replaces either of the fossil fuels is equal to the amount which nearly 800 European citizens would on average consume in one year (this is what is meant by “European inhabitant equivalents”).

Remarks and conclusions

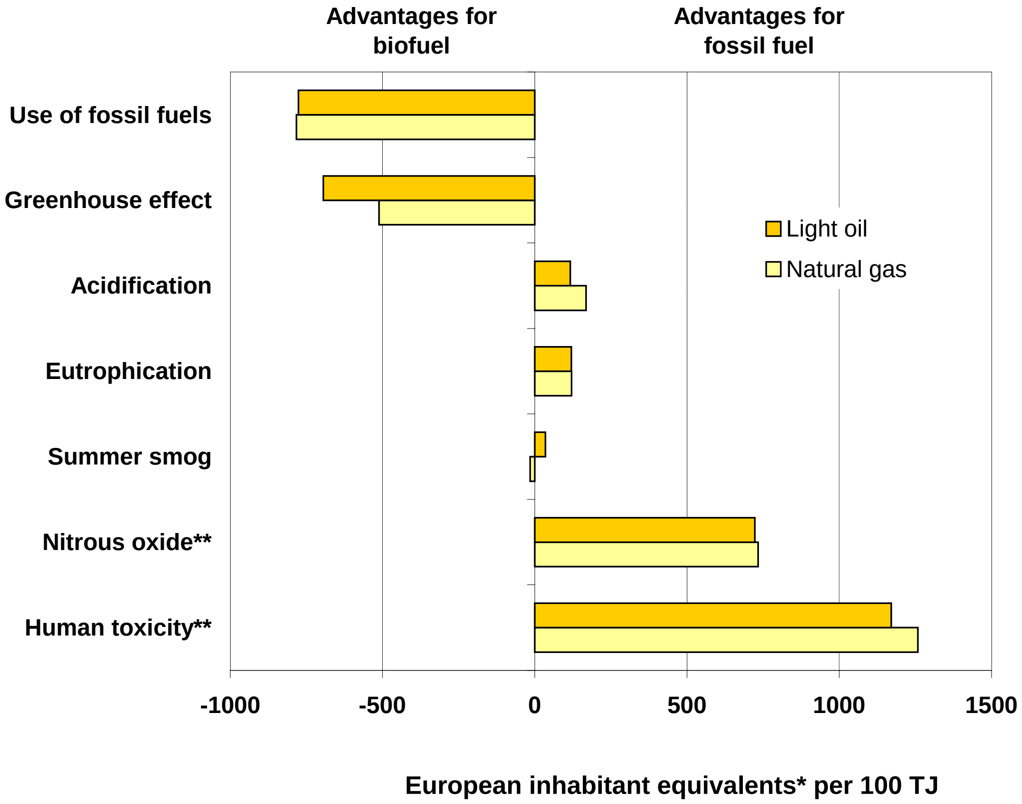
The results show that both willow as well as light oil and natural gas have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, summer smog (small)
- Advantages of the fossil fuel: acidification, eutrophication
- Low or no significance: –

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against willow or light oil / natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.3 Miscanthus versus light oil / natural gas for district heat production



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where light oil and natural gas respectively are substituted by Miscanthus for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 4,000 inhabitants of Europe in one year or a Miscanthus production of about 450 ha/a. In this case for example the amount of fossil fuel saved if light oil is substituted by Miscanthus is equal to the amount which nearly 800 European citizens would on average consume in one year (this is what is meant by “European inhabitant equivalents”).

Remarks and conclusions

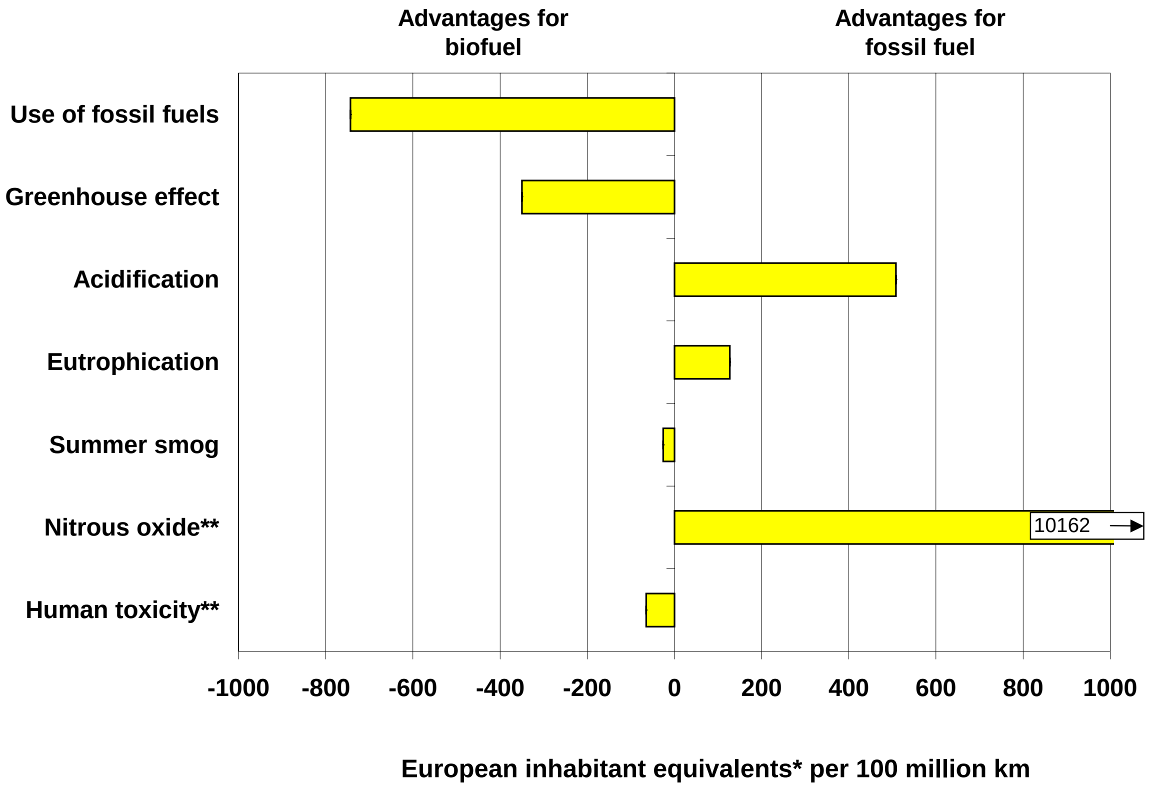
The results show that both Miscanthus as well as light oil and natural gas have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, compared to natural gas also summer smog (small)
- Advantages of the fossil fuel: acidification, eutrophication, compared to light oil also summer smog (small)
- Low or no significance: –

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against Miscanthus or light oil / natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.4 RME versus diesel fuel for transportation



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where RME is used in passenger cars instead of diesel fuel. The results are given for a distance of 100 million km being covered by passenger cars using the biofuel instead of fossil fuel. This is equivalent to the average annual mileage of about 4,000 Europeans. In this case for example the amount of greenhouse gas emissions that is being saved by substituting diesel fuel by RME is equal to the amount which about 700 European citizens would on average generate in one year (this is what is meant by “European inhabitant equivalents”).

Remarks and conclusions

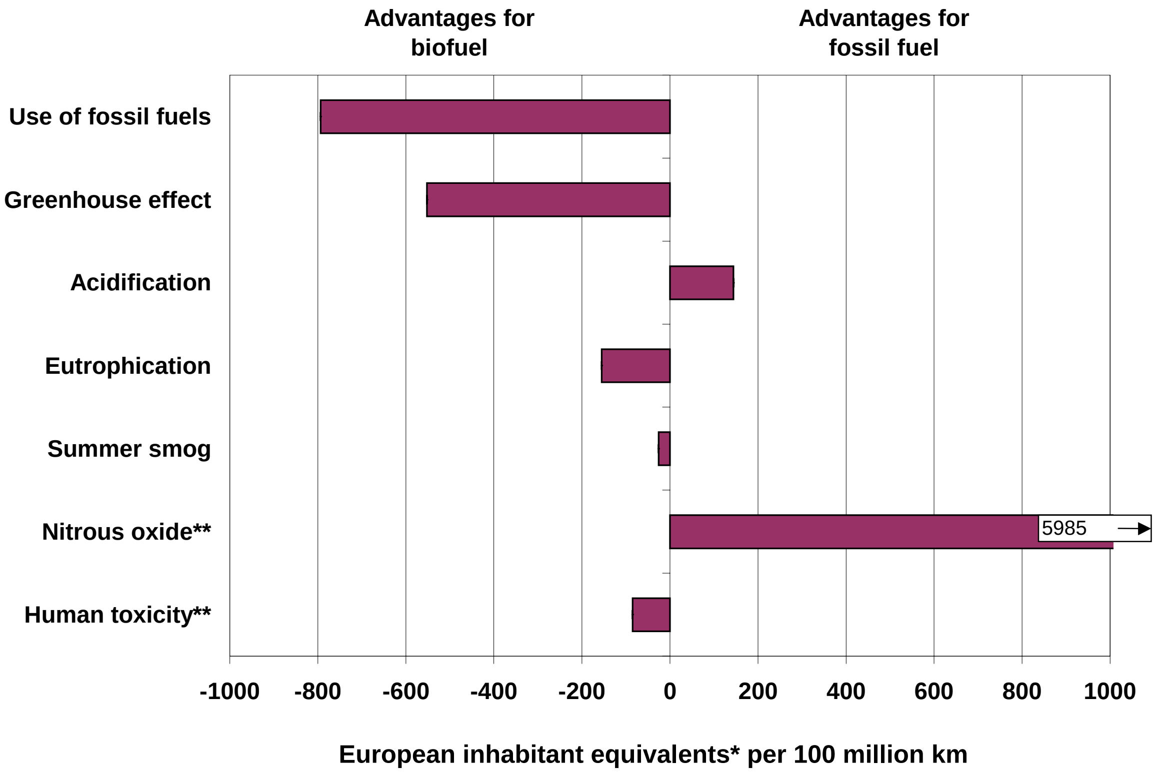
The results show that both RME as well as diesel fuel have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect
- Advantages of the fossil fuel: acidification, eutrophication
- Low or no significance: summer smog

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against RME or diesel fuel cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.5 SME versus diesel fuel for transportation



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where SME is used in passenger cars instead of diesel fuel. The results are given for a distance of 100 million km being covered by passenger cars using the biofuel instead of fossil fuel. This is equivalent to the average annual mileage of about 4,000 Europeans. In this case for example the amount of greenhouse gas emissions that is being saved by substituting diesel fuel by SME is equal to the amount which about 800 European citizens would on average generate in one year (this is what is meant by “European inhabitant equivalents”).

Remarks and conclusions

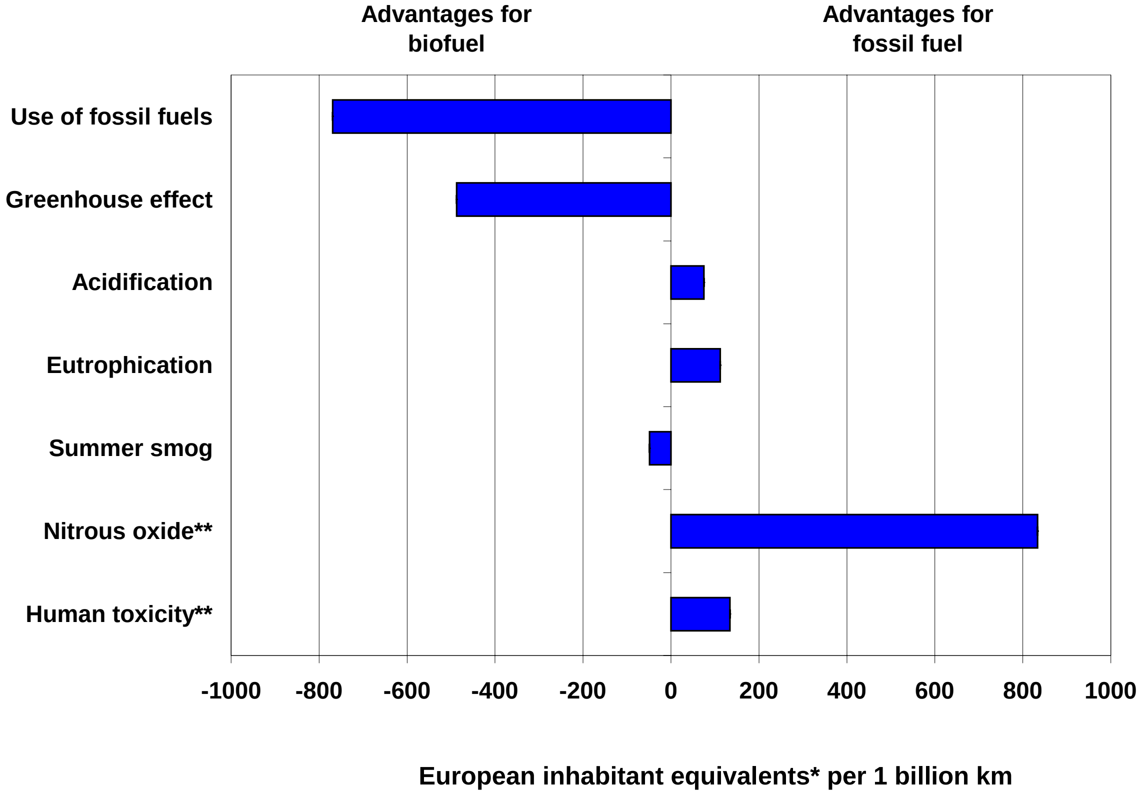
The results show that both SME as well as diesel fuel have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, eutrophication
- Advantages of the fossil fuel: acidification
- Low or no significance: summer smog

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against SME or diesel fuel cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.6 ETBE versus MTBE for transportation (components of gasoline)



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where gasoline with component ETBE from sugar beet (12 vol. % = 10 % of energy content) is used in passenger cars instead of gasoline with fossil MTBE (12 vol. %). The results are given for a distance of 1 billion km being covered by passenger cars using the gasoline with the bio-component instead of fossil component. This is equivalent to the average annual mileage of about 40,000 Europeans. In this case for example the amount of greenhouse gas emissions that is being saved by substituting MTBE by ETBE is equal to the amount which nearly 800 European citizens would on average generate in one year (this is what is meant by "European inhabitant equivalents").

Remarks and conclusions

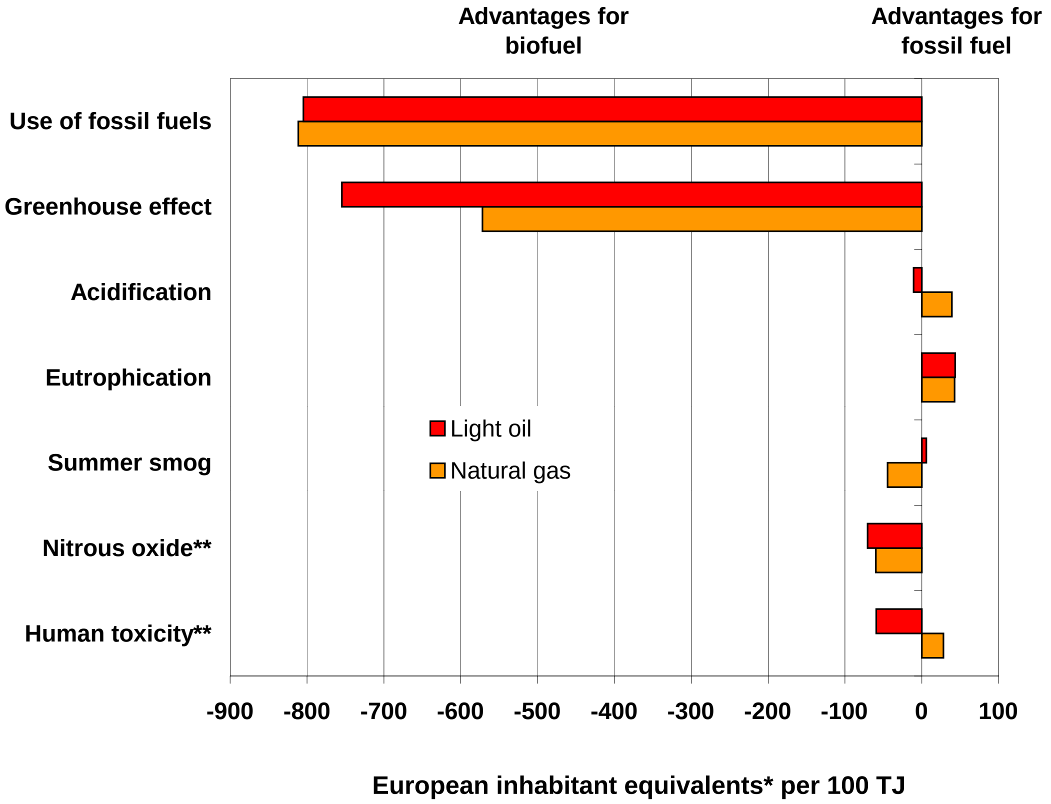
The results show that both ETBE as well as MTBE have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect
- Advantages of the fossil fuel: acidification, eutrophication
- Low or no significance: summer smog

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against ETBE or MTBE cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.7 Traditional firewood versus light oil / natural gas for residential heat production



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where light oil and natural gas respectively are substituted by traditional firewood for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 4,000 inhabitants of Europe in one year or a firewood production of about 900 ha/a. In this case for example the amount of fossil fuel saved if firewood replaces either of the fossil fuels is equal to the amount which nearly 800 European citizens would on average consume in one year (this is what is meant by “European inhabitant equivalents”).

Remarks and conclusions

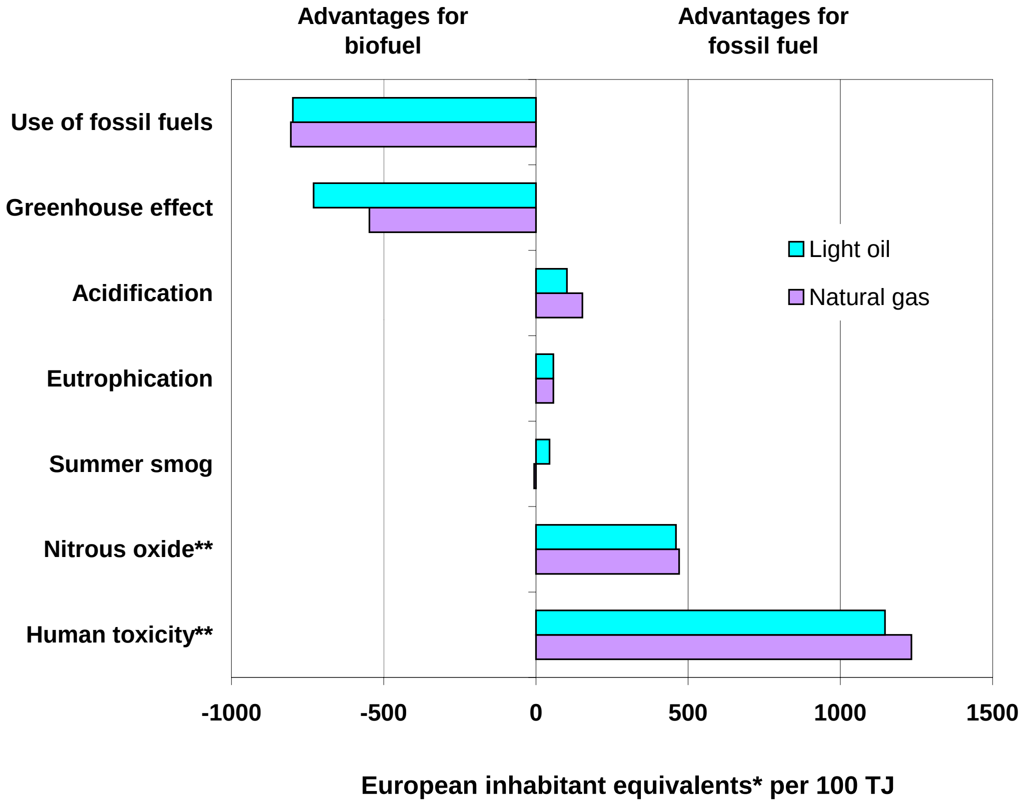
The results show that both traditional firewood as well as light oil and natural gas have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, compared to natural gas also summer smog
- Advantages of the fossil fuel: eutrophication, compared to natural gas also acidification
- Low or no significance: comparison with light oil only: acidification and summer smog

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against traditional firewood or light oil / natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.8 Wheat straw versus light oil / natural gas for district heat production



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where light oil and natural gas respectively are substituted by wheat straw for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 4,000 inhabitants of Europe in one year or a wheat straw production of about 1,300 ha/a. In this case for example the amount of fossil fuel saved if light oil is substituted by wheat straw is equal to the amount which more than 700 European citizens would on average consume in one year (this is what is meant by “European inhabitant equivalents”).

Remarks and conclusions

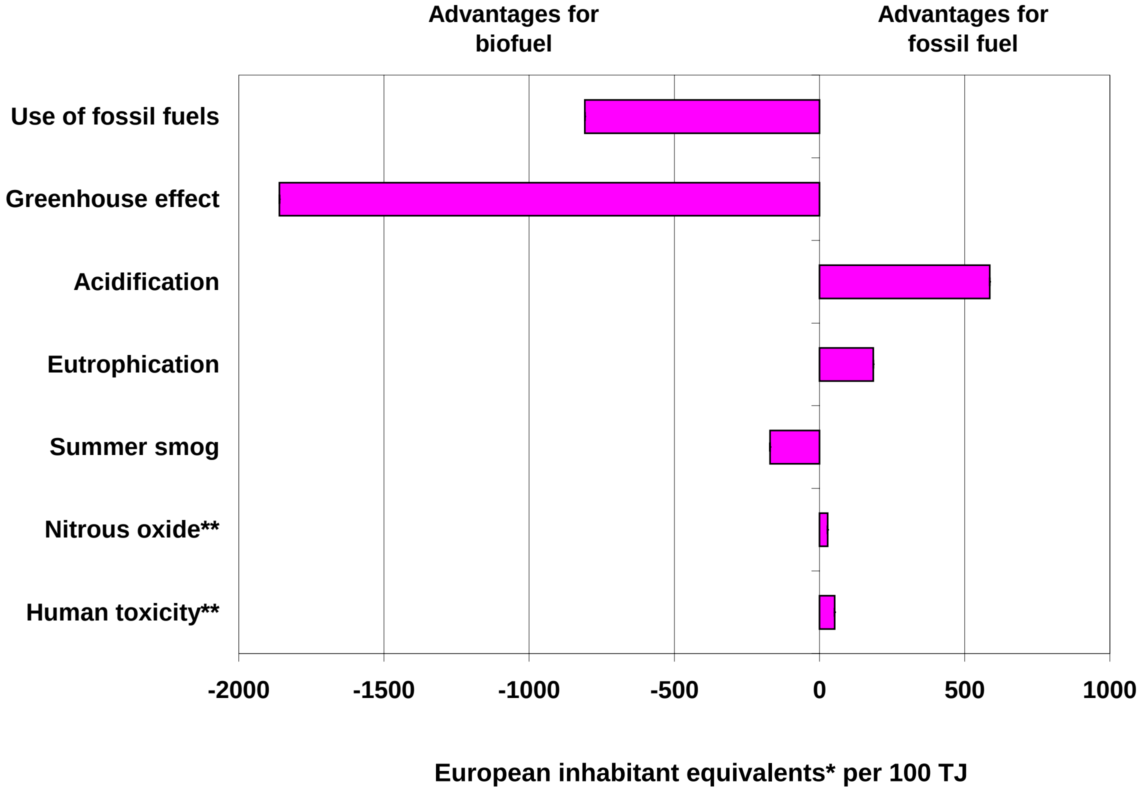
The results show that both wheat straw as well as light oil and natural gas have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, compared to natural gas also summer smog (very small)
- Advantages of the fossil fuel: acidification, eutrophication, compared to light oil also summer smog
- Low or no significance: –

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against wheat straw or light oil / natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.9 Biogas versus natural gas for combined heat and power production



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where natural gas is substituted by biogas for energy (heat and power) production. The unit refers to an amount of 100 TJ of energy. In this case for example the amount of fossil fuel saved is equal to the amount which about 800 European citizens would on average consume in one year (this is what is meant by “European inhabitant equivalents”).

Remarks and conclusions

The results show that both biogas as well as natural gas have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, summer smog
- Advantages of the fossil fuel: acidification, eutrophication
- Low or no significance: –

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

A further assessment in favour of or against biogas or natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.2.10 Results on biodiversity and soil quality

As discussed in the Chapter 3.4.1, four parameters were chosen to describe biodiversity and soil quality:

a) Soil compaction
b) Ecosystem occupation as an indicator of loss of biodiversity
c) Ecosystem occupation as a measure for life support functions of the soil
d) Harmful rainfall as an indicator of erosion

Of these, only the latter two yielded quantitative results, while for the other two parameters no calculations could be carried out. Furthermore, even the results for the two parameters that could be calculated were not included in the graphs of the previous sections. This is first of all due to their poor data reliability, which is a result of yet insufficiently developed assessment methodologies and secondly, because the two selected parameters do not describe biodiversity and land use issues sufficiently. However, certain results have been obtained nonetheless which will be discussed in the following sections. These results should be interpreted with care and not be used as a scientific decision base regarding the biofuels in question. Bearing these limitations in mind however, they may be regarded as a first indication of the nature of the results obtainable by means of more advanced assessment methods in the future.

Results on ecosystem occupation as a measure for life support functions of the soil

As explained in Chapter 3.4.1, ecosystem occupation is defined in terms of various parameters such as yield, area, growing period and others. While most of these could be assessed fairly easily (see Annex 7.5 for further information), the values for the so called free net primary production were difficult to assess for a number of crops due to a lack of data for aboveground production, root production and corresponding decomposition rates. In many cases only a mean value could be given, while in other cases values are estimates rather than hard figures. Hence the results should be interpreted with care. Because of the poor overall data quality no sensitivity analysis was made. As the examples show free net primary production values and yield data for the same crop differ between countries.

Examples for free net primary production in t/(ha*a) are:

Triticale:	-4,0	(France)	to	7,1	(Denmark)
Wheat straw:	4,9	(Germany)	to	8,6	(Austria)
Sugar beet:	-7,0	(The Netherlands)	to	10,4	(France)

Examples for yield in t/(ha*a) are:

Rape seed :	2,7	(Austria)	to	6,4	(Germany)
Miscanthus:	7,5	(Denmark)	to	16,8	(Netherlands)

These differences indicate a level of uncertainty which prohibits a meaningful interpretation. They may partly be due to differences in management practices between regions and countries, e.g. different harvesting methods. In addition, climate and soil differences may have a substantial influence. This issue requires further investigation.
Regarding the overall parameter ecosystem occupation the results can be summarised as follows:

- The ranking of crops according to their result on ecosystem occupation differs between countries. For instance, sugar beet has the highest ecosystem occupation in Germany, and the lowest in the Netherlands. Similarly, triticale has the highest score in Denmark, whereas in France it has the lowest value. These differences need to be explored further in order to understand them.
- In some countries, ecosystem occupation values for rape seed, triticale and wheat turn out to be negative. This implies that these crops are – with regard to those regions – better in providing free net primary production than the average one in mid-Europe. Maybe information on soil structure could explain the differences – possibly in combination with the annual addition of organic matter.
- In some countries, rape seed is followed by a grass filler crop in the same year. Hence in comparison with grass fallow used here as a reference crop, the figures for ecosystem occupation by rape seed and grass filler crop would have to be summed up if they were available.

- In Austria, rape seed might be cultivated instead of cattle fodder in the fields. In this case, more cattle feed would need to be imported, e.g. soy bean from Brazil. The cultivation of soybean takes place at the expense of tropical rainforest. Therefore, values for the ecosystem occupation from the tropical rainforest might have to be used, and soy bean as reference values for rape seed.

Conclusions

Concerning the impact of energy crops on soil quality and biodiversity as assessed in this study the following conclusions can be drawn:

- The assessment of the impact of soil quality by energy crops could only partly be carried out due to a lack of data. Most gaps were found in data concerning the weight and the rate of decomposition of the fractions of plant material.
- No data are available to validate the results obtained so far with this method. Hence the value of the method used could not be ascertained.
- The method does not take into account the scarcity of ecosystems and their ability to regenerate. Therefore, results obtained with this method should be interpreted with care.
- There appears to be a difference in the impact on soil quality between cereals, perennials, and other crops. More research is needed to verify and explain this result.

Results on harmful rainfall

An indication of the erosion hazard during a calendar year is obtained using data, per cropping stage, for the cropping factor and rainfall, which are combined into the so called harmful rainfall (see Chapter 3.4.1). The results obtained showed significant differences, thus for example regarding the energy crops, the amount of harmful rainfall varies from 138 (willow in Germany) to 695 mm/a (sunflower in Italy). In contrast, the amount for grass fallow varies from 56 (Austria) to 143 mm/a (Netherlands) – for more data and results see Annex 7.5. Nevertheless, some results could be drawn:

- Rape seed appears to result in high values for harmful rainfall.
- As shown in Germany and the Netherlands, perennial crops cause lower erosion risks than annual crops. This may well be explained by the provision of winter cover.
- For the annuals, wheat and triticale appear to result in lower erosion risks than sugar beet and rape seed . This is possibly due to the larger row intervals for the latter.
- Top three in erosion hazard are sunflower, hemp and sugar beet.

Conclusions

Concerning the impact of energy crops on erosion as assessed by the method of harmful rainfall, the following conclusions can be drawn:

- The method uses readily available data and can easily be carried out. However, factors not included in this method may play a large role in the occurrence of erosion. Therefore, the method needs validation with actual data on erosion.
- The method may be improved by including factors to assess the effect of management practices on erosion risk.
- Following this method, soil cover is the best way of reducing the harmful effect of rainfall. This is demonstrated by the lower erosion risks from perennial crops and cereals with short row intervals.

Still, more research is needed to investigate this issue further and to integrate it into the issue of land use discussed within LCAs. This accounts for both the assessment of primary data as well as an adoption and/or modification of the methodology to LCA standards.

4.3 European results: biofuels for specific objectives

In the following sections, comparisons between the various biofuels are presented. These are based on the individual comparisons of the biofuels with their respective fossil counterparts. The objective here is to assess which one of the investigated biofuels is best suited for any given purpose. **Table 4-3** shows the utilisation objectives and the related biofuels.

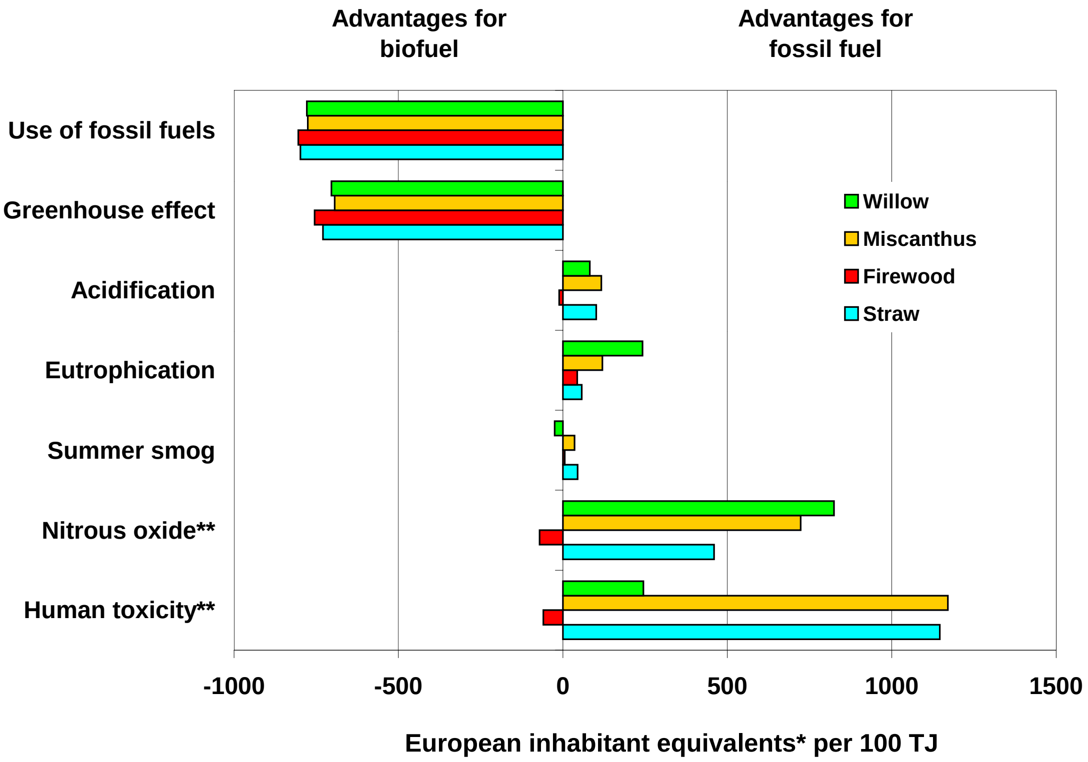
Some results are described as "non-significant". This refers to a possible reversal of signs if the uncertainties are very large. Therefore, these assessments are not based on the magnitude of the values shown in the graphs given in "inhabitant equivalents", but rather on the magnitude of the *relative differences biofuel-fossil fuel related to the fossil fuel (bio-fossil / fossil)* without normalisation. (The results of the life cycle comparisons biofuel-fossil fuel presented as relative differences are documented in Chapter 7.2.).

For further information on the result presentation, the parameters used and sensitivity analysis see Chapter 4.1 and for more detailed information Chapter 3.

Table 4-3 Biofuels compared in the light of different objectives

Objective	Life cycle comparisons considered
Technical applications I: Heat production	Willow versus light oil Miscanthus versus light oil Traditional firewood versus light oil Wheat straw versus heating oil
Technical applications II: Transport	Rape seed oil methyl ester versus diesel fuel Sunflower oil methyl ester versus diesel fuel ETBE from sugar beet versus MTBE
Ecological aspects I: Efficiency of land use	Triticale versus hard coal Willow versus light oil Miscanthus versus light oil Rape seed oil methyl ester versus diesel fuel Sunflower oil methyl ester versus diesel fuel ETBE from sugar beet versus MTBE
Ecological aspects II: Impacts related to saved energy	Triticale versus hard coal Willow versus light oil Miscanthus versus light oil Rape seed oil methyl ester versus diesel fuel Sunflower oil methyl ester versus diesel fuel ETBE from sugar beet versus MTBE Traditional firewood versus light oil Wheat straw versus heating oil Biogas from swine excrements

4.3.1 Technical applications I: heat production



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where straw, firewood, willow and Miscanthus respectively are used for heat production instead of light oil. The results are given for an amount of 100 TJ. This is equivalent to the average heat requirement of 4,000 inhabitants of Europe in one year or for example a Miscanthus production of about 450 ha/a. In this case for example the amount of greenhouse gas emissions that is being saved by substituting light oil by firewood is equal to the amount which about 750 European citizens would on average generate in one year. (This is what is meant by "European inhabitant equivalents".)

Remarks and conclusions

Comparing the four investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:

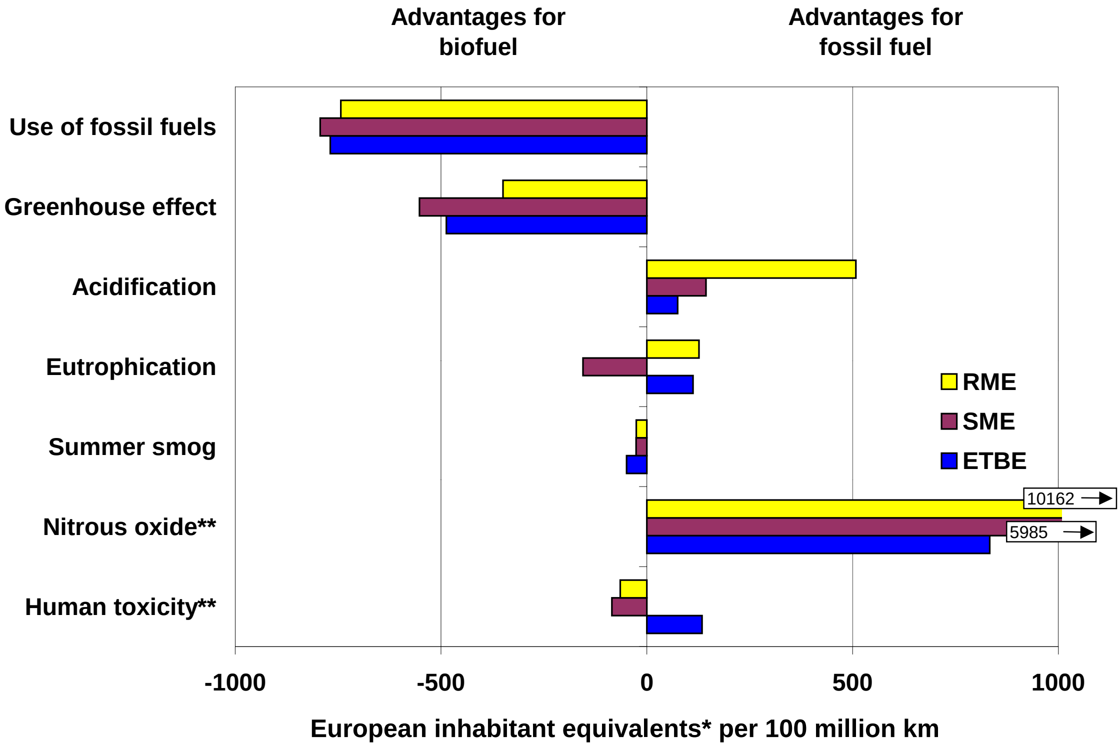
- Use of fossil fuels and greenhouse effect: all biofuels show quite similar advantages.
- Acidification: the biofuels show similar disadvantages or a non-significant result (firewood)
- Eutrophication: the residues firewood and straw show small, the cultivated biofuels bigger disadvantages.
- Summer smog: willow shows a small advantage, straw and Miscanthus disadvantages and firewood a non-significant result.

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

Overall traditional firewood seems to have more and greater advantages (or less and smaller disadvantages respectively) than the other biofuels.

A further assessment in favour of or against one of the biofuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.3.2 Technical applications II: transport



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where RME, SME and ETBE respectively are used in passenger cars instead of their respective fossil counterparts. The results are given for a distance of 100 million km being covered by passenger cars using the biofuel instead of fossil fuel. This is equivalent to the average annual mileage of 4,000 Europeans. In this case for example the amount of greenhouse gas emissions that is being saved by substituting MTBE by ETBE is equal to the amount which about 500 European citizens would on average generate in one year. (This is what is meant by "European inhabitant equivalents".)

Remarks and conclusions

Comparing the three investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:

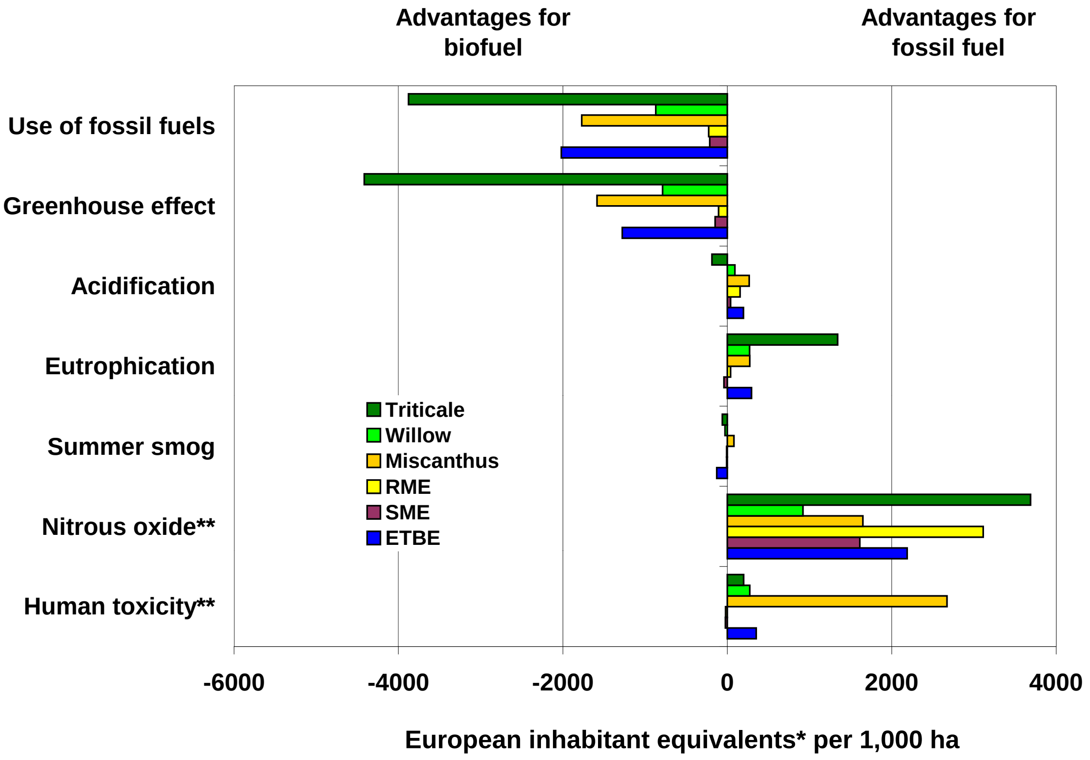
- Use of fossil fuels: all biofuels show quite similar advantages.
- Greenhouse effect: all biofuels show advantages which are quite different. SME gives the highest and RME the lowest benefit.
- Acidification: the biofuels show disadvantages of very different magnitude with ETBE having the lowest impacts and RME by far the largest.
- Eutrophication: SME is the only biofuel with an environmental advantage over the fossil fuel.
- Summer smog: the results are non-significant.

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

Overall RME seems to have more and greater disadvantages (or less and smaller advantages respectively) than the other biofuels.

A further assessment in favour of or against one of the biofuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.3.3 Ecological aspects I: land use efficiency



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where RME, triticale, willow, Miscanthus, ETBE and SME respectively are used for energy production instead of their respective fossil counterparts. The results are given for an area of 1,000 ha being cultivated with the respective crop. In this case for example the amount of greenhouse gas emissions that is being saved when 1,000 ha of Miscanthus are cultivated and used to substitute light oil, is equal to the amount which about 1,500 European citizens would on average generate in one year. (This is what is meant by “European inhabitant equivalents”.)

Remarks and conclusions

Comparing the six investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:

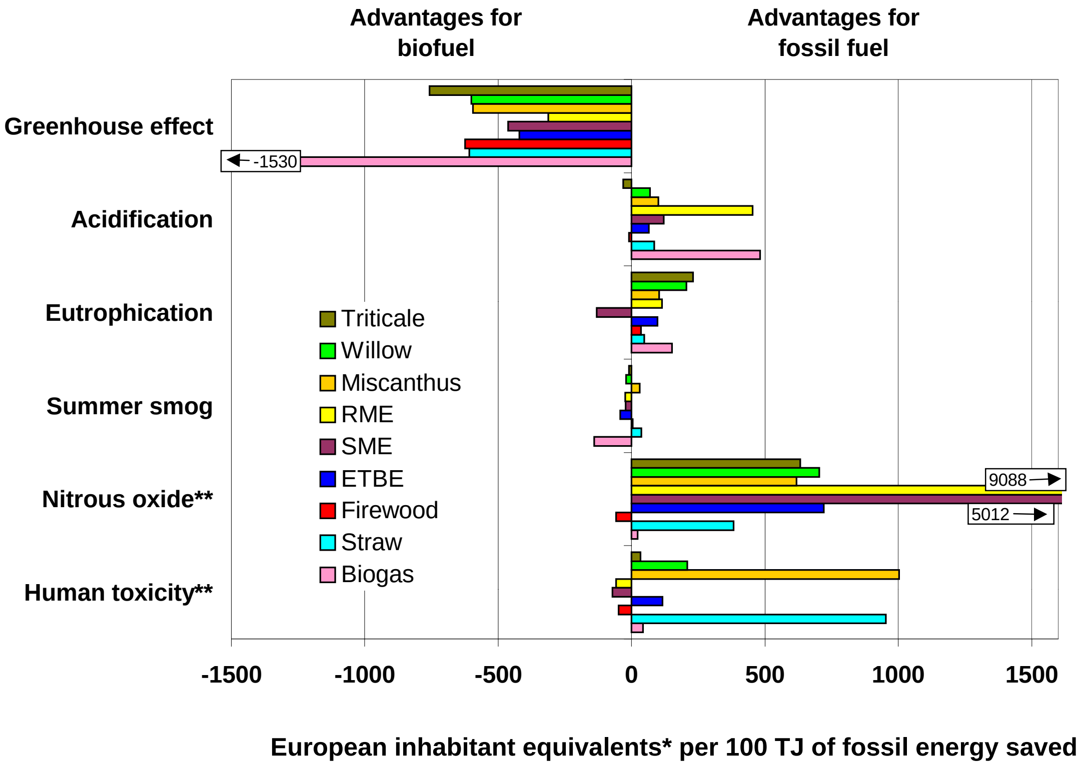
- Use of fossil fuels and greenhouse effect: all biofuels are advantageous. Triticale reveals by far the highest benefits. RME and SME show the smallest advantages.
- Acidification: nearly all biofuels show disadvantages, Miscanthus the greatest, SME the smallest. The result for triticale is non-significant.
- Eutrophication: all biofuels show disadvantages, triticale the greatest.
- Summer smog: triticale and willow show advantages, Miscanthus show a disadvantage. The results for RME, SME and ETBE are non-significant.

The data for nitrous oxide and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4)

All in all, RME appears to have the least favourable results compared to the other biofuels. Regarding the other biofuels, a clear ranking is not possible.

A further assessment in favour of or against one of the biofuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.3.4 Ecological aspects II: impacts related to saved energy



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where all investigated biofuels are used for energy production instead of their respective fossil counterparts. The results for the various categories are given with reference to the category use of fossil fuels, i.e. 100 TJ of fossil energy saved. For example, for every 100 TJ of fossil energy saved through the substitution of diesel fuel by RME, the amount of greenhouse gas emissions avoided is equal to those on average generated by about 300 inhabitants of Europe in one year. (This is what is meant by “European inhabitant equivalents”.)

Remarks and conclusions

Comparing the investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:

- Greenhouse effect: all biofuels have advantages over the fossil fuels. This effect is by far the greatest for biogas, followed by triticale and lowest for RME.
- Acidification: apart from firewood and triticale all biofuels have negative impacts in this category, particularly biogas and RME. For firewood and triticale the results are non-significant.
- Eutrophication: only SME shows an advantage.
- Summer smog: biogas, willow and triticale show slight advantages, wheat straw and Miscanthus show slight disadvantages. The results of RME, SME and ETBE as well as for firewood are non-significant.

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

For most of the biofuels a negative “side-effect” results compared to the fossil fuels regarding most of the categories apart from the greenhouse effect. RME shows the worst results compared to all other biofuels except for Miscanthus and wheat straw with regard to the category summer smog. The results for all other biofuels are more ambiguous. Thus for every MJ fossil energy saved, an additional ozone depletion effect results for all biofuels except for firewood. For SME and RME this effect is relatively large. Regarding acidification, and eutrophication, the negative “side-effects” of the biofuels are smaller in comparison. For acidification, again firewood as well as triticale exhibit slight advantages over the fossil fuel (although these do not appear significant, but the results can at least be regarded as “neutral”), while all other biofuels have negative impacts in this category, particularly biogas and RME. Regarding eutrophication, only SME shows an advantage over its fossil equivalent (diesel fuel). With respect to summer smog, apart from wheat straw, firewood and Miscanthus the biofuels show slight advantages over the fossil fuels. A further assessment in favour of or against one of the biofuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

4.4 Summary of country specific results

In this chapter, the results of the life cycle comparisons between biofuels and fossil fuels in each participating country are summarised and described. The full results are given in the Annex (Chapter 7.1) to which the interested reader is referred for details. Regarding an overall picture of the biofuels in the various countries, the main conclusions are generally similar to those for the European results, i. e. that the biofuels are advantageous with regard to the parameters use of fossil fuels and greenhouse effect, but the fossil fuels have, by and large, greater advantages with respect to the other parameters.

It should be noted that the representatives of each participating countries were fully responsible for the results presented in Chapter 7.1 as well as the following summaries, including the form of presentation and interpretation. Therefore the structure of these presentations differs from country to country.

4.4.1 Austria

Austria investigated Triticale for electricity, firewood and wheat straw for heat, rape seed oil methyl for transport fuel and biogas for combined heat and electricity. For the evaluation the Austrian Energy Policy, the “White Paper” of the Commission, the Kyoto Goals and the UN/ECE Convention on Air Pollution were used. N_2O and photo-oxidants were considered on a scientific level.

Triticale for the electricity production compared with hard coal displays major advantages concerning the use of fossil energy and greenhouse gas emissions. The effects on acidification and on summer smog are positive but minimal, no changes could be observed in the category human toxicity. Deterioration is observed by N_2O and eutrophication, but the absolute increase is rather small.

Traditional firewood compared with light oil and natural gas for heat production shows major advantages concerning fossil energy and greenhouse gases. Regarding acidification, eutrophication, summer smog and human toxicity the differences are small. The substitution of oil shows better results in greenhouse gases and in acidification, the substitution of gas reduces summer smog.

Wheat straw compared with light oil and natural gas for heat production displays major advantages concerning fossil energy and greenhouse gases. The differences regarding acidification, eutrophication, summer smog and human toxicity are small. If straw substitutes oil the emissions of greenhouse gases and acidification are improved considerably, the substitution of gas will reduce summer smog.

Rape seed oil methyl ester compared with fossil diesel for transportation shows advantages concerning fossil energy and greenhouse gases. The effects on eutrophication, summer smog and human toxicity are positive but minimal. Considerable increase is observed in N_2O-emissions and acidification. The absolute change in acidification is rather insignificant but the N_2O burden increases significantly.

Biogas from swine excrements compared with natural gas for heat and electricity shows advantages concerning fossil energy and clear advantages concerning greenhouse gases. The effects on acidification, eutrophication, summer smog, N_2O and human toxicity are minimal.

For an overall comparison the different levels of development, different types of useful energy, the different states of the technology and the different costs must be considered. The following table compares the chains only on the basis of fossil fuel saving and availability of land (based on a mix of bioenergy we have estimated a possible increase of 50 to 80 PJ until 2010 under a committed policy for Austria, *the evaluation in the following table refers to a reduction of 20 PJ fossil energy per chain*). Political and social effects are not taken in account.

Impact category		Triticale	Firewood	Wheat straw	RME	Biogas
Greenh. effect	Mio. t CO_2	- 1.81	- 1.49	-1.45	- 1.05	- 3.64
Acidification	1000 t SO_2	- 1.03	- 0.481	0.553	3.04	10.6
Eutrophication	1000 t NO_3	12.2	1.216	0.910	- 7.74	6.36
Summer smog	t Ethylene eq.	- 48	19	129	- 122	- 2020
Nitrous oxide	t N_2O	215	- 22	151	1610	13
Feasibility		Realistic	Ambitious	Possible	Ambitious	Impossible

A negative sign means “advantage for bioenergy”
Impacts for 20 PJ fossil fuel saved

All types of biofuel are well suited to reduce greenhouse gas emissions in substantial quantities. The highest effect per unit can be reached with biogas. The effects of triticale, firewood and straw are similar, the difference is caused by the different fossil fuel counterpart. Biodiesel leads to the lowest effect. With all biofuels acidification, eutrophication, summer smog and human toxicity will not be changed dramatically. Except for RME the same results can be observed with N_2O. RME would increase the N_2O burden from 9,000 t/a to 10,600 t/a. With Triticale, wood, straw and rape seed a saving of 20 PJ can be reached by each, energy from biogas cannot be produced in the afforded quantity.

4.4.2 Denmark

The Danish results show a quite unambiguous picture: All the biofuels under study have positive impacts because they

- decrease the use of non-renewable, fossil fuels, and
- decrease the emissions of CO_2 and thus decreases the possible greenhouse effect.

With regard to environmental problems such as acidification, eutrophication and summer smog, the fossil fuels come out as most advantageous.

These result can not directly be used for recommendations concerning which biofuels should be supported, if any, because this recommendation depends upon the relative importance which the readers/decision makers assigns to the different environmental impact categories.

Overall it can be said, that biofuels should only be supported, if the decision makers value saving of fossil fuels and greenhouse effect relatively higher than the other environmental impacts.

Among the biofuels used for heat production, Miscanthus does not have significant advantages concerning the environmental impacts under study. On this basis there is no reason to support this production.

Impact category	Triticale	Willow	Miscanthus	RME	Wheat straw	Biogas
Use of fossil fuels	+	+	+	+	+	+
Greenhouse effect	+	+	+	+	+	+
Acidification	+/-	-	-	-	+/-	-
Eutrophication	-	-	+/-	-	+/-	-
Summer smog	+/-	+/-	+/-	+/-	-	-
Nitrous oxide	-	-	-	-	-	+/-
Human toxicity	+/-	-	-	+/-	+/-	+/-

(+) advantage for biofuel (-) advantage for fossil fuel (+/-) insignificant or ambiguous result
(see Chapter 4.1.4)

The biofuels used for heat production may substitute either heat produced by natural gas or by light oil. Compared to the biofuels, there is no significant difference between the environmental impacts of heat produced by natural gas and light oil, and the results will be similar whether the biofuels will substitute any of these two fossil fuels.

All biofuels show big contributions to emission of nitrous oxide. Nitrous oxide contributes to ozone depletion, but the mechanism is not quite clear. The problem of ozone depletion is traditionally connected to CFC (chloro-fluoro-carbon) gases, but there are no CFC gases present in any of the energy systems. The size of the bars does therefore not mean that biofuels contribute extensively to ozone depletion.

4.4.3 France

The bioenergy strategy in France is depending on the existing energy producers and the availability of raw materials from the forestry and agriculture sectors. Traditional fuelwood for domestic use is the most important source of bioenergy in France (about 8-10 Mtoe per year). A large-scale programme, managed by ADEME (Agence de l'environnement et de la maîtrise de l'énergie), is promoting a better use efficiency for this fuel wood and also a utilisation in industries and collectivities. More recently, at the beginning of the 1990's, liquid biofuels for transportation have been implemented at a large-scale level according to the Levy's mission (1991). This project is based upon two chains: a) RME – rape seed oil methyl ester – from rape seed oil blended with diesel (5 % in volume without labelling, up to 30 % in urban captive fleets), today this chain represents roughly 300 000 tons of RME per year (~300 000 ha of rape seed grown on set-aside areas) and b) ETBE – ethyl tertiobutyl ether – (47 % ethanol and 53 % isobutylen) from ethanol produced from sugar beet or wheat blended with gasoline (15 % in volume), this chain represents today 100 000 tons of alcohol per year and extension based upon alcohol ex sugar beet is planned. These chains benefit from temporary tax exemption: 0.50 Euro per litre of alcohol and 0.35 Euro per litre of RME. These bioenergy chains, fuelwood and mainly liquid biofuels, are now mature and implemented on an industrial scale. Other bioenergy chains based on lignocellulosic raw materials for electricity and heat production are today in France at the experimental or demonstration level. Specific experiments exist at the agricultural level (Miscanthus, fibre sorghum, Arundo etc.) but agricultural dry residues such as cereal straw represent a high potential of lignocellulosic raw material for these chains.

The life cycle comparisons that were investigated in France are:

- Triticale versus coal
- Miscanthus versus natural gas
- Rape seed oil methyl ester (RME) versus fossil diesel fuel
- Sunflower methyl ester (SME) versus fossil diesel fuel
- ETBE from sugar beet versus MTBE
- Wheat straw versus natural gas

For more information on these comparisons in France, see chapter 7.1.3.

In comparison with fossil energy, all the bioenergy chains represent a significant advantage in term of global impact: resources depletion such as primary energy, global warming potential. This advantage is higher with biomass as raw material for electricity and heat than with liquid biofuels. But liquid biofuels are today the single source of bioenergy for transportation. The advantage of bioenergy at the global scale is sometimes weighted by the local or regional impacts such as eutrophication or acidification. In terms of the environment, biomass utilisation may be positive but it's not automatic, especially due to potential negative impacts on a local scale. Moreover, the variability between different situations, especially at the farm scale level, may introduce a wide range of uncertainty in the local impacts. This comment illustrates the needs for the identification of the production areas where negative local impacts are minimal. Moreover, these different impacts represent a partial view of the environmental impacts such as landscape, which are directly related to the spatial distribution of the energy crops at the national scale and land use.

4.4.4 Germany

The following biofuels were investigated:

- Triticale versus coal for electricity production
- Miscanthus versus heating oil and natural gas for district heat production
- Willow versus heating oil and natural gas for district heat production
- Wheat straw versus heating oil and natural gas for district heat production
- Rape seed oil methyl ester versus fossil diesel fuel for transportation
- ETBE from sugar beet versus MTBE for transportation

The German results (see Table below) show a quite unambiguous picture: all the biofuels under study have positive impacts because they

⇒ decrease the use of non-renewable, fossil fuels,
⇒ decrease the emissions of CO_2 and thus decrease the possible greenhouse effect, but
⇒ with regard to environmental problems such as acidification, eutrophication and summer smog, the fossil fuels come out as most advantageous in most cases.

These results cannot directly be used for recommendations concerning which biofuels should be supported, if any, because this recommendation depends upon the relative importance which the reader / decision maker assigns to the different environmental impact categories. Overall it can be said that biofuels should only be supported if the decision makers value saving of fossil fuels and greenhouse effect relatively higher than the other environmental impacts. (For more details see Chapter 7.1.4.)

Impact category	**Triticale**	**Willow**	**Miscanthus**	**RME**	**ETBE**	**Wheat straw**
Use of fossil fuels	+	+	+	+	+	+
Greenhouse effect	+	+	+	+	+	+
Acidification	+/-	-	-	-	-	-
Eutrophication	-	-	-	-	-	-
Summer smog	+	+	+/-	+/-	+/-	+/-

(+) advantage for biofuel (-) advantage for fossil fuel (+/-) insignificant or ambiguous result
(see Chapter 4.1.4)

Regarding the comparisons between the various biofuels in the light of different objectives, Germany investigated two application fields and two ecological aspects:

- **Heat production: Miscanthus, willow and straw.** Whereas there is no significant difference in the results concerning the use of fossil energy and greenhouse effect, with the other environmental parameters no clear ranking occurs. Thus, the final ranking must be done by subjectively according to the priorities of the decision maker
- **Biofuels for transportation: RME and ETBE**. In all environmental categories under investigation ETBE comes out better than RME.
- **Efficiency of land use: triticale, willow, Miscanthus, RME and ETBE.** Triticale achieves good results except for the categories eutrophication and N_2O, whereas RME is the least efficient biofuel under concern, but it scores well on eutrophication. Miscanthus and ETBE achieve similar results in most categories. Similar to RME, willow has a relatively low efficiency regarding the use of fossil fuels and the greenhouse effect, but has also relatively low impacts regarding the other categories.
- **Impacts related to saved energy: triticale, willow, Miscanthus, RME, ETBE and wheat straw.** The solid fuels all save more CO_2 emissions per MJ of energy saved than the liquid fuels for transport. With regard to acidification, triticale is the only biofuel that shows a (very small) advantage; while RME has the largest impact in this category. With regard to eutrophication, straw has a much lower impact than all other biofuels.

Note that the rankings given here refer exclusively to the reliable and quantifiable parameters investigated in this project. For a further assessment other parameters must be included as were considered in this study (see particularly Chapter 6).

4.4.5 Greece

Within the context of this project the life cycle comparisons investigated for Greece were:

- Wheat straw versus light oil and natural gas for district heating.
- Sunflower oil methyl ester (SME) versus fossil diesel fuel for transportation.
- Biogas from liquid swine manure versus natural gas for combined heat and power production.

According to the results, presented in summary in the table below, all biofuels studied for Greece present advantages and disadvantages compared to their respective fossil counterparts, while the comparison of biofuels among one another does not come to a final conclusion. However the following remarks might be useful:

In the impact categories use of fossil fuels and greenhouse effect all the biofuels under study present more favourable results than their fossil counterparts. Net savings in finite energy are higher when SME replaces diesel oil while biogas instead of natural gas saves more than two times higher global warming related emissions than the other two biofuels under study.

In the impact categories nitrous oxide, acidification and eutrophication all biofuels appear disadvantageous compared to their fossil counterparts. (Note that the data for ozone depletion tend to have a high uncertainty – see Chapter 4.1.2 – and therefore these impact categories should not be included in the final assessment.)

Biogas proves to be the least disadvantageous in terms of N_2O emissions and straw concerning acidification and eutrophication related emissions.

Concerning summer smog creation all biofuels appear more favourable than their fossil counterparts with the exception of wheat straw versus light oil. Savings in the related emissions are higher in the biogas chain.

All biofuels with the exception of SME give less favourable results than the fossil fuels they are compared with in the impact category human toxicity, indicating that SME is the most favourable biofuel in this impact category (as with ozone depletion however, the data for human toxicity tend to have a high uncertainty and therefore these impact categories should not be included in the final assessment).

Impact categories	**SME**	**Wheat straw vs. light oil**	**Wheat straw vs. nat. gas**	**Biogas**
Use of fossil fuels	+	+	+	+
Greenhouse effect	+	+	+	+
Acidification	-	-	-	-
Eutrophication	-	-	-	-
Summer smog	+	-	+	+
Nitrous oxide	-	-	-	-
Human toxicity	+	-	-	-
(+) advantage for the biofuel (-) disadvantage for the biofuel				

Taking into account the above remarks no further assessment in favour or against the use of the biofuels under study instead of their fossil counterparts or one biofuel instead of another can be carried out on a scientific basis. Subjective value judgements regarding the individual environmental categories are required for this purpose, which differ from person to person.

4.4.6 Italy

The assessment of the Italian chains under study focused on the following comparisons:

- Sunflower oil methyl ester (SME) versus fossil diesel fuel
- Firewood versus heating oil and natural gas
- Biogas versus natural gas

The results can be summarised briefly as follows: it is difficult to identify the best biofuel among those studied since each one has its own characteristics and specific advantages and disadvantages, although firewood seems to be the energy carrier with the highest environmental advantages, thanks to a good performance over light oil in the whole set of impact categories considered.

In more detail:

- Use of fossil fuels: all biofuels present a better performance than the respective fossil fuels.
- Greenhouse effect: all the biofuels under study are better than the respective fossil fuels. This is due to the fact that all the CO_2 produced during the combustion of the biofuels is considered to be recycled by the growing crops.
- Acidification: all the analysed biofuels are worse than the respective fossil fuels except wood in comparison to light oil. This means that biofuels in general lead to an increase in acidification.
- Eutrophication: SME has a very good record with respect of this category due to the system expansion with soy meal which gives a credit in favour of SME.
- Summer smog: all biofuels perform differently compared to their respective fossil fuels. The biogas chain has the highest advantage, due to the credits regarding its methane content.

Impact category	**Sunflower (SME)**	**Firewood vs. light oil**	**Firewood vs. nat. gas**	**Biogas**
Use of fossil fuels	+	+	+	+
Greenhouse effect	+	+	+	+
Acidification	-	+	-	-
Eutrophication	+	-	-	-
Summer smog	-	+	+	+
(+) advantage for biofuel; (-) advantage for fossil fuel				

Two other environmental parameters were studied within this project, even if due to a high uncertainty of their base data the results should be considered with caution (for more information on these parameters see Chapters 3.4 and 4.1.2):

- Nitrous oxide: the only biofuel able to decrease the nitrous oxide is firewood for district heating. The biogas chain presents as low N_2O emissions as wood, but compared with natural gas the value for this parameter becomes negative. SME performs unfavourably with regard to N_2O because of the fertilisation of the sunflower crop. In fact, the agricultural part of the sunflower chain, even if decreased by the agricultural reference system, is characterised by a certain amount of fertiliser that leads to large N_2O emissions.
- Human toxicity: SME seems to have a little advantage over fossil diesel, firewood versus light oil seems to have a smaller advantage whereas biogas has a negative effect with respect to this impact, but again it should be stressed that the results relevant to this last impact are characterised by a large uncertainty.

4.4.7 The Netherlands

Bioenergy chains that have been investigated for The Netherlands are willow and Miscanthus for heat production, hemp for electricity, sugar beet for ETBE (transport) and biogas from pig manure. The environmental analysis leads to the following conclusions:

- The amount of useful energy produced (gross energy times efficiency of conversion) by the energy crops investigated range from 125 GJ/ha for ETBE to 212 GJ/ha for Miscanthus. As expected all bioenergy chains use far less primary energy than the fossil reference system and far less greenhouse gases are emitted. This is caused by the use of biomass for the production of biofuel instead of using fossil resources.
- Besides that, all biofuels have lower impacts regarding summer smog. Only for Miscanthus the difference between it and the fossil fuel is quite small. This is due to the combustion of Miscanthus which emits relatively more VOC and benzene than other biofuels.
- On the other hand all biofuels lead to a larger impact on eutrophication. This is partly caused by an increase in agricultural activities (fertilising) when energy crops are grown compared to fallow land in the reference system. The increased eutrophication in the case of biogas is mainly related to the increase in ammonia volatilisation from fermented manure.
- For ozone depletion only nitrous oxide is looked at. All biofuels except biogas cause a higher nitrous oxide emission than the fossil reference system. This is due to fertilising, and for Miscanthus the main reason is the emission from combustion.
- For acidification all biofuels cause a higher impact than their fossil counterparts. For hemp and ETBE this is explained by ammonia emission from fertilising. For willow and Miscanthus it is mainly caused by NO_x emissions from combustion. Biogas from manure leads to more ammonia volatilisation, which is related to the increased mineral nitrogen content in manure due to fermentation.
- For human toxicity, willow and especially Miscanthus (dioxins from combustion) have distinct disadvantages compared to the fossil fuels. The other chains have only a minor disadvantage (hemp, ETBE and biogas).
- Environmental issues that have not been included in the analysis – due to methodological or data quality problems – should nevertheless be taken into account. From an earlier study (Biewinga & Van der Bijl 1996, on energy crops in the northern part of The Netherlands) we expect that the impact on ecotoxicity and persistent toxicity from pesticides will only increase significantly when growing sugar beet. Willow, Miscanthus and hemp can be grown with little or no pesticides. The same study expects that the biodiversity – compared with grass fallow – improves when growing Miscanthus. Hemp scores neutral, sugar beet and willow score negative.

As The Netherlands are a densely populated country, land use efficiency is important. In the intensive crop rotations in The Netherlands, the space for perennial crops is limited. This limited space can be used for willow or Miscanthus. The choice probably depends on energy production (higher with Miscanthus) and polluting emissions from combustion (lower with willow). Multifunctional land use becomes more and more important in The Netherlands. Therefore biodiversity (better with Miscanthus) and landscape (better with willow, see chapter 5.3) also play an important role.

Annual crops, like hemp and sugar beet, fit much better into Dutch arable farming than perennials. In general the results for the annuals sugar beet and hemp go in the same direction, when compared with their fossil counterparts. When implemented in The Netherlands, the relatively high amount of fertilisation of hemp is a point for improvement. On the other hand, the useful energy yield of hemp is higher than from sugar beet. But of course the fuels produced are different: electricity and MTBE respectively.

Finally biogas has good perspectives in The Netherlands, because of the high availability of manure. Biogas scores better than natural gas, with exceptions for acidification and eutrophication. Biogas does not compete with energy crops, as no extra land is needed for its production.

4.4.8 Switzerland

In the result table below there is an overview of the advantages and disadvantages from the biofuels compared to their fossil counterparts. The scheme for determining and assessing the significance of the results for each impact category was published in Wolfensberger and Dinkel (1997).

Impact category	**RME**	**Firewood vs. light oil**	**Firewood vs. nat. gas**	**Biogas**
Use of fossil fuels	Very favourable	Very favourable	Very favourable	Very favourable
Greenhouse effect	Favourable	Very favourable	Very favourable	Very favourable
Acidification	Unfavourable	Comparable	Unfavourable	Unfavourable
Eutrophication	Favourable	Unfavourable	Unfavourable	Comparable
Human toxicity	Comparable	Favourable	Very unfavourable	Unfavourable
Summer smog	Comparable	Favourable	Unfavourable	Favourable

Regarding the major reasons of the authorities for promoting biofuels (saving of fossil fuels and reduction of global warming), all three investigated biofuels are highly recommendable. But one has to be aware of the fact that for biogas these advantages have to be partly paid with higher potentials in acidification and human toxicity. Moreover, the outcome for RME, which is more favourable as it was the case in previous studies (the results are unfavourable here only for acidification), partly depends on the procedure applied for taking into account the contribution of rape seed meal (this comment is valid first of all for eutrophication and the use of fossil fuels). Research is needed concerning the real relevance of these negative environmental aspects in the whole assessment. The results indicate that the probably best biofuel is wood compared to oil heating, because there only the impact potential eutrophication is unfavourable and the result does not depend on a methodological choice.

4.5 Summary of comparisons between the countries for each biofuel

This chapter is a summary of the results presented in Chapter 7.2 in the Annex, where the environmental effects of all biofuels are compared between the various countries that investigated them. **Table 4-4** lists the comparisons carried out in this context:

Table 4-4 Life cycle comparisons and the countries that investigated them

Life cycle comparison	**Countries involved**
Traditional firewood vs. light oil	Austria, Italy, Switzerland
Triticale vs. coal	Austria, Denmark, France, Germany
Miscanthus vs. light oil / natural gas	Denmark, France, Germany, Netherlands
Willow vs. light oil / natural gas	Denmark, Germany, Netherlands
Wheat straw vs. light oil / natural gas	Austria, Denmark, France, Germany, Greece
Biogas from swine excrements vs. natural gas	Austria, Denmark, Greece, Italy, Netherlands, Switzerland
Rape seed oil methyl ester vs. diesel fuel	Austria, Denmark, France, Germany, Switzerland
Sunflower oil methyl ester vs. diesel fuel	France, Greece, Italy
ETBE from sugar beet vs. MTBE	France, Germany, Netherlands

The results reflect differences in production and conversion methods within the various countries, leading to differences in the environmental performance of the different fuels. This comparison enables an assessment of where within Europe it might be most efficient to produce any of the biofuels considered here. All country representatives were responsible for the input data of their respective country.

Differences in yields also influence the results of the environmental analysis. The differences between countries are most profound with the perennial crops, which may be explained by differences in the scarce experiences with these crops and their cultivation. The influence of this variation in yields on the results is limited however, if GJ primary energy is used as functional unit. The influence is larger when the analysis focuses at efficiency of land use.

The results give a very heterogeneous picture: for certain biofuels and impact categories the differences between the countries are relatively small, while for others they are significantly large. The magnitude of the differences appears to be more dependent on the biofuel than the impact categories, thus for some chains, such as wheat straw, the values for all countries and with respect to most impact categories lie relatively closely about the European average, while for other chains, e.g. biogas, the values differ significantly. It is noticeable that with the exception of biogas for all biofuels the parameters use of fossil fuels, greenhouse effect and human toxicity show very similar results between the countries, while for the other categories the differences tend to be larger.

5 Socio-economic and political analyses

The environmental analysis is the central part of this study. But of course, the actual implementation of bioenergy depends on other factors too. What are the economic costs and benefits of bioenergy? How will the public respond to changes in the landscape due to energy crops? Particularly important for many rural areas: will bioenergy lead to extra employment? What is the view of environmental and nature organisations? And last but not least: which policies do national governments and the European Commission have? The purpose of this chapter is to complement the findings resulting from the environmental analysis. Its function is to show support, or lack of it, for the results of the environmental analysis, from a socio-economic and political point of view. The points of discussion and the institutions and laws mentioned here are to be taken as examples. It must be particularly emphasised that this is not a comprehensive analysis, as this would by far exceed the scope of this project.

5.1 Methodology and data generation

The methodology followed falls into three parts. The first part on socio-economic effects is mainly quantitative. For the cost calculation the same input and yield figures are used as have been used in the environmental analysis (chapter 4), supplemented with price data from the literature. The second and third parts are qualitative and contain effects on landscape and an impression of policy and political arguments by each country in favour of or against certain biofuel chains.

I Socio-economic aspects

All items for which data have been collected for each chain can be found in the annex (see Annex 7.5). The results reported in Chapter 5.2 may be summarised as follows:

- **Costs of farm activities:** This factor was successfully assessed for the various biofuel systems. (The costs of transport, pre-conversion, conversion, logistics and end-use were collected by the participants of the project too. However, there was a large variation between the countries, which could not be explained within the time frame of the project. As these data could not be validated, they are not included in this report. Therefore, also a comparison between biofuels and fossil fuels proved to be beyond the scope of the present project.)
- **Employment:** A large labour requirement is a positive asset when the labour is remunerated with at least a minimum remuneration per labour day. For an estimation of employment effects, extra data had to be gathered. A valuation has been made of the effects of introducing biofuels on employment for a selected number of chains, of which information was already available.

II Visual impact of landscape changes

A full ‘scientific’ assessment of the impact of energy crops on the landscape would take years. Therefore, a simple procedure that requires no field trials has been carried out regarding the effect of bioenergy production on the aesthetic, visual quality of the landscape, with special attention to the variation of structure and colour in the landscape (Biewinga and Van der Bijl 1996).

- **Effects on the variation of structure:** Important characteristics for this criterion are the height and density of the crop in relation to other crops in the area. Crops that lead to greater variation in the structure will have a positive visual impact, provided the introduction of that crop does not affect the landscape type, e. g. the openness of the landscape.
- **Effects on the variation of colour:** Crops with colours that vary from the existing crops or with a large variety of colours will enhance the landscape value and thus receive a positive evaluation.

Both parameters were assessed by the country representatives who investigated the respective biofuels. This was done by means of expert judgements based on professional knowledge and experience as well as communication with other authorities where relevant.

The main results of the analysis are shown in Chapter 5.3.

III Political factors

For a description of the major political aspects concerning biofuels, information has been collected from literature and policy documents on the following:

- **Future land claims:** One condition for growing energy crops is that in 2010 part of the agricultural area is not needed for food production anymore. There are many land use potentials other than energy crops. In some European areas there is a large pressure on land, in others land abandonment may occur. Agricultural policy is one of the main factors.
- **Alternative energy sources:** Bioenergy is one of the possible alternatives for fossil energy sources. Information is gathered on the forces and policies that promote the use of the biofuels investigated in this study, and those which promote the use of other alternative energy sources (e.g. wind, solar, nuclear).

As the information obtained is qualitative and thoroughness differs between the participating countries, the political factors in Chapter 5.4 are discussed qualitatively.

5.2 Socio-economic aspects

5.2.1 Production costs

Total production costs of energy crops consist of the sum of the costs of farm activities, transport, preconversion, conversion, logistics and end-use. The quality of the collected data sets differs for some biofuels considerably between the countries. Major differences may be attributed to differences in:

- data sources: measured values versus estimates;
- year of reference;
- availability of data;
- inconsistencies (e. g. implausible values).

The unexplained variation was in particular large for the phases behind the farm gate. Therefore, this chapter only shows the costs of the farming phase. An overview of these costs in the participating countries is given in **Tables 5-1** and **5-2**.

Table 5-1 Production costs of biofuels at farm level (€/ha yr)

	Austria	Denmark	France	Germany	Greece	Italy	Netherlands	Switzerland
Triticale	925	791	575	650				
Rape seed	798	806	669	811				2,098
Sunflower			697		691	920		
Sugar beet			998	1,073			2,134	
Hemp							1,581	
Miscanthus		1,294	639	540			883	
Willow		649		464			910	
Wheat straw	147	13	157	29	15			
Wood logs	907					575		1,203
Reference:								
Fallow	446	404	383	365	266	563	1,023	1,503

In **Table 5-1** (costs per ha) large differences between countries can be seen, except for triticale. Apart from possible inconsistencies in the data, several reasons can be found. To start with, land prices differ very much between the countries. During cultivation, differences in the production costs for the same crop result from differences in cultivation practices. For instance, in Italy and Greece no sowing is practised on fallow land, whereas seed costs in Switzerland are very high (439 Euro/ha/yr). Another example is the time consumption of soil preparation, which is highest and therefore most expensive in various crops in the Netherlands and in Switzerland.

Table 5-2 Production costs of biofuels at farm level (€/GJ useful energy)

	Austria	Denmark	France	Germany	Greece	Italy	Nether-lands	Switzer-land
Triticale	12	12	9	11				
Rape seed	40	52	43	53				158
Sunflower			55		50	60		
Sugar beet			7	17			17	
Hemp							16	
Miscanthus		1	2	3			4	
Willow		4		4			6	
Wheat straw	2.0	0.3	1.7	0.3	0.2			
Wood logs	7					5		9

Useful energy output after combustion is calculated by the yield per ha * caloric value * efficiency of combustion.

The most important explanation for variations in costs per ha is the difference in yields. In general, costs per ha are higher in countries with higher yields. Differences in yields are mainly caused by differences in soil and climate conditions. It is typical that differences in actual yields are most profound with the perennial crops, e.g. for Miscanthus in Germany yield is 14,380 kg/ha and in France 25,600 kg/ha. The same applies for willow, with a yield in Germany of 9,850 kg/ha and in The Netherlands of 19,250 kg/ha. These differences may also be explained by differences in experience with the crop and its cultivation. There was no standard methodology used for assessing yields from relatively new crops.

In **Table 5-2** (costs per MJ useful energy) the variation between the results is much smaller. This is due to the relation between yields and produced amount of useful energy. The results can be seen as an indication for the attractiveness of various energy crops for farmers. Low costs per MJ means low costs per ha and a high energy yield, thus a high income. Of course the results are only an indication, as conversion costs can be rather high and fuel prices will differ. Furthermore, farmers may have farm specific reasons to grow energy crops. For example, perennial crops are not easy to implement in an intensive arable farm.

Conclusions on production costs

For the farming phase these can be best be drawn on the basis of **Table 5-2**:

- The most interesting option is heat generation from wheat straw. Straw is a residue, to which only a small part of the production costs is allocated.
- The second best options are heat production by willow, Miscanthus and wood logs. The dry matter yields for these perennial energy crops or residues are relatively high. This is reflected in the farmers' cost range of 1 to 9 Euro/GJ useful energy.
- Farm phase costs for triticale (electricity) and sugar beet (ETBE) are slightly higher.
- Finally the farming costs for rape seed (RME) and sunflower (SME) production are clearly much higher (around 50 Euro/GJ useful energy).

5.2.2 Employment

Data on the effect of biofuels on employment are scarce and mainly concern estimates at a global level. However, some observations can be made.

Sector level estimates: in the Community's "White Paper" (European Commission 1997) it is stated that "biomass has the particularity of creating large numbers of jobs for the production of raw material." The so-called TERES II study predicts that renewable energy sources (mainly biomass, wind and solar energy) will create 500,000 direct jobs in the renewable sector and indirect jobs in the supplying sectors. The European Biomass Association assumes a necessity of 1 million jobs to achieve a share of 12 % of renewable energy from biomass. A comprehensive development of bioenergy in Austria could create 30,000 new jobs (Köpetz, in Prankl & Wörgetter 2000). According to CIEMAT (data quoted in Itabia position paper) the labour requested to produce electricity by bio-resources is 15 times the labour requirement to produce the same quantity of electricity by coal. Of the biofuels, transport fuels seem to create relatively large numbers of jobs. For example, a study on biodiesel production in Germany speaks of a net positive effect of 5,000 jobs, associated with 300,000 ha rape seed for biodiesel (Schöpe 1996).

The sector level data seem to overestimate the employment effects, when a more detailed level is looked at. Note that only a few examples will be mentioned.

On the farm: for employment on farms we should look at the labour demand of energy crops versus grass fallow. Biewinga and van der Bijl (1996) provide labour requirements for energy crops in the Netherlands. Annual crops have a requirement of 2 to 4 labour days per ha per year. Perennials cost about 1 day per year, which is the same as the labour costs for rotational set aside. Compared with grains, perennials even lead to a loss of employment. The "Short-Rotation Willow Coppice – Growers Manual" (Swedish Institute of Agricultural Engineering 1998) reports that the labour requirement for growing willow is less than for grain production. They state: "During the planting year, the labour inputs of the grower may be of the same magnitude as in grain production. In subsequent years, the labour requirement for the grower is only one to two hours per hectare per year." Data from Greece for biogas production show that it takes 2 hours a day to operate a relatively small biogas plant. It seems that small-scale production might raise the labour hours needed.

Conversion / Combustion process: the specific manpower needed depends on the size of the plant as can be seen in **Table 5-3**. The table shows an example for rape seed oil and RME production in Germany. The data for German fossil oil refineries (about 15 plants, each with several millions of tons output) are also given. **Table 5-4** shows corresponding data for electricity from biomass (Miscanthus and willow for instance) and public power production (dominated by large plants). The combustion plant in Ostritz-St. Marienthal is almost fully automatic. The number of employees for the Schonau-Altenstadt plant might also include "paperwork-personnel".

The tables show that the specific demand of manpower in the larger biofuel plants is more or less the same as in an average oil refinery (comparison with RME) or an average power plant (comparison with electricity from solid biomass).

Table 5-3 Employment in rape seed oil or RME plants and fossil oil refineries (Germany)

Plant size	Annual production t oil or RME / year	Number of employees	Person-h per t oil or RME
Small decentralised pressing plant	75 (oil)	0.25	5.87
Pressing plant (5 times the size of the small one)	800 (oil)	1	2.20
Average oil mill / pressing plant	100,000 (oil)	15	0.26
Large oil mill / pressing plant / extraction plant	300,000 (RME)	60	0.35
Very large oil mill / pressing plant / extraction plant	900,000 (RME)	120	0.23
German fossil oil refineries in 1997	110 Mio. (all prod.)	19,000	0.32

Source: MWV 2000; assumptions by IFEU (1760 h/(worker*a))

Table 5-4 Employment in biomass and traditional power plants (Germany)

Combustion plant	Annual production MWh/a*	Investment costs (Euro)	Number of employees	Person-h per MWh**
Biomasse-Heizkraftwerk Ostritz-St. Marienthal (12.8 MW)	100,915	12,270,000	4	0.070
Biomasse-Kraftwerk Schonau-Altenstadt (10 MW (electricity), 35 MW (heat))	78,840	28,890,000	20	0.45
Public power in Germany 1997	549,000,000		224,100	0.72

Source: plant owners; BMWi 1999; assumptions by IFEU; * 7884 h/a ** 1760 h/a person-h/a

Conclusions on employment effects

- Estimates at sector level show a large employment effect, up to 1 million jobs in the EU if the potential for biomass is fully exploited.
- More detailed examples provide a more prudent estimation. At farm level, more employment is created with annual crops (e. g. sugar beet) than with perennial crops (e. g. willow). In the conversion / combustion process, employment effects in the liquid biofuel chain seem to be mainly related to the scale of the plant, whereas the solid biofuels do not provide extra employment at all.
- Extra labour requirement will be needed to produce bioenergy, but this is possibly relatively small. However, bioenergy still may have positive employment benefits. It may cause employment shifts from urban to rural areas. This is in particular important in areas where the growing of food crops has competitive disadvantages (compared to other EU regions) and the alternative would be abandonment and marginalisation.

5.3 Visual impact of landscape changes

The assessment of the visual impact of biofuels on landscape as compared to an alternative one-year fallow (regarding annual crops) or a long-term fallow (regarding perennial crops) is qualitative. We give a description of the effect of energy crops on the variation in colour and structure, illustrated with examples from the various countries.

5.3.1 Variation in structure

Most of the energy crops in this survey do not contribute positively to the variation in structure of the landscape. Wood is the only source of bioenergy for which a positive score on this aspect was given (Italy). Other energy crops, such as triticale and sugar beet are most likely to be grown in regions where their cultivations (for food and feed purposes) have already been established. It depends on the relative proportion of the extra area of these already established crops whether its effect is regarded as ‘neutral’ (France) or ‘negative’ (Germany, Netherlands, Denmark). In Germany set-aside fallow land is cultivated in various ways, thus favouring this reference crop to monocultures of cereals and sugar beet.

The perennials Miscanthus and willow contribute largely to the variation in structure of the landscape. Miscanthus is furthermore characterised by a relatively high diversity throughout the year (growth period ‘from zero to 3 meters, maturation period, drying period), whereas the cultivated fallow land is closer to conventional agriculture (Germany). Willow (SRF – short rotation forestry) contributes to landscape structure over its growth period of several years. Due to the historical values of willow in the landscape, small or medium-sized plantations of SRF may be perceived positively by the public (Netherlands). Indeed, the exact location of the plantation and the shape of the plantation’s edge may be crucial factors in the question whether SRF is actually appreciated (Denmark).

5.3.2 Variation in colour

The shining bright yellow flower of rape seed is very attractive, both to the farmer and the public (Germany, Netherlands, Switzerland). However, flowering only occurs for a restricted period of time. Thus during a large part of the year this crop is visually not very attractive, resulting in disapproval of

the crop (Denmark). Experience in Switzerland with rape seed shows not much difference in attractiveness compared to small strips of fallow. Large fields of fallow could be disapproved of due to the impression of decay and disorder during winter. Sunflower is much appreciated for its yellow flowers (Greece, Italy – northern plains). On the other hand, the perception of this could be negative in hilly regions with its own colour changes (Italy – central part).
Miscanthus and willow do not offer much for variation in colour compared to fallow crops with high diversity in colour and in flowering periods.

A summary of the results is given in Table 5.5, showing the overall conclusion per crop as assessed by expert judgements per country.

Table 5-5 Expert judgements on visual impact of landscape changes by energy crops

	Positive	Negative	Neutral
Triticale		Germany, Denmark	France, Austria
Rape seed	Germany, Switzerland Netherlands, Austria	Denmark	France
Sunflower	Italy (north), Greece	Italy (central)	France
Sugar beet		Germany, Netherlands	France
Miscanthus	Denmark	Denmark	Germany, Netherlands, France
Willow	Denmark, Netherlands	Denmark	Germany
Firewood	Italy, Austria, Switzerland		
Hemp			Netherlands

It should be noted that these results are neither objective nor representative of the respective populations. Nonetheless they give an illustration of the impact of energy crops on landscape and confirm that the perception of people towards the impact of energy crops on the landscape varies within countries and between countries.

Conclusion on visual impact of landscape changes

- The method to assess the impact of biofuels on landscape by the variation is structure and colour seems a valuable method that is relatively easy to carry out and for which data are readily available. However, the method needs improvement on aspects relating to objectiveness and representativity.
- The clear yellow flowers of rape seed and sunflowers are appreciated by many. However, in areas that are attractive without these flowers, their introduction may be seen as a disruption.
- The positive contribution of perennials to the attractiveness of a landscape is due to their variation in structure; while the negative aspect lies in the fact that the same crop remains for many years and that in the later stages the crops may block the view as a result of their height. All in all the positive and negative aspects appear to balance each other out.

5.4 Political factors

How does the future for bioenergy look like? This depends on the demand for bioenergy and the space for producing it. At this moment, bioenergy is hardly an interesting energy option. It is clear however that there is a societal demand for green energy, in order to reduce the greenhouse effect. The European Commission's White Paper "Energy for the future: renewable sources of energy" (European Commission 1997) clearly states that most sources of bioenergy should be promoted with all possible means. Currently biomass accounts for 3 % of total inland energy consumption (for the EU15). If bioenergy is promoted effectively, an increase up to 8.5 % should be feasible. The White Paper also states that no more than 7 % of the agricultural area in the EU could be used for biomass crop production in a sustainable way. Moreover, surplus agricultural land can also be used for other purposes. One could extensify food production (less fertilisers and pesticides) or even go for organic food production. For this, more land is needed, due to lower yields. Another option is to expand nature areas. Clearly, the implementation of bioenergy does not only have advantages. This chapter will give an impression of the political arguments pro and con bioenergy.

5.4.1 Land availability

The utilisation of land for agricultural and non-agricultural purposes is a point of great interest in all countries. It bears heavily on the perspectives for energy crops, since this new agricultural activity must compete with already established activities. Land availability is and will be determined by world food market considerations. Processes and uncertainties are illustrated by Gosse and Mauguin (1997) by the world grain market and the EU position in this global market. They show that both the mean grain production per inhabitant and the area devoted to grain production is roughly stable since 1965. In the mean time the population has increased rapidly. The rising demand is fulfilled through increasing yields. Further yield increases are expected due to genetic improvements and better fertiliser end crop protection management. For the EU as a grain producer this will lead to either an increasing supply to the world market and/or a larger land availability.

In all countries, changes in the utilisation of land are expected, although in Germany it is a political goal to maintain the area for agriculture at the present level. In the Netherlands, agriculture is shifting from 100 % food production to agriculture with various functions at the same time, e.g. combinations of agriculture, recreation, and non-food crops. In many countries changes in land utilisation are expected from the increasing interest in organic farming (Netherlands, Greece, Denmark). This will lead to more extensive types of agriculture, requiring more fields to maintain production, as is foreseen in the case of Switzerland.

As a result of the expected changes in land utilisation and agriculture, the availability of land for growing energy crops is likely to change as well. However, it is not clear yet what the outcome of the development and the discussions in the countries will be. Technical explorations show that the possibilities exist to have 40 to 100 million ha of agricultural land available (EU-12) for other purposes by the year 2025 (Ground for Choices 1992). An increased emphasis on extensification, nature development, new outlets and reduction of imports may have the result that land availability becomes the major threshold for energy crops. The “White Paper” (1997) says that it is doubtful that more than a maximum of 10 Million hectares, i.e. 7.1 % of the agricultural area would be sustainable for bioenergy production. The actual availability of land will vary from one region to the next.

National governments may fulfil their Kyoto-reduction partly with biofuels. In some of them scenario studies have been carried out to assess the potentially available area for energy crops. In the Netherlands, a maximum of 200,000-400,000 ha would be needed for energy crops to deliver a substantial contribution (NOVEM 1999). This is a very small area as compared to the other countries. So far, no government directives are known that regulate the area available for energy crops.

5.4.2 Environmental groups

Environmental groups in the Community have different opinions about biofuels. The German branches of Greenpeace, WWF (World Wide Fund for Nature) and BUND (Bund für Umwelt- und Naturschutz Deutschland / Friends of the Earth Germany) call for a significant increase in the usage of renewable energies (while demanding first of all to save energy). When it comes to translating such ideas into public policy however, there are in some cases substantial doubts. For instance, Friends of the Earth, active in various countries, is against large-scale cultivation of bioenergy carriers. The reason is that this results in monocultures, with negative impacts on landscape and environment. The Danish branch of Friends of the Earth (NOAH) makes in its support for bioenergy a distinction between annual and perennial crops. Their argument is that annual energy crops will decrease the humus and carbon content of the soil; for the same reason they are against the use of straw for energy.

Environmental groups in the Netherlands are in the position to support biofuels under strict conditions. This is for example the case with an energy forest of 200 ha in Flevoland in which they participate, together with a. o. Shell and the energy company NUON. Energy crops should be implemented in the landscape with care. Preferably energy crops contribute to biodiversity instead of being monocultures with little nature and landscape values. Pollution from energy crops by fertilisers and chemicals should be limited.

Energy companies are developing an interest in bioenergy. This is true e. g. for Shell and British petrol, but also for national electricity producing companies in the Netherlands, Denmark and Germany.

5.4.3 Fair competition

Recently, the EC decided to open up the energy market (liberalisation). Energy producing and distributing companies are becoming responsible for the buying and selling of energy to the consumers, who in the future can buy energy from any energy company. An open market is characterised by fair competition between the producers of the goods. This means that there should be no regulations favouring one source of energy to another and that the economics of bioenergy will ultimately determine the production and use of biofuels. Unfortunately, internalisation of external costs is not widely practised by the energy producing and distributing companies: the environmental damage resulting from energy production is not reflected in the cost price. However, in some countries the national regulations concerning the emissions from new installations seriously limit the development of new lines of energy production such as bioenergy (Germany, The Netherlands). It is likely that in these countries initiatives for bioenergy will be transferred to countries with less severe regulations as a result of this. In addition to this, environmental groups such as Greenpeace have shown that in total fossil fuels receive much larger subsidies for their production than renewables (959.5 million US$ and 131.3 million US$ respectively annually in the period 1990-1995) (Greenpeace 1997).

5.4.4 Introduction of biofuels in agricultural practice

The introduction and expansion of biomass from agricultural and forest sources is difficult to achieve. Farmers experience three main constraints with biofuels: unfavourable farm economics, poor integration in existing cropping systems and poor logistics concerning harvest and post-harvest management. Farm economics have already been discussed in section 5.2. Poor economics are a feature of all biofuels alike, although clear differences between crops exist. The other constraints are known mostly of arable cropping systems with a four-year rotation of annual crops. Farmers in Germany, Denmark and the Netherlands know that perennial crops such as Miscanthus and willow do not fit well in their rotations. The establishment of perennials requires high investments and it takes about 5 years before perennials begin to pay off. Thus, farmers are not able to respond flexibly to changes in prices or financial support, e.g. area payments under the set-aside scheme. In addition, perennials in arable farming shorten the rotation, which may lead to an increase in infestation pressure. A higher proportion of sugar beet and rape seed in the rotation may have the same effect. Farmers also experience difficulties with the harvest of perennials and the subsequent post-harvest management. Appropriate machinery for the harvest and chipping is often not available, and storage facilities and transportation are inadequate as well.

National governments – facilitated by the EU – have implemented some financial incentives to stimulate farmers and foresters to produce biofuels, for example:

- Growing energy crops on set-aside land. The set-aside premium given to the farmer makes the cultivation of energy crops more or less economically viable.
- Payments per ha/yr for oil seed production and the energy conversion of biomass that could also be used for food or feed (Switzerland, only for pilot and demonstration plants).
- Investment subsidies for the production of biomass from annual and perennial energy crops (Development Law 2601/98, Greece), smaller biomass based boilers (Law on use of sustained energy sources, Denmark).

Other financial incentives can be given either in the shape of subsidies or security of demand, but can also be integrated with other policy goals. An example of the latter is the policy regarding biogas in Denmark: when the *Water Environment Act I* was launched in 1987 with a demand for increased capacity for storing manure, a range of central biogas plants was established. By 1995 the increased capacity prescribed by law should be reached, and the expansion stopped. Today only few new biogas plants are established, even though most biogas plants have a waiting list of potential suppliers of manure (Hjorth-Gregersen, 1998).

It has to be noted that financial incentives are not the only means to encourage the production of biofuels. Other policy instruments may be helpful as well, in particular extension services and research and development on cultivation and harvest. Certainly of major importance is the influence of the Common Agricultural Policy. Currently, the growing of energy crops on set-aside land may be interesting for farmers. However, the opportunities following the requirement that farmers leave 15 % of the land fallow are decreasing, now that Community food stocks are on the decline. Food production will remain the core business of European farmers, and energy crops will be a valuable addition to farmers' income in times of surpluses.

5.4.5 CO_2-reduction policies

Following the Kyoto convention, virtually all countries have implemented a general policy to increase production from alternative energy sources. For instance in the Netherlands, where a goal is set by the Ministry of Economic Affairs for a 10 % production of alternative energy in 2020. It is a goal of the Danish government that 20 % of the Danish electricity consumption in 2003 should be produced from renewable energy. In most countries, the means to achieve such goals and the utilisation of which types of energy sources are to be particularly encouraged have not been decided and has practically been left to the market to decide.

The Kyoto protocol states that extra carbon sequestration through forestry can be taken into account with 1990 as the reference year. To which extent changes in C-sequestration caused by changes in land use (e. g. changes of crops or ploughing at less depth) are allowed to be included is not clear yet. On this contribution a decision will be made at the Conference of Parties (COP6) in The Hague, November 2000. The European Commission is critical about the recognition of C-sequestration as a measure to achieve the Kyoto goals. The reason for this is a fear that particular soils, which have the potential to contain a lot of carbon, would benefit from this. The United States is one of the countries that could profit from it. Nevertheless, if farmers could receive payments for C-sequestration through land use changes, this could be interesting for European farmers too. It could give an extra profit to farmers growing energy crops, provided that the carbon content in the soil increases by growing the energy crop.

In some countries, e.g. Germany and the Netherlands, the subject of renewable energy sources is not being dealt with by a single ministry or department, but by a number of different ministries as well as various departments. Each governmental body deals with a different aspect of the subject matter, as for example economical, ecological or agricultural factors. Consequently, governmental opinions on the perspectives of biofuels may differ according the governmental body. In the Netherlands, for instance, biofuels are favoured mostly by the Ministry of Economic Affairs whereas the Ministry of Agriculture shows less interest in the subject.

In the "White Paper" (1997) on renewable energy the European Commission declares to make additional proposals for legislation and amendments to existing directives, including tax exemption on renewable energy sources. The Commission wants to encourage Member States to promote renewable energy. This can be done by flexible depreciation of renewable energy investments, favourable tax treatment for third party financing of renewable energies, start up subsidies for new production plants, green funds, public renewable energy funds and soft loans and special facilities from institutional banks (White Paper 1997). Detaxation of biofuels is currently made on a limited scale. EC Directive 82/81 on harmonisation of the structures of excise duties allows such detaxation on a pilot scale. The Commission considers a market-share of 2 % for liquid biofuels (almost reached by Austria, Germany, France and Italy) still as a pilot phase.

Examples of government incentives are:

- Guaranteed higher financial return for renewable energy than for conventionally generated electricity (Stromeinspeisungsgesetz, Germany).
- Regulation of electricity from renewable sources on the grid (Law 2244/94, Greece) and of licensing procedures (Greece).
- Tax relief on biofuels. A tax relief is for example the exclusion of RME from the oil tax (Mineralölsteuerbefreiung, Germany, Switzerland, only for pilot and demonstration plants). In the Netherlands exclusion of bioethanol from the energy tax takes place as a pilot project and for electricity and heat that has been produced sustainably this is currently being proposed. In France there is a tax relief on RME, SME and ETBE. The Austrian Law on Tax Reform 2000 exempts the use of pure biodiesel and the blending of biodiesel up to 3 %.
- Green certificates: energy that has been produced sustainably may opt for a green certificate (currently being investigated in the Netherlands). Labelling of renewable energy takes place in Germany.

Conclusions on political factors

- In order to successfully introduce or increase the cultivation of energy crops, not only laws and directives are needed but also the support from local authorities, environmental groups and farmers.
- Land availability in the EU may in theory rise by up to 100 million ha. However, to dedicate a maximum of 10 % of this area to bioenergy is more realistic. An increased emphasis on extensification, nature development, new outlets and reduction of food imports leads to alternative uses of available land.
- Environmental groups are in favour of renewable energy, but are worried about the effects of energy crops on the landscape (monocultures) and emissions of pesticides and fertilisers. They tend to be more in favour of perennial crops instead of the more intensive annual crops.
- Despite the goal of opening up the energy market, there is no level playing field as yet. Major distortions are the differences in environmental regulations and in subsidies, giving fossil fuels advantages over renewables. The tax reliefs for biofuels which are in force in some Member States, the legal possibility for farmers to grow energy crops on set-aside land and national regulations and targets for the production of green energy help to overcome these competitive disadvantages.

6 Conclusions and recommendations

As explained in Chapter 2, in this project ten different biofuels were assessed and compared to equivalent fossil fuels with regard to their environmental impacts and nine of these were investigated for the whole European Union. Eight European countries participated in this study for which also different biofuels out of these ten were investigated.

This chapter provides a brief summary of the main findings presented in this report and subsequently conclusions and recommendations will be given. In accordance with the goals of this study and the chosen methodology, the following issues will be addressed:

- Results of the comparisons ”biofuels versus fossil fuels”
- Results of the comparisons ”biofuels versus biofuels”
- Results of the comparisons between the countries for each biofuel
- Results of the socio-economic and political analyses
- Conclusions and recommendations

I Results of the comparisons "biofuels versus fossil fuels”

The purpose of the comparisons between the various biofuels and their fossil counterparts investigated in this project was to show the environmental advantages and disadvantages of the different fuels in the various countries involved as well as the European Union. This was done by means of life cycle analyses (LCA). Several environmental impact categories were investigated for this purpose. It was found that for some of these no quantitative results could be obtained within this project that were reliable enough for a sound scientific assessment. This was partly due to the lack of sufficiently developed methodology and partly to the lack of available data, given the scope of this study.

The following categories were assessed quantitatively and yielded results that can be regarded as very reliable:

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog

In addition, the categories/parameters below were also assessed quantitatively but yielded much less reliable results.

- Ozone depletion by nitrous oxide
- Human toxicity
- Ecotoxicity
- Persistent toxicity
- Ecosystem occupation
- Harmful rainfall

The net effect of nitrous oxide regarding ozone depletion is not ascertained as yet, as explained in Chapter 3.4.2. The results are included in the graphs but should be regarded with caution. The category human toxicity was also included in the result diagrams, but should be taken into consideration with care, as the data are of a lesser reliability than those for the categories in the first list above. The categories ecotoxicity and persistent toxicity were found to yield results too unreliable for further assessment. Finally, the category biodiversity and soil quality was investigated regarding four parameters, for two of which quantitative results were obtained which again however did not possess a satisfactory level of scientific reliability. It must be concluded that for the toxicity the lack of data concerning fossil fuels made the systems incomparable. For the biodiversity and soil quality categories further methodological developments are required before these can form a reliable part of a life cycle assessment.

Regarding the categories for which reliable values were obtained, the results are summarised below (see also **Table 6-1**). The full results are given in the Chapters 4.1 (for Europe) and 7.1 (for each country). The main conclusions are generally similar between the various countries and Europe:

Use of fossil fuels: all biofuels have, to a greater or lesser extent, advantages over their fossil equivalents regarding this category. This is due to the fact that through the production and use of biofuels the utilisation of fossil fuels is reduced.

Greenhouse effect: this factor is causally connected to the use of fossil fuels (which leads to the emission of greenhouse gasses) and therefore gives very similar results, i. e. always to the advantage of the biofuels.

Acidification: most biofuels show disadvantages for this category as well, with the exception of triticale and traditional firewood.

Eutrophication: again the biofuels compare unfavourably against their fossil equivalents. The only exceptions are RME and SME in certain countries, which receive credits for co-products that make up for the impacts caused by the biofuel production and utilisation. The large differences for the cultivated crops are due to the utilisation of fertiliser and its inevitable partial escape into water bodies.

Summer smog: most biofuels have (relatively small) advantages over the fossil fuels, with the exception of the transport fuels where the results cannot be regarded as significant.

Table 6-1 Results of the European comparisons between biofuels and fossil fuels

Biofuel	Use of fossil fuels	Green-house effect	Acidifi-cation	Eutro-phica-tion	Summer smog
Triticale	+	+	+/-	-	+
Willow	+	+	-	-	+
Miscanthus	+	+	-	-	+
Rape seed oil methyl ester (RME)	+	+	-	-	+/-
Sunflower oil methyl ester (SME)	+	+	-	+/-	+/-
ETBE from sugar beet	+	+	-	-	+/-
Traditional firewood	+	+	+/-	-	+
Wheat straw	+	+	-	-	+
Biogas from swine excrements	+	+	-	-	+

+ advantage for biofuel; - advantage for fossil fuel; +/- insignificant or ambiguous result

The following categories/parameters yielded results which – for various reasons explained in each section – are less reliable than those discussed above:

Nitrous oxide: all biofuels have higher emission values than the fossil fuels. The large differences for the cultivated crops are due to the utilisation of fertiliser in agricultural production. Since however the net effect of nitrous oxide regarding ozone depletion is not yet ascertained, the results should not form a part of a final assessment.

Human toxicity: this category assesses human toxicity via air. Depending on the comparison the results showed either very small differences or else were in favour of the fossil fuels. Due to a lack of data however, the results have a high uncertainty and should therefore not form a part of a final assessment.

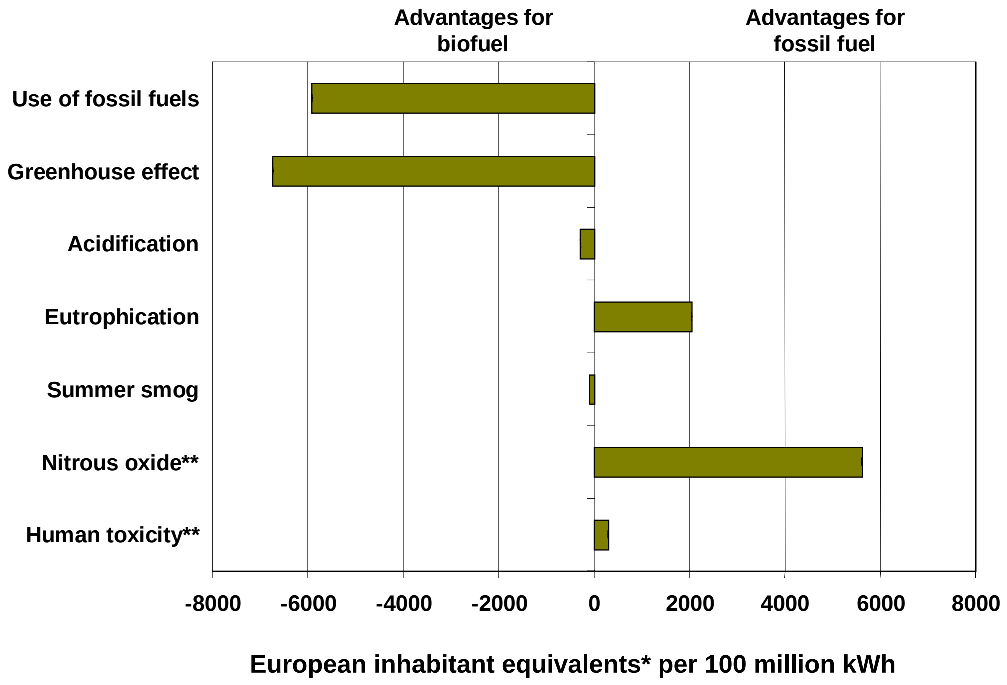
Ecotoxicity and persistent toxicity: these categories assess acute and persistent toxicity towards humans and ecosystems. It was decided not to include these results in the graphs because of a lack of data and more specifically inconsistencies in data quality for the two compared systems: for biofuels, pesticides were assessed on a very detailed level, whereas the same level of detail was not obtained for the fossil fuels. Due to these differences, it was not possible to draw any conclusions, but the data on biofuels serve as a good basis for further work on the subject.

Biodiversity and soil quality: this category was assessed using four parameters, namely

- ecosystem occupation as an indicator of loss of biodiversity,
- ecosystem occupation as a measure for life support functions of the soil,
- harmful rainfall (as an indicator of erosion) and
- soil compaction.

For the first and the last one of these no results were obtainable due to a lack of suitable methodology and data. Regarding ecosystem occupation as a measure for life support functions of the soil there appears to be a difference in the impacts of cereals, perennials, and other crops respectively. However, more research is needed to verify and explain this result. Perennial crops and cereals with short row intervals show lower erosion risks due to their higher degree of soil cover, which reduces the effect of harmful rainfall.

Result of the comparison between triticale and hard coal for electricity production



*** How to interpret the diagram**

The figure shows the results of comparisons between complete life cycles where hard coal is substituted by triticale for electricity generation. The unit refers to an amount of one hundred million kWh of electricity. This is equivalent to the average electricity requirement of about 20,000 inhabitants of Europe in one year or a triticale production of about 5,500 ha/a. In this case for example the amount of fossil fuel saved is equal to the amount which nearly 6,000 European citizens would on average consume in one year (this is what is meant by “European inhabitant equivalents”).
See Chapter 4.2.1 for a discussion of the results.

Figure 6-1 Example of result diagram for the comparison between triticale and hard coal

Result interpretation: concerning the interpretation of the results, different approaches are possible, since this part goes beyond the scientific analysis and incorporates subjective choices. For the presentation of the quantitative results two different approaches were chosen by the various country representatives, as explained in Chapter 3.5. The first involved a discussion of the direct values calculated in the life cycle impact assessment. The second one used converted units in order to enable a comparison of the relative impacts regarding the various categories. For this purpose the so-called inhabitant equivalents were used, which express the impacts of the respective fuel production and consumption in comparison to the average annual impacts of the country inhabitants of the particular country. The latter form was chosen for Europe also. (**Figure 6-1** shows an example of a result diagram for Europe.) It should be stressed that this choice is a subjective one concerning the form of presentation only and does not influence the results. Furthermore certain country representatives, as in the case of Greece, chose to summarise their results in the form of simplified tables.

To summarise: a final assessment in favour of or against a particular fuel cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required, which differ from person to person. Whether a specific biofuel is assessed as better or worse than its fossil equivalent depends upon the focus and priorities of the decision maker. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, then the biofuel will be better suited. If on the other hand other parameters are deemed to be most important, then depending on the specific results of the comparison in question, the fossil fuel might be preferred. Thus decision makers, political institutions, etc. are encouraged to carry out their own assessment on the basis of the results presented here, and – very importantly – to express their priorities by which they carry out the assessment.

II Results of the comparisons “biofuels versus biofuels”

In this part those biofuels which fulfil the same purpose were compared against each other, for Europe and for each individual country (Chapters 4.2 and 7.1 respectively). The following issues were addressed:

- Technical applications I: heat production
- Technical applications II: transport
- Ecological aspects I: efficiency of land use
- Ecological aspects II: impacts related to saved energy

The comparisons were carried out on the basis of the differences between the biofuels and their respective fossil equivalents with regard to the same environmental impact categories referred to in the previous section. It should be noted here that a comparison of products with different end-uses is difficult. For example, the energy demand for space heating can be covered by ambient and solar heat as well as all types of biomass with proven technologies. The technological requirements on fuels for power production on the other hand are higher. Electricity can be produced easily from biogas, but because of the amount and the properties of the ash of triticale further research and development are necessary when it is used in power plants. Ethanol and vegetable oil methyl esters are the only renewable transport fuels which have reached market maturity.

Heat production: traditional firewood, Miscanthus, willow and wheat straw were compared against each other. Regarding the use of fossil fuels and the greenhouse effect there are no significant differences between any of the biofuels, but traditional firewood shows the most favourable values in all categories apart from summer smog (for which the results are too small however to be regarded as significant).

Transport: RME, SME and ETBE were compared against each other. SME achieves the best results regarding the use of fossil fuels, the greenhouse effect and eutrophication, while RME achieves the lowest for most categories.

Efficiency of land use: triticale, willow, Miscanthus, RME, SME and ETBE were compared against each other. In this case the impacts of each fuel produced on an equal amount of land area were assessed. Triticale reveals by far the highest benefits regarding the categories use of fossil fuels, greenhouse effect and acidification. However, it has also the greatest disadvantages with respect to ozone depletion and eutrophication. RME and SME show the smallest advantages regarding the use of fossil fuels and the greenhouse effect.

Impacts related to saved energy: here the comparison revealed the "side-effects" of each biofuel for every MJ saved through its use instead of the fossil fuel. All biofuels were compared against each other. The results here are very heterogeneous, depending on the biofuel and "side-effect" impact category respectively. For every MJ fossil energy saved, a reduction in greenhouse gas emissions also ensues for all biofuels. This effect is by far the greatest for biogas, followed by triticale, and is lowest for RME. On the other hand, for most of the biofuels a negative "side-effect" results compared to the fossil fuels regarding most other categories.

To summarise: no single biofuel can be regarded as "the best" for any of these issues. An evaluation must consider the different types of energy (for space heating, power production, transport fuel), the different levels of technological development (mature technology, demonstration or pilot stage, experimental) and additionally the subjective judgements of the individual decision maker regarding which of the impact categories is most important. Still the observations listed above can be useful in such a decision process. These results themselves can be regarded as very reliable, since generally the uncertainties of the data for the various biofuels are due to similar factors and therefore tend to cancel each other out in the comparison among each other.

III Results of the comparisons between the countries for each biofuel

Here the results of each country for each biofuel were compared against each other. This was done with regard to the differences between the biofuels and their corresponding fossil fuels. For further details on this as well as the presentation of the result graphs the reader is referred to Chapter 7.2.

The results give a very heterogeneous picture: for certain biofuels and impact categories the differences between the countries are relatively small, while for others they are significantly large. The magnitude of the differences appears to be more dependent on the biofuel than the impact categories, thus for some chains, such as wheat straw, the values for all countries and with respect to most impact categories are relatively similar to the European average, while for other chains, e. g. biogas, the values differ significantly. It is noticeable that with the exception of biogas for all biofuels the parameters use of fossil fuels, greenhouse effect and human toxicity show very similar results between the countries, while for the other categories the differences tend to be larger.

Differences in yields also influence the results of the environmental analysis. The differences between countries are most profound with the perennial crops, which may be explained by differences in the scarce experiences with these crops and their cultivation. The influence of this variation in yields on the results is limited however, if primary energy is used as functional unit. The influence is larger when the analysis focuses on efficiency of land use.

IV Results of the socio-economic and political analyses

The purpose of these analyses was to complement the findings resulting from the environmental analysis. Their function was to show support, or lack of it, for the results of the environmental analysis, from a socio-economic and political point of view. It must be particularly emphasised that this part of the assessment is not a comprehensive one, as this would have exceeded the scope of this project by far. Also, in many cases the methodology was not advanced enough or insufficient reliable data could be obtained to enable an adequate assessment. This present assessment comprised three sectors: economic aspects, visual impact of landscape changes and political factors.

The first part is mainly quantitative. For the cost calculation the same input and yield figures were used as in the environmental analysis (Chapter 7), supplemented with price data from the literature. The second and third parts are qualitative and contain effects on landscape and an impression of policy and political arguments by each country in favour of or against certain biofuel chains.

Economic aspects

- Due to the lack of reliable data the economic analysis could only be carried out for forestry and agricultural production of the biofuels. The processing and utilisation as well as the production of the fossil fuels and a final comparison could therefore not be carried out.
- The economic analysis of forestry and the agricultural production of the biofuels showed partly large differences between the various countries. This is due to differences in land prices, production costs, cultivation practices and yields. A cost assessment based on the production costs at farm gate level leads to the following ranking (based on useful energy as a reference unit): wheat straw is the most economic option (being a residue produced at low costs), followed by willow, Miscanthus and wood logs, then triticale and ETBE and finally rape seed and sunflower as the most expensive ones.

Visual impact of landscape changes

- The bright yellow flowers of rape seed and sunflowers are widely appreciated. However, in areas that are attractive without these flowers, their introduction may be seen as a disruption. Furthermore, especially with regard to sunflowers, the crop is not particularly sightly outside the flowering period, which only lasts for about a month.
- The positive contribution of perennials to the attractiveness of a landscape is due to their variation in structure; while the negative aspect lies in the fact that the same crop remains for many years and that in the later stages the crops may block the view as a result of their height. All in all the positive and negative aspects appear to balance each other out.
- The method to assess the impact of biofuels on landscape by the variation in structure and colour seems a valuable method that is relatively easy to carry out and for which data are readily available. However, the method needs improvement on aspects relating to objectivity and representativity.

Political factors

- In order to successfully introduce or increase the cultivation of energy crops, not only laws and directives are required but also the support from local authorities, e.g. environmental groups and farmers.
- An increased emphasis on extensification, nature development, new outlets and reduction of imports may have the result that land availability becomes the major limiting factor for energy crops.
- Despite the goal of opening up the energy market, there is no level playing field as yet. Major distortions are the differences in environmental regulations and in subsidies, giving fossil fuels advantages over renewables.
- With certain biofuels farmers experience three main constraints: poor farm economics, poor fit into cropping systems and poor logistics concerning harvest and post-harvest management.
- Within the liberalised energy market, temporary regulations are required to ensure the contribution of energy crops to the national CO2-reductions.

V Conclusions and recommendations

The objective of this study was to create a decision tool, based on reliable scientific data, with regard to the question of which biofuels or fossil fuels are ecologically the most suitable for specific purposes and countries within Europe. Within the scope of this project this goal has been partly successfully achieved:

- The LCA method has been adapted so that any energy carrier can be assessed (10 biofuels were investigated in this project).
- The calculation tool has been successfully implemented.
- The socio-economic analysis on the other hand was only partially successful.

One important outcome however is the realisation that with respect to certain environmental impact categories – i. e. toxicological impacts as well as biodiversity and soil quality – the data availability and current methodology is as yet not adequate for a reliable scientific assessment. Furthermore, the socio-economic and political analyses could not be carried out in sufficient depth to allow their inclusion in a final assessment. This was due to the relatively poor data availability and the resource limitations of this project. In all these subject areas it is urgently required to carry out or continue relevant work on the methodological developments.

Regarding the *comparison between the biofuels and fossil fuels* the most significant findings were as follows:

- Concerning the major goal of the target groups with respect to the promotion of biofuels – also defined in the “White Paper” of the European Commission – i. e. energy saving and greenhouse gas reduction, it can be concluded that bioenergy should be promoted.
- On the other hand there are certain negative impacts, the degree depending on the individual fuel.
- The relevance of these negative impacts cannot be directly assessed scientifically. There is a clear requirement for further research. Instruments for decision making should be tested or developed further, in addition to the current ones used in LCA.
- Every fuel has its particular advantages and disadvantages; the final decision of which fuel to prefer therefore remains with the ultimate decision maker.
- It was unfortunately not possible to reach many definitive conclusions on the socio-economic issue.
- The choice for a certain bioenergy chain cannot generally be regulated at EU level. The actual choice depends on how national authorities value the different environmental parameters. It also depends on the possibilities to adapt chains in such a way that environmental disadvantages are diminished in order to fit a certain energy crop into a specific region. The European Commission is therefore recommended to develop a set of criteria which can be used by authorities to assess whether a certain chain fits into their specific region.
- Some of the chains investigated here are fairly established, but others still require further research and development. The conclusions of this study are valid only for the chains investigated here. The results of can be used as a basis for further improvements. The detailed balance reveals the strengths and weaknesses of the different chains and can initiate further work.

Regarding the *comparison between the various biofuels*, a ranking according to their environmental performance is somewhat easier, e. g. regarding almost all environmental impacts, the solid biofuels such as triticale and traditional firewood generally achieve more favourable results than the liquid biofuels for the transportation sector. Still, however, here again no single biofuel can be regarded as “the best” for any of these issues because again the final decision depends upon the subjective judgements of the individual decision maker regarding which of the impact categories is most important.

As a further recommendation it should be pointed out that the respective disadvantages of the various biofuels may possibly change in the future due to further development of the production, conversion and combustion processes, utilisation of by-products etc. These disadvantages are not necessarily inherent characteristics of the biofuel production systems. Rather they are able to be reduced or even avoided altogether. For example, as a result of improved farming methods and technologies the NH_3 emissions arising from agricultural processes may be reduced and yields may be increased, leading to lower environmental impacts per unit of useful energy. The exact potential for this depends on the specific biofuel however.

Thus while no definitive answer can be given here with regard to which biofuel or fossil fuel is the best, due to the fact that the final decision depends on subjective judgements, the results obtained in this project can be used as an important tool for decision makers.

7 Annex

7.1 Country specific life cycle comparisons

In the following subchapters the results for each individual country are presented. Each country investigated a specific selection of biofuels as explained in Chapter 2.1. The representatives of each respective country were responsible for the results of their own country. As explained in Chapter 3.5, two different methods of result presentation and interpretation were used, and with regard to this issue the responsibility was also that of the country representatives. For those countries using normalisation (see Chapter 3.4.4) the presentation is similar to that of the European results, for those using the LCIA units, a different format was chosen. Brief summaries of the country specific results are given in Chapter 4.3.

Table 7-1 Biofuels investigated by each participating country

Biofuel	Austria	Denmark	France	Germany	Greece	Italy	Netherlands	Switzerland	EU
Cultivated solid biofuels									
Triticale	X	X	X	X					X
Willow		X		X			X		X
Miscanthus		X	X	X			X		X
Cultivated liquid biofuels									
Rape seed (RME)	X	X	X	X				X	X
Sunflower (SME)			X		X	X			X
Sugar beet (ETBE)			X	X			X		X
Biofuels from residues									
Trad. firewood	X					X		X	X
Wheat straw	X	X	X	X	X				X
Biogas	X	X			X	X	X	X	X
Novel production line									
Hemp							X		

Further assessments in favour of or against the biofuels (or fossil fuels) besides those which are given in this chapter cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. Thus decision makers, political institutions, etc. are encouraged to carry out their own assessment on the basis of the results presented here, and – very importantly – to express their priorities by which they carry out the assessment.

The category biodiversity and soil quality is not included in the graphs of the following sections since they are extremely difficult to quantify.

For further information on the result presentation, the parameters used and sensitivity analysis see Chapter 3.

7.1.1 Country specific results – Austria

Within the context of this project, Austria investigated five biofuels in comparison to their respective fossil counterparts, as was explained in Chapter 2. While the results for the whole of Europe are presented in Chapter 4, in this chapter the results for Austria are presented, on which the European results are partly based. In the following section the results are discussed for all those life cycle comparisons that were investigated in Austria. These are:

- Triticale versus hard coal for electricity production
- Traditional firewood versus light oil and natural gas for heat production
- Wheat straw versus light oil and natural gas for heat production
- Rape seed oil methyl ester versus fossil diesel for transport fuel
- Biogas versus natural gas for combined heat and electricity production

In addition, comparisons between the various biofuels have been carried out in order to assess which one is the most suitable in ecological terms for a specific objective. This lead to a number of different questions, in the light of which the various biofuels were compared. Austria looked at three of these, namely: Heat production (traditional firewood and wheat straw), efficiency of land use (RME and triticale), impacts related to saved energy (triticale, RME, traditional firewood, wheat straw and biogas).

For more information on these comparisons the reader is referred to Chapter 2. As for the European chains, the life cycle comparisons were carried out with regard to specific environmental impact parameters. These were: use of fossil fuels, greenhouse effect, acidification, eutrophication, summer smog, nitrous oxide, human toxicity. The criteria according to which these were selected as well as an explanation of their meanings can be found in the Chapters 3.3 and 3.4.

Basically the assessment of different impact categories will lead to arguments in favour of *and* against the biofuel. In this case a clear decision cannot be made without a value judgement regarding the individual environmental categories required. Whether bioenergy is assessed as better or worse than the fossil counterpart depends on the focus of the decision. Thus decision makers, political institutions, etc. are encouraged to carry out their own assessment on the basis of their specific priorities.

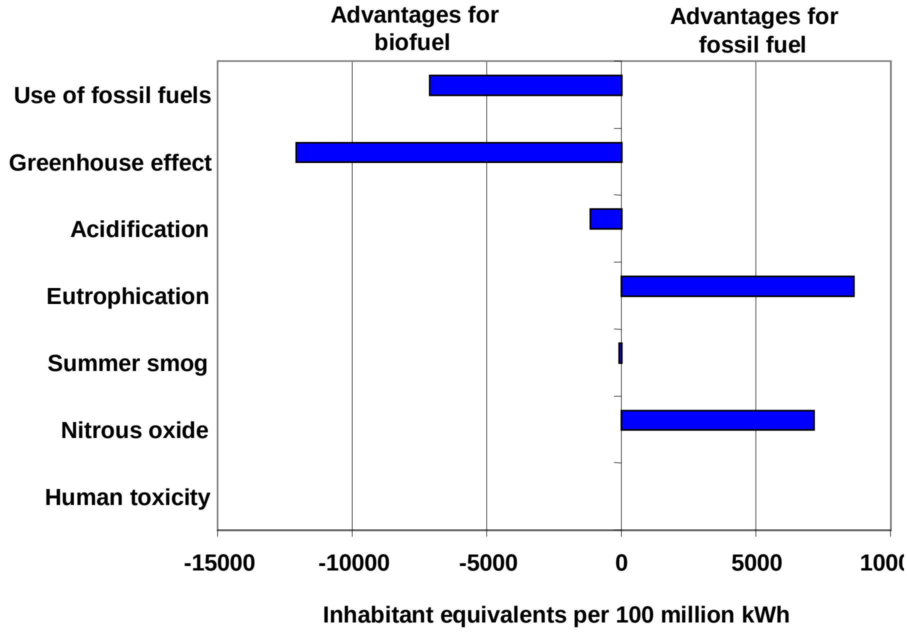
From the point of view of the Austrian authors those parameters are of special importance which are currently embodied in international agreements and national programmes. Within the scope of the investigations of this project the agreements and programmes of interest are the following:

- **Use of fossil energy:** Essential objectives of the Austrian energy policy are a reduced consumption of fossil energy achieved by means of a sensible and rational use of energy – and thus an increase in energy efficiency and the support of renewable sources of energy – (source: "Energiebericht der Österreichischen Bundesregierung 1993") as well as the indicative objective of the White Paper of the European Commission "Energy for the future – renewable sources of energy", which provides for doubling the use of renewable energy.
- **Reduction of green house gas emissions:** The obligations of the Kyoto Conference providing for a reduction of greenhouse gas emissions from 75.4 million tons in 1990 to 66 million tons in the year 2010.
- **Reduction of acid emissions and eutrophication of waters:** in accordance with the UN/ECE Convention on Long-range Transboundary Air Pollution, which deals with SO_2, NO_x, VOC, Heavy Metal, Persistent Organic Pollutants and Acidification, Eutrophication and Ground level Ozone in eight protocols.

Being aware that the scientific results are ahead of the national programmes and the international agreements the following parameters which have been investigated during the project but have not been included in the before mentioned list shall be paid special attention: N_2O (because of the potential danger of stratospheric ozone depletion) as well as the emissions of photo-oxidants (because of the well-known risk of summer smog formation).

The conclusions for Austria are drawn from the standardised data presented in diagrams and the absolute values referring to an important unit in connection with a decision in Austria (area, animal population, energy amount).

Triticale versus hard coal for electricity production – Austria



How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where hard coal is substituted by triticale for electricity generation. The unit refers to an amount of one hundred million kWh of electricity. This is equivalent to the average electricity requirement of about 14,800 inhabitants in Austria in one year, or a triticale production of about 4,600 ha/a. In this case for example the amount of fossil fuel saved is equal to the amount which about 7,100 Austrian citizens would on average consume in one year (this is what is meant by „Austrian inhabitant equivalents“).

Conclusions

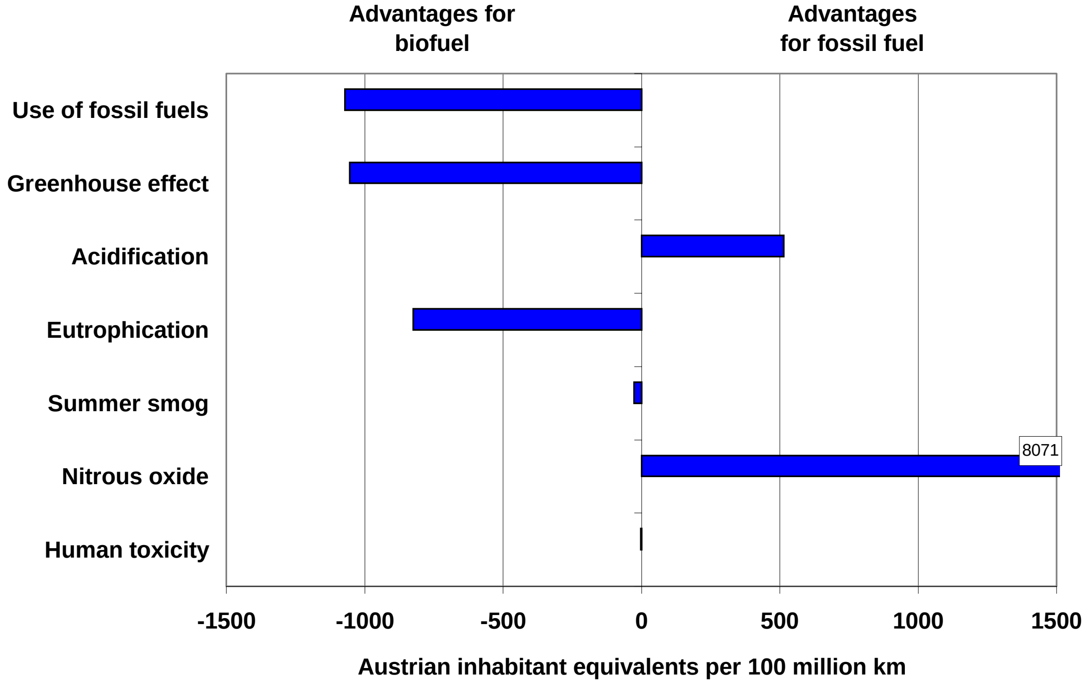
It can be assumed that the production of grain for energy will compete with fallow land at the time of economic realisation. Triticale can be cultivated on all Austrian areas of arable land (approx. 1.4 million ha), the production of energy crops on 100,000 ha is considered appropriate. With this area 19 PJ fossil fuel, 1.8 Mt CO_2, 1 kt SO_2 and 0.05 kt ethylen-equivalent can be saved. On the other hand eutrophication and nitrous oxide emission will increase (12 kt NO_3, 0,2 kt N_2O).

Triticale used for the production of energy displays major advantages concerning the use of fossil energy and greenhouse gas emissions. In the year 2010 1.6 % of the demand in primary energy can be covered by an area of 7 % of the arable land. Triticale can contribute 19 % to the demanded reduction in greenhouse gas emissions of 9.4 million tons by substituting hard coal.

The effects on acidification and on summer smog are positive but minimal, no changes could be observed in the category "human toxicity".

Considerable deterioration is observed in the emission of nitrous oxide and in eutrophication. The absolute increases seem to be rather small with 208 t N_2O (2.3 % of N_2O-burdens in the year 1999) or 11,805 t NO_3.

Rape seed oil methyl ester versus fossil diesel for transportation – Austria



How to interpret the diagram

The figure shows the results of complete life cycle comparisons where RME is used in passenger cars instead of diesel fuel. The results are given for a distance of 100 million km being covered by passenger cars using the biofuel instead of fossil fuel. This is equivalent to the average annual mileage of about 12,000 inhabitants of Austria. In this case for example the amount of greenhouse gas emissions that being saved by substituting diesel fuel by RME is equal to the amount which about 1,050 Austrian citizens would on average generate in one year (this is what is meant by "Austrian inhabitant equivalents").

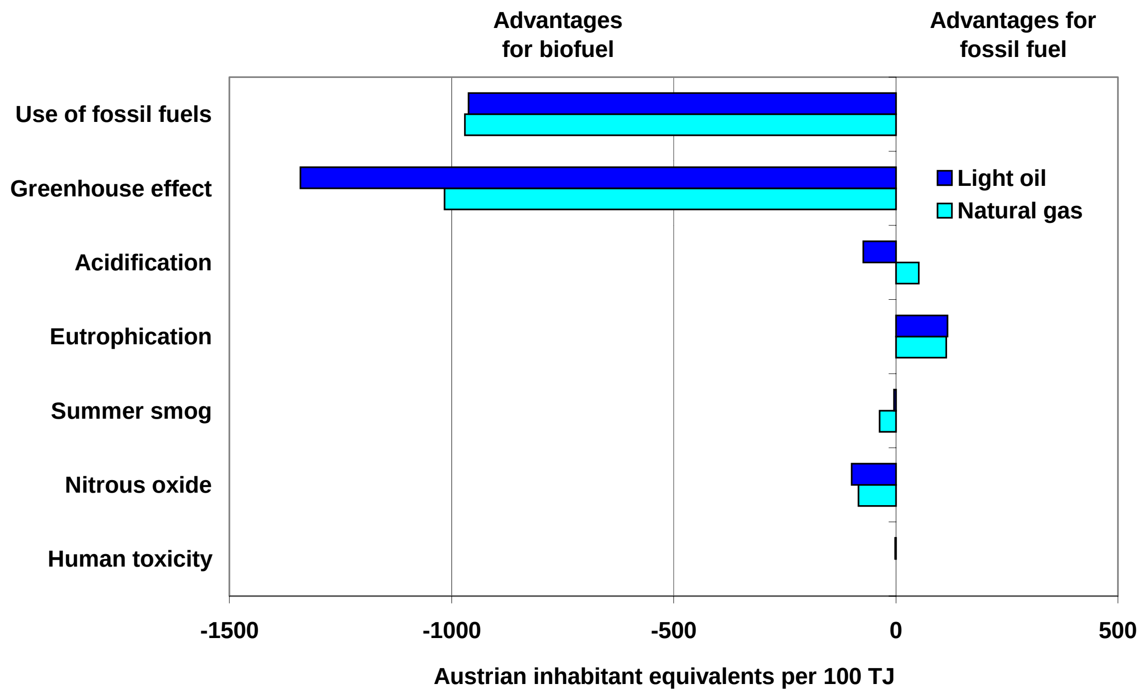
Conclusions

It is to be assumed that the production of rape seed for energy will be competing with fallow land at the time of economic realisation. In Austria rape seed can be cultivated nearly on the entire arable land (approx. 1.4 million ha), the production of energy crops on 100,000 ha seems to be appropriate. With this area 6 PJ fossil fuel and 0.3 Mt CO_2 can be saved while eutrophication and summer smog decrease to a smaller extent (2.4 kt NO_3 and 0,04 kt ethylen eq.). Acidification and nitrous oxide emission will increase (1 kt SO_2 and 0.5 kt N_2O).

Rape seed used for the production of fuel shows advantages concerning the use of fossil energy and concerning greenhouse gas emissions. In the year 2010 an area of 7 % of the arable land might suffice to cover 2.6 % of the fuel demand (238 PJ in 1999). Rape seed can contribute 3.5 % to the demanded reduction in greenhouse gas emissions of 9.4 million tons. The effects on eutrophication, summer smog and human toxicity are positive but minimal.

Considerable disadvantages are observed in nitrous oxide-emissions and acidification. The absolute change in acidification with 951 tons seems to be rather insignificant. The burden imposed by nitrous oxide increases significantly with 504 t (5.6 % of the nitrous oxide-burden in the year 1999).

Traditional firewood versus light oil and natural gas for heat production – Austria



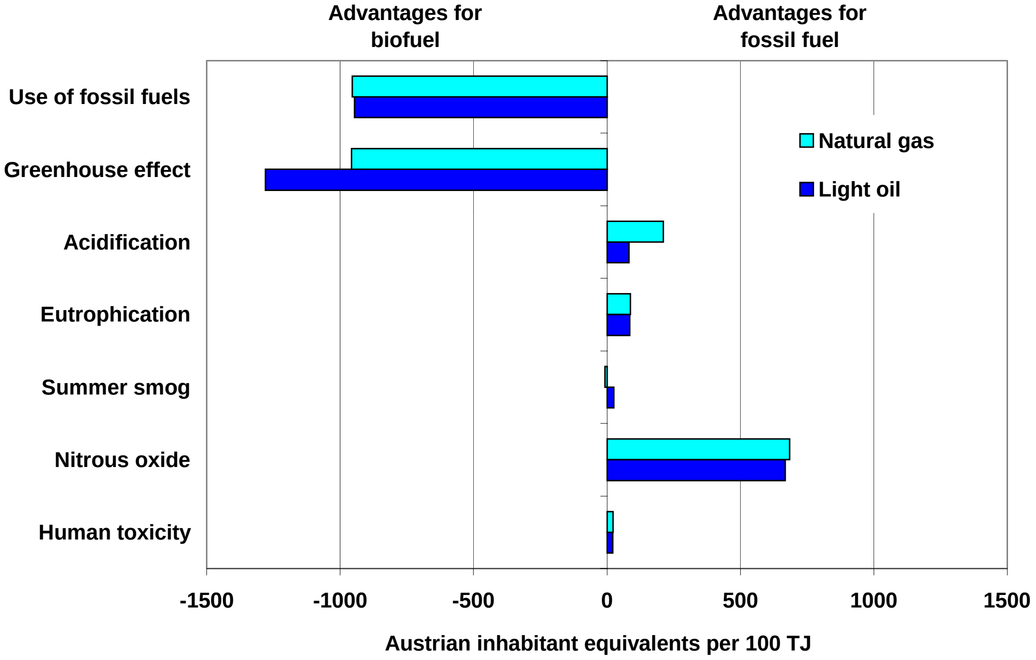
How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where light oil or natural gas is substituted by traditional firewood for heat production. The unit refers to an amount of 100 TJ heat. This is equivalent to the average heat requirement of about 2,900 inhabitants in Austria in one year. In this case for example the amount of fossil fuel saved is equal to the amount which about 1,000 Austrian citizens would on average consume in one year (this is what is meant by „Austrian inhabitant equivalents“).

Conclusions

For an annual increment of approx. 31 million m^3 approx. 20 million m^3 wood are harvested in Austria; in addition, forest land is increasing. Firewood is apportioned 3 to 4 million m^3 corresponding to 1.2 to 1.6 million tons. Firewood shows major advantages concerning the use of fossil energy and greenhouse gas emissions as compared to light oil and natural gas. With 500,000 tons of wood (corresponding to an annual increment of 125,000 to 150,000 ha) 7 PJ fossil fuel and 0.5 Mt CO_2 could be saved. As compared to acidification, eutrophication, summer smog and human toxicity only minor differences can be observed. The substitution of oil shows better results in greenhouse gases and in acidification, the substitution of gas yields positive results with regard to summer smog.

Wheat straw versus light oil and natural gas for heat production – Austria



How to interpret the diagram

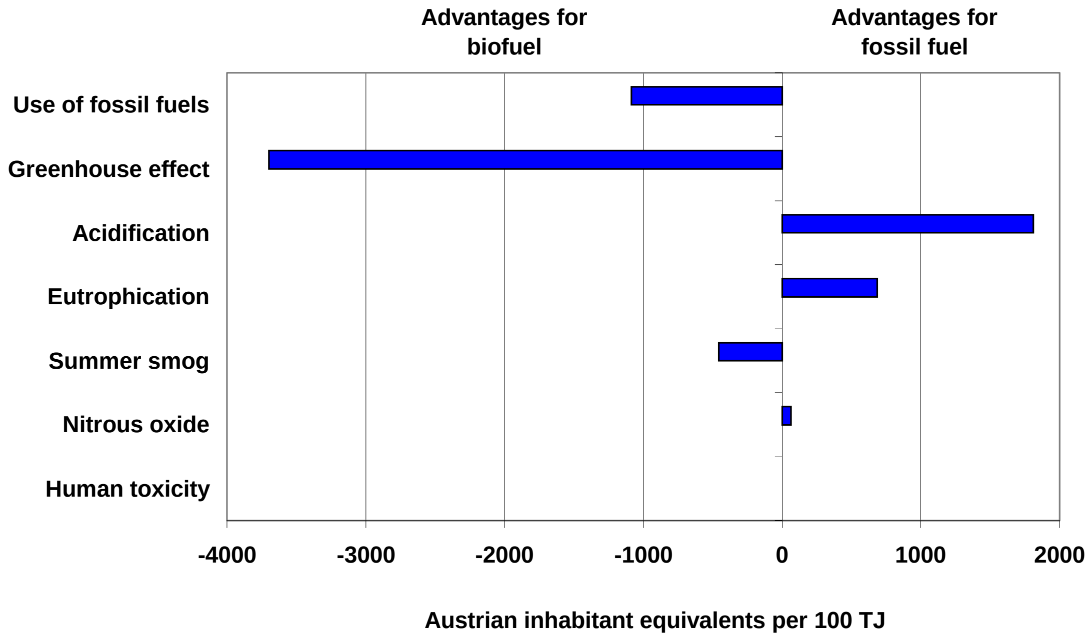
The figure shows the results of comparisons between complete life cycles where light oil and natural gas respectively are substituted by wheat straw for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 2,900 inhabitants in Austria in one year. In this case for example the amount of fossil fuel saved is equal to the amount which about 950 Austrian citizens would on average consume in one year (this is what is meant by „Austrian inhabitant equivalents“).

Conclusions

In Austria grain is cultivated on an area of approx. 0.9 to 1.0 million ha, approx. half of it is situated in arid areas and is thus suitable for energetic use. For a conclusion it is assumed that every year the straw yield of 100,000 ha is used for the production of heat. Compared to oil nearly 9 PJ of fossil energy and 0.6 Mt CO_2 could be saved while nitrous oxide would increase insignificantly (+ 0.07 kt N_2O). Straw can contribute almost 7 % to the demanded reduction in greenhouse gas emissions of 9.4 million tons if it substitutes oil or gas.

Concerning acidification, eutrophication, summer smog and human toxicity the differences are rather insignificant. If straw substitutes oil the emissions of greenhouse gases and acidification are improved considerably, if straw substitutes gas advantages concerning summer smog can be observed.

Biogas from swine excrement versus natural gas for combined heat and electricity production – Austria



How to interpret the diagram

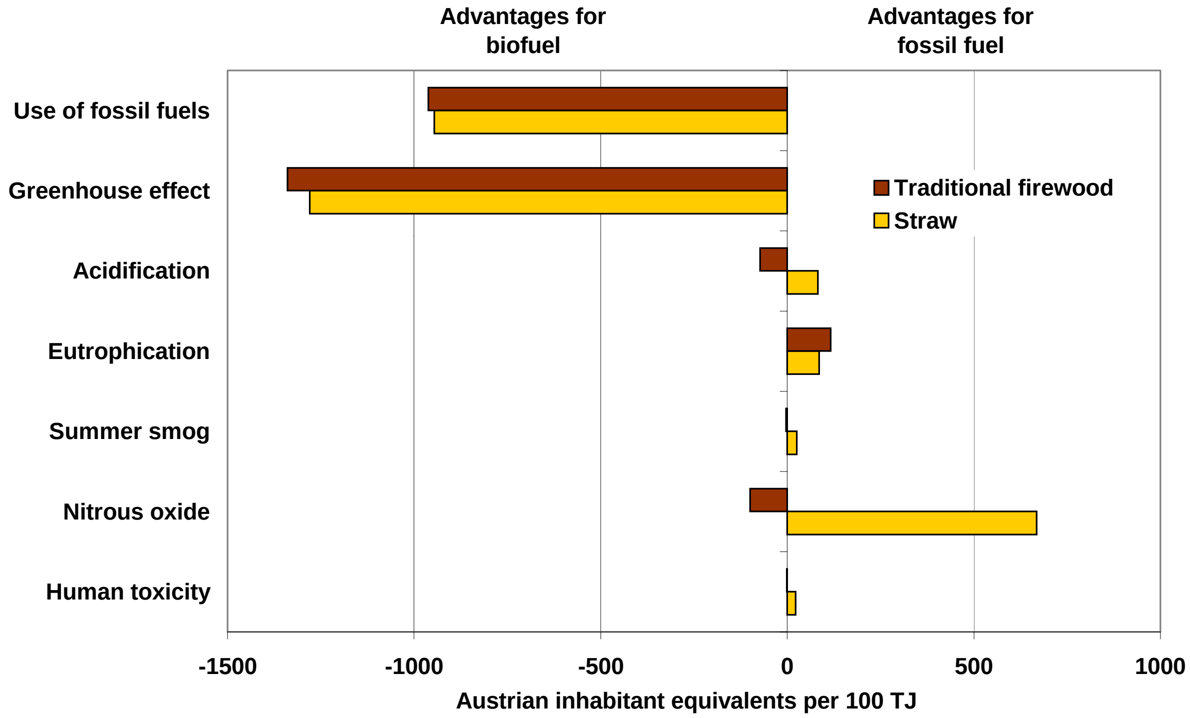
The figure shows the results of comparisons between complete life cycles where natural gas for small scale combined heat and electricity production is substituted by biogas. The unit refers to an amount of 100 TJ net energy output, the ratio of heat to electricity is 1 to 1.11. In this case for example the amount of fossil fuel saved is equal to the amount which about 1,100 Austrian citizens would on average consume in one year (this is what is meant by "Austrian inhabitant equivalents").

Conclusions

In 1999 the total Austrian livestock amounted to 2.14 million LSU (livestock unit). The share in pigs amounted to 412,510 LSU, including 111,176 LSU in 3118 undertakings of more than 50 LSU. The production of biogas out of excrement seems to be of interest especially with undertakings of such size. With the biogas production out of the liquid manure of 100,000 pig-LSU 0.3 PJ fossil fuel and 0.05 Mt CO_2 can be saved. The effect on acidification, eutrophication, summer smog and nitrous oxide will be low (+ 0.15 kt SO_2, + 0.09 kt NO_3, - 0.03 kt ethylene eq. and + 0.0002 kt N_2O).

Biogas shows advantages concerning the use of fossil energy and clear advantages concerning the emission of greenhouse gases. 0.02 % of the Austrian demand in primary energy can be covered by the liquid manure of 5 % of the entire livestock. Biogas can contribute almost 0.6 % to the demanded reduction in greenhouse gas emissions of 9.4 million tons. The effects on the impact categories acidification, eutrophication, summer smog, nitrous oxide-emission and human toxicity are minimal.

Technical applications: heat production – Austria



How to interpret the diagram

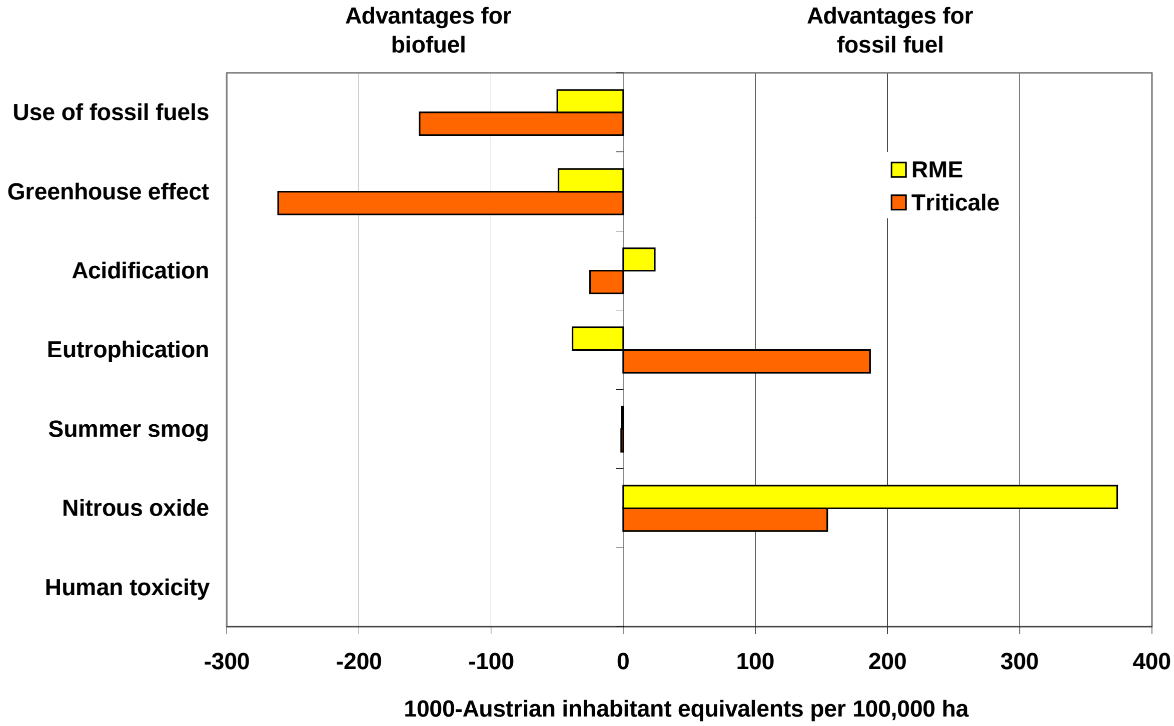
The figure shows the results of comparisons between complete life cycles where light oil is substituted by traditional firewood respectively wheat straw for heat. The unit refers to an amount of 100 TJ heat. This is equivalent to the average head requirement of about 2,900 inhabitants in Austria in one year. Concerning the parameters "use of fossil fuel" and "greenhouse effect" the two biofuels are very similar. The biggest difference is in the parameter "nitrous oxide". The amount of fossil fuel saved is in both cases equal to the amount which about 950 Austrian citizens would on average consume in one year (this is what is meant by "Austrian inhabitant equivalent").

Conclusions

The Austrian demand in primary energy amounted to 1,234 PJ in 1994, 238 PJ were used for the heating of rooms. The share of bioenergy used to cover the demand in primary energy amounted to 138 PJ or 11.2 %. The doubling of the share of bioenergy which is demanded in the White Paper of the Commission seems to be unfeasible in Austria under current framework conditions. An increase by 85 PJ seems to be feasible if considerable effort is made; the most important increase will be achieved with wood (+35 PJ), straw (+15 PJ) and triticale (+25 PJ).

If we substitute 10 PJ heating oil with firewood we can save 0.75 Mt CO_2 with an insignificant change in the categories acidification, eutrophication, summer smog and nitrous oxide (-0.24 kt SO_2, +0.6 kt NO_3, -0.01 kt ethylene eq. and –0.01 kt N_2O). If we substitute the same amount with straw results are similar (-0.7 Mt CO_2, + 0.3 kt SO_2, +0.5 kt NO_3, + 0.06 kt ethylene eq. and + 0.08 kt N_2O). Wood and straw can contribute considerably to the reduction of greenhouse gas emissions, the effects on the other impact categories are low.

Ecological aspects I: land use efficiency – Austria



How to interpret the diagram

The figure shows the results of complete life cycle comparisons where RME and triticale are used for energy production instead of their respective fossil counterparts. The results are given for an area of 100,000 ha being cultivated with the respective crop. In this case for example the amount of greenhouse gas emissions that is being saved when 100,000 ha of triticale are cultivated and used to substitute hard coal for electricity production is equal to the amount which about 261,000 Austrian citizens would on average generate in one year (this is what is meant with "Austrian inhabitant equivalents").

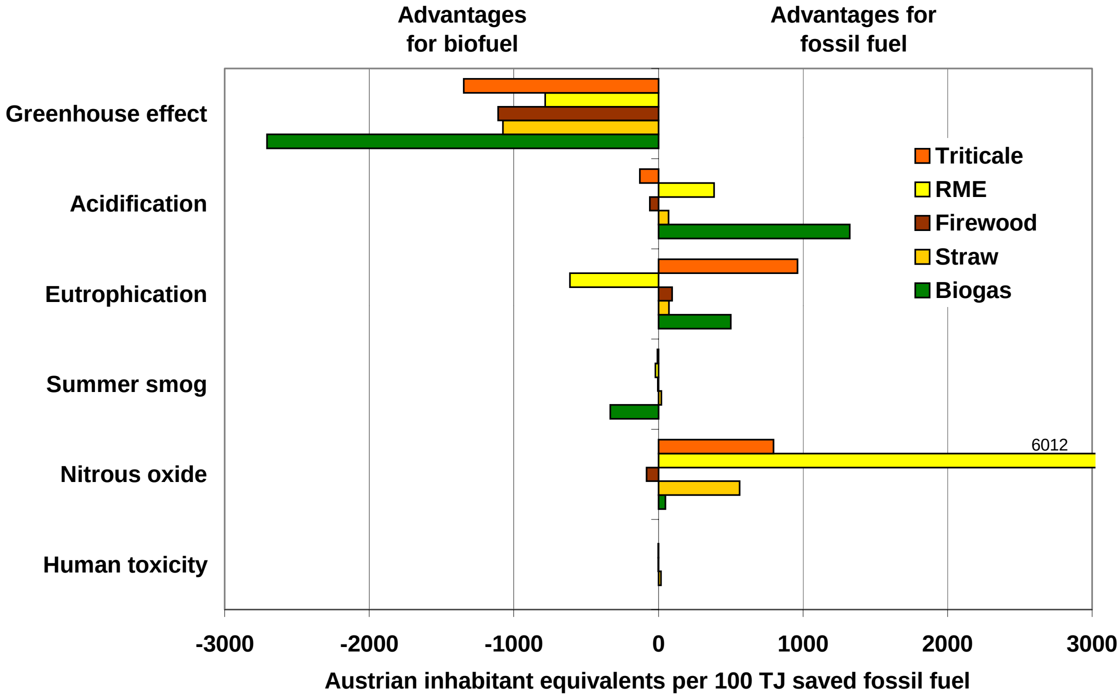
Conclusions

It has to be assumed that the production will be competing with fallow land at the time of economic realisation. Rape seed and triticale can be cultivated on nearly the entire arable land in Austria (i.e. 1.4 million ha), the production of energy crops on 100,000 ha seems appropriate.

Rape seed and triticale can contribute considerably to a reduced use of fossil energy and a reduction of greenhouse gas emissions, the advantages concerning electricity generation being considerably higher (rape seed: - 6 PJ fossil fuel, - 0.3 Mt CO_2; triticale: -19 PJ fossil fuel, -1.8 Mt CO_2). Eutrophication increases substantially with electricity from triticale (triticale: +12 kt NO_3^-, rape seed: –2.4 kt), with rape seed a significant increase in the emission of nitrous oxide is to be observed (rape seed: + 0.5 kt N_2O, triticale: +0.2 kt). The further impact categories are only influenced to a minor extent by the substitution.

It should be mentioned that a comparison of products with different use is difficult. Conclusions can only be drawn for a comparison of the environmental impacts of the cultivation on the mentioned area, but not for the appropriateness of a substitution. With the cultivation of rape seed on an area of 7 % of the arable land 2.6 % of the fuel demand (238 PJ in the year 1999) and a considerable share in the demand in protein-feed for animals can be covered. With electricity produced from triticale cultivated on the same area 3 % of the electricity demand (162 PJ in 1994) can be covered. Referring to the (low) thermal power production (37 PJ in 1994) the consumption of coal can be reduced by half.

Ecological aspects II: impacts related to saved energy – Austria



How to interpret the diagram

The figure shows the results of complete life cycle comparisons where all biofuels investigated by Austria are used for energy production instead of their respective fossil counterparts. The results for the various categories are given with reference to the category "Use of fossil fuel", i.e. 100 TJ of fossil energy saved. For example, for every 100 TJ of fossil energy saved through the substitution of light oil by traditional firewood, the amount of greenhouse gas emissions avoided is equal to those on average generated by about 1,100 Austrian inhabitants in one year. (This is what is meant by "Austrian inhabitant equivalents".)

Conclusions

European or national energy strategies cannot be based on a sole energy source or energy carrier. A prospective estimation of the bioenergy development is rather difficult. For an overall comparison the different levels of development, different types of useful energy, the different states of the technology and the different costs must be considered. The following table compares the chains only on the basis of fossil fuel saving and availability of land (based on a mix of bioenergy we have estimated a possible increase of 50 to 80 PJ until 2010 under a committed policy for Austria, the evaluation refers to a reduction of 20 PJ fossil energy per chain). Political and social effects are not taken in account.

Impact category		**Triticale**	**Firewood**	**Wheat straw**	**RME**	**Biogas**
Greenh. effect	Mio. t CO_2	- 1.81	- 1.49	-1.45	- 1.05	- 3.64
Acidification	1000 t SO_2	- 1.03	- 0.481	0.553	3.04	10.6
Eutrophication	1000 t NO_3	12.2	1.216	0.910	- 7.74	6.36
Summer smog	t Ethylene eq.	- 48	19	129	- 122	- 2020
Nitrous oxide	t N_2O	215	- 22	151	1610	13
Feasibility		Realistic	Ambitious	Possible	Ambitious	Impossible
A negative sign means “advantage for bioenergy” Impacts for 20 PJ fossil fuel saved						

All types of biofuels are well-suited to reduce the greenhouse gas emission in a substantial quantity. The highest effect per unit can be reached with biogas. The effects of triticale, wood and straw are similar, the difference is caused by the different fossil fuel counterparts. Biodiesel leads to the lowest effect.

With all types of biofuels acidification, eutrophication, sommer smog and human toxicity will not be improved or deteriorated dramatically. Except RME the same results can be observed with nitrous oxide. With 20 PJ rape the overall Austria nitrous oxide burden would increase significantly (from 9,000 t/a to 10,600 t/a).

With triticale, wood, straw and rape seed, savings of 20 PJ can be reached by each. Biogas from pig manure cannot be produced in the afforded quantity.

7.1.2 Country specific results – Denmark

In this chapter the results for the Danish energy chains are presented. These are:

- Triticale versus coal for electricity production
- Miscanthus versus heating oil and natural gas
- Willow versus heating oil and natural gas
- Wheat straw versus heating oil and natural gas
- Biogas versus natural gas for electricity production
- Rape seed oil methyl ester (RME) versus fossil diesel fuel

In addition, the following biofuels are compared towards each other in order to assess which one is the most suitable in ecological terms for a specific objective.

- Technical application
  - Heat production: Miscanthus, willow and straw
- Ecological aspects
  - Efficiency of land use: willow, RME, triticale and Miscanthus
  - Saving of energy resources: triticale, Miscanthus, willow, straw, biogas, RME

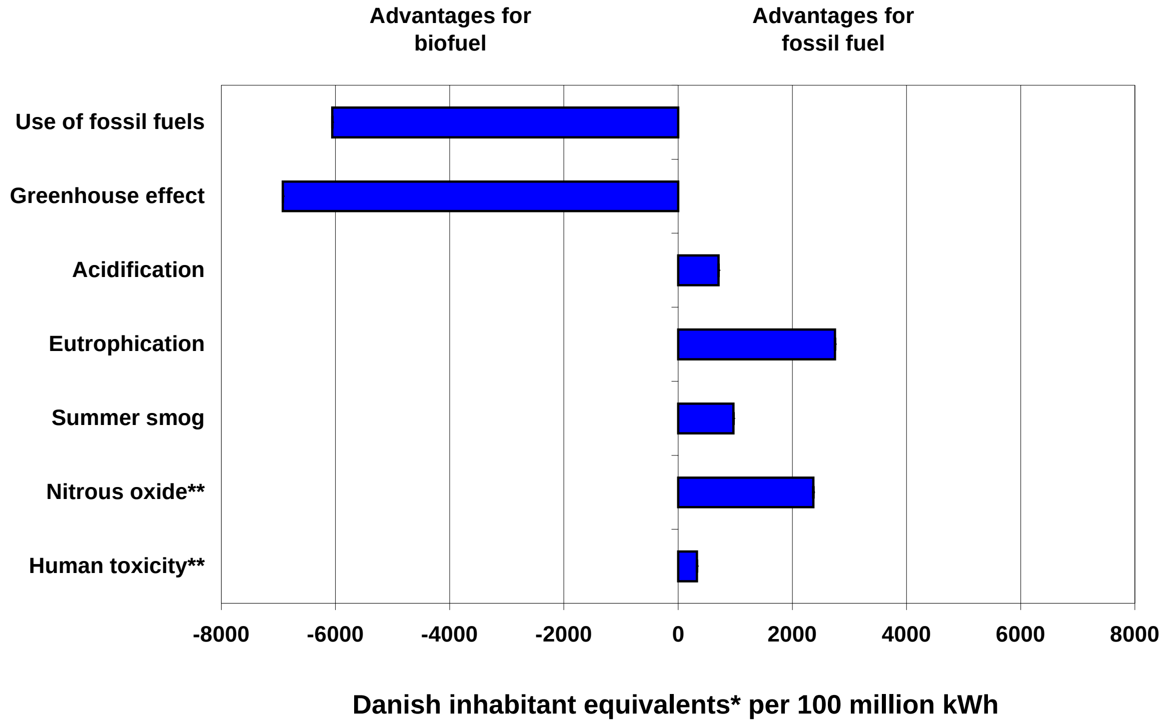
For more information on these comparisons the reader is referred to Chapter 2. As for the European chains, the life cycle comparisons were carried out with regard to specific environmental impact parameters. These were:

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Nitrous oxide
- Human toxicity

The criteria according to which these were selected as well as an explanation of their meanings can be found in the Chapters 3.3 and 3.4.

For reasons of clarity of presentation, the results of minimum-maximum evaluations have not been presented in the result graphs. For more information on this the reader is referred to Chapter 4.1.3.

Triticale versus hard coal for electricity production – Denmark



* How to interpret the diagram

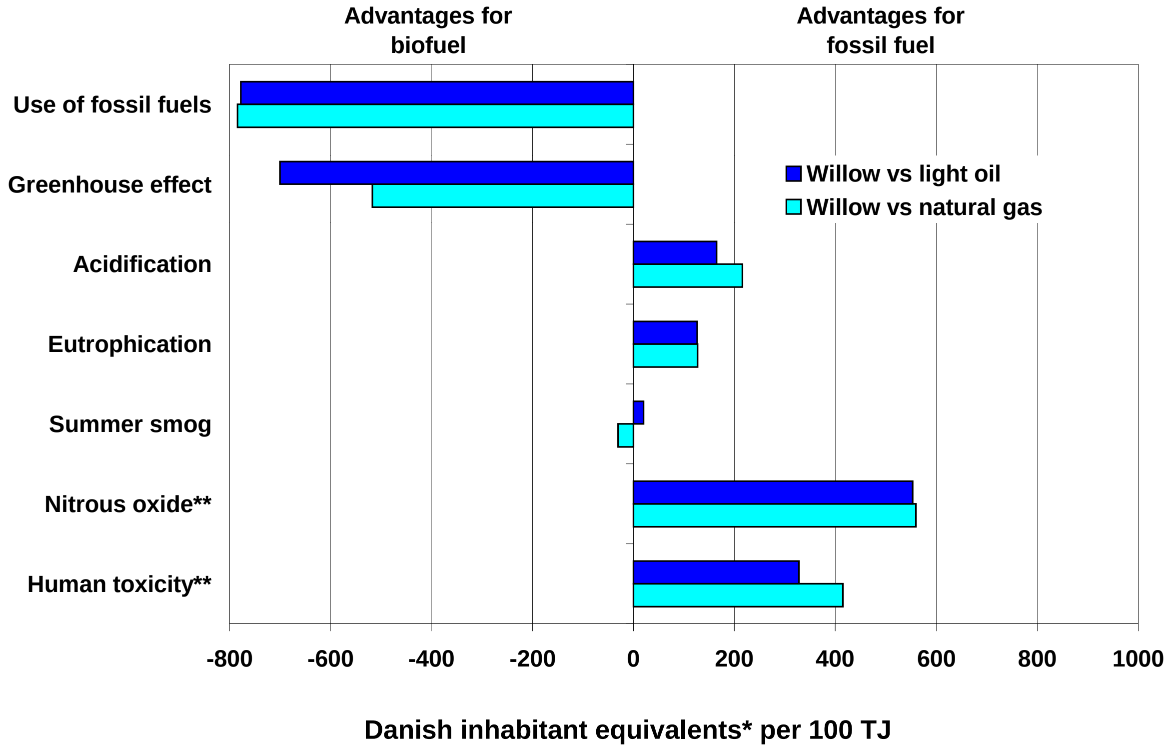
The figure shows the results of comparisons between complete life cycles where hard coal is substituted by triticale for electricity generation. The unit refers to an amount of one hundred million kWh of electricity. This is equivalent to the average electricity requirement of about 12,750 inhabitants of Denmark in one year or a triticale production of about 19,300 ha/a.

Conclusion

The results show that both triticale as well as hard coal have certain ecological advantages and disadvantages, depending on the parameters given highest priority. Thus for example, triticale has significant environmental advantages over coal with regard to the greenhouse effect and use of fossil fuels but on the other hand hard coal is superior with regard to nitrous oxide and eutrophication. The other parameters show less significant result in favour of hard coal. The data for human toxicity tend to have a high uncertainty. Therefore this category should not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against triticale or hard coal cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. Whether triticale is assessed as better or worse than coal depends upon the focus and priorities of the decision makers. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, triticale will be better suited. If on the other hand the parameters nitrous oxide and eutrophication are deemed to be more important, then coal would be preferred.

Willow versus light oil or natural gas for heat production – Denmark



* How to interpret the diagram

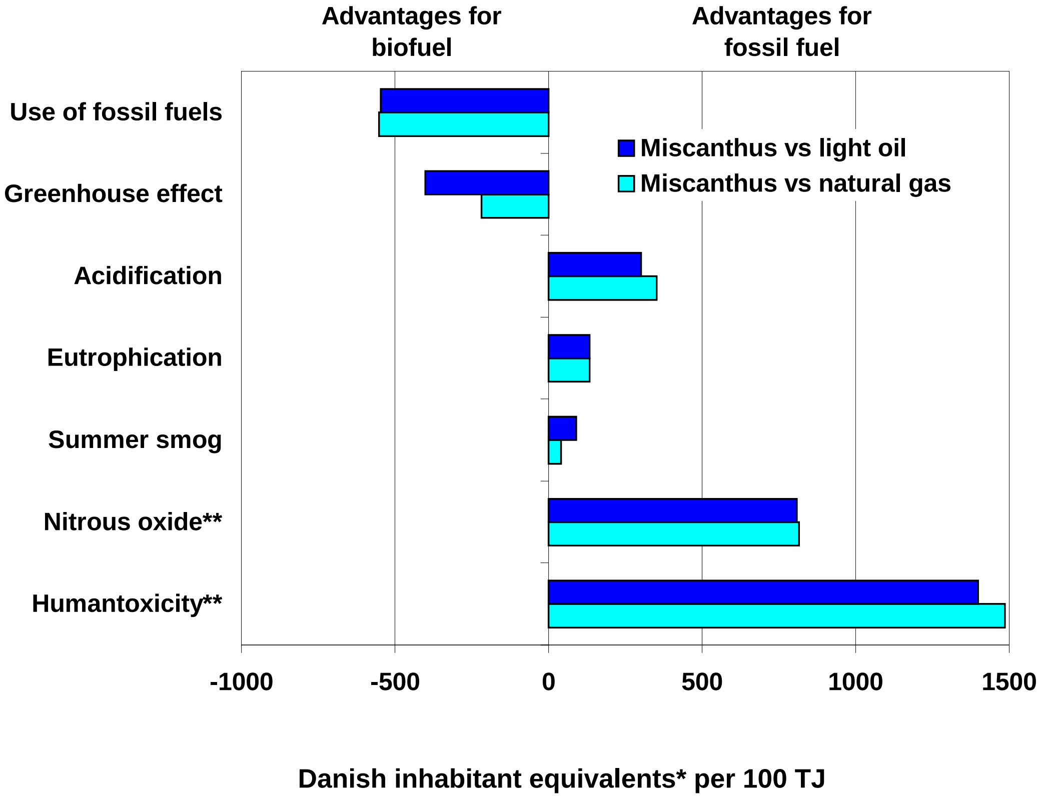
The figure shows the results of comparisons between complete life cycles where light oil (blue rows) or natural gas (light blue) is substituted by willow for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 4,700 inhabitants of Denmark in one year or a willow production of about 600 ha/a.

Conclusion

The results show that both willow as well as light oil/natural gas have certain ecological advantages and disadvantages, depending on the parameters given highest priority. Willow has significant environmental advantages over light oil with regard to the parameters greenhouse effect and use of fossil fuels but on the other hand the fossil fuels are superior with regard to nitrous oxide and human toxicity. The other parameters show less significant result mostly in favour of fossil fuel. As mentioned, the data for human toxicity tend to have an uncertainty higher than average, and should therefore not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against willow or fossil fuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, willow will be better suited. If on the other hand the parameter nitrous oxide were deemed to be most important, then light oil or natural gas would be preferred.

Miscanthus versus light oil or natural gas for heat production – Denmark



* How to interpret the diagram:

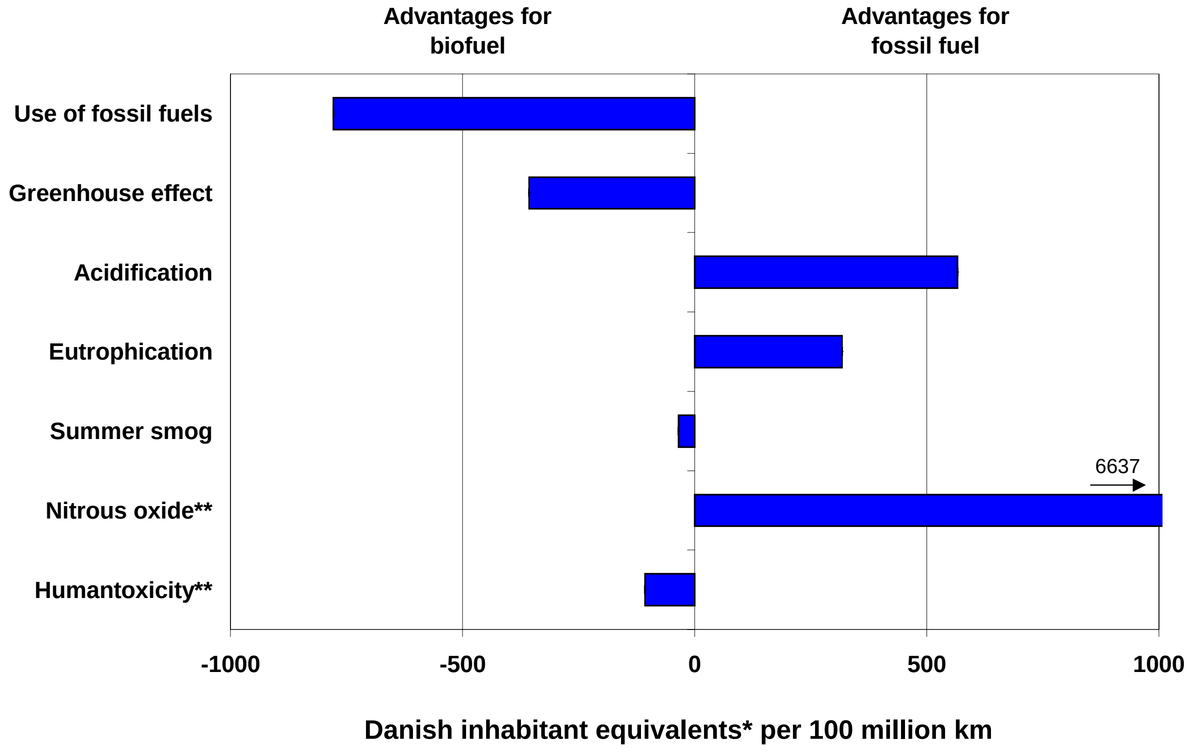
The figure shows the results of comparisons between complete life cycles where light oil (blue rows) or natural gas (red rows) is substituted by Miscanthus for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 4,700 inhabitants of Denmark in one year or a Miscanthus production of about 1,100 ha/a.

Conclusion

The results show that both Miscanthus as well as light oil or natural gas have certain ecological advantages and disadvantages, depending on the parameters given highest priority. Thus for example, Miscanthus has significant environmental advantages over the fossil fuels with regard to the parameters greenhouse effect and use of fossil fuels but on the other hand light oil or natural gas is superior with regard to nitrous oxide, acidification and human toxicity. The other parameters show less significant result in favour of fossil fuel. However, the data for human toxicity tend to have a uncertainty higher than average, and should therefore not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against Miscanthus or light oil/natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. Whether Miscanthus is assessed as better or worse than the relevant fossil fuels depends upon the focus and priorities of the decision makers. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, Miscanthus will be better suited. If on the other hand the parameters nitrous oxide and eutrophication are deemed to be most important, then light oil or natural gas would be preferred.

RME versus Diesel fuel for transportation – Denmark



* How to interpret the diagram

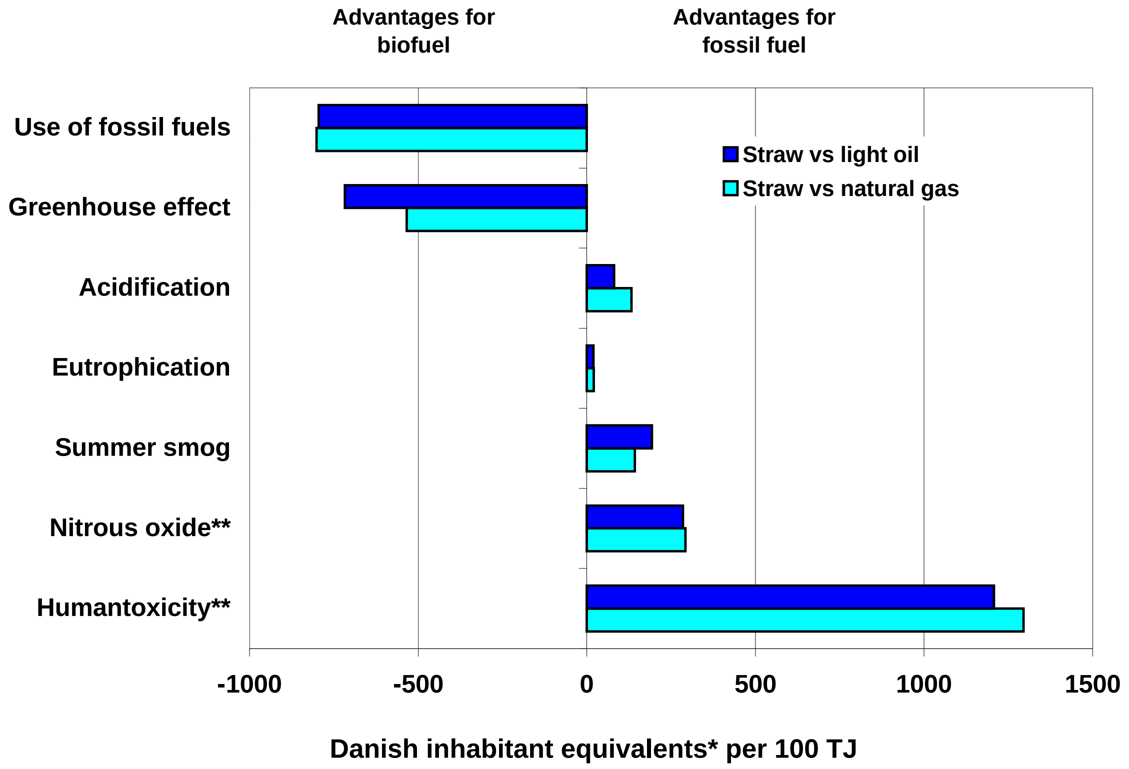
The figure shows the results of complete life cycle comparisons where RME is used in passenger cars instead of Diesel fuel. The results are given for a distance of 100 million km being covered by passenger cars using the biofuel instead of fossil fuel. In this case for example the amount of greenhouse gas emissions that is being saved by substituting Diesel fuel by RME is equal to the amount which about 300 Danish citizens would on average generate in one year (this is what is meant by “Danish inhabitant equivalents”).

Conclusion

The results show that both RME as well as diesel fuel have certain ecological advantages and disadvantages, depending on the parameters given highest priority. RME has environmental advantages over diesel fuel with regard to the parameters greenhouse effect and use of fossil fuels but on the other hand diesel fuel is superior with regard to nitrous oxide, acidification and eutrophication. The parameters summer smog and human toxicity show less significant results in favour of RME, but it should be noted that the data for human toxicity tend to have a high uncertainty, and should not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against RME or diesel fuel cannot be carried out on a scientific basis, because for this purpose subjective value judgements. Whether RME is assessed as better or worse than diesel fuel depends upon the focus and priorities of the decision makers. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, RME will be better suited. If on the other hand the parameters nitrous oxide and acidification are deemed to be most important, then diesel fuel would be preferred.

Wheat straw versus light oil or natural gas for heat production – Denmark



* How to interpret the diagram:

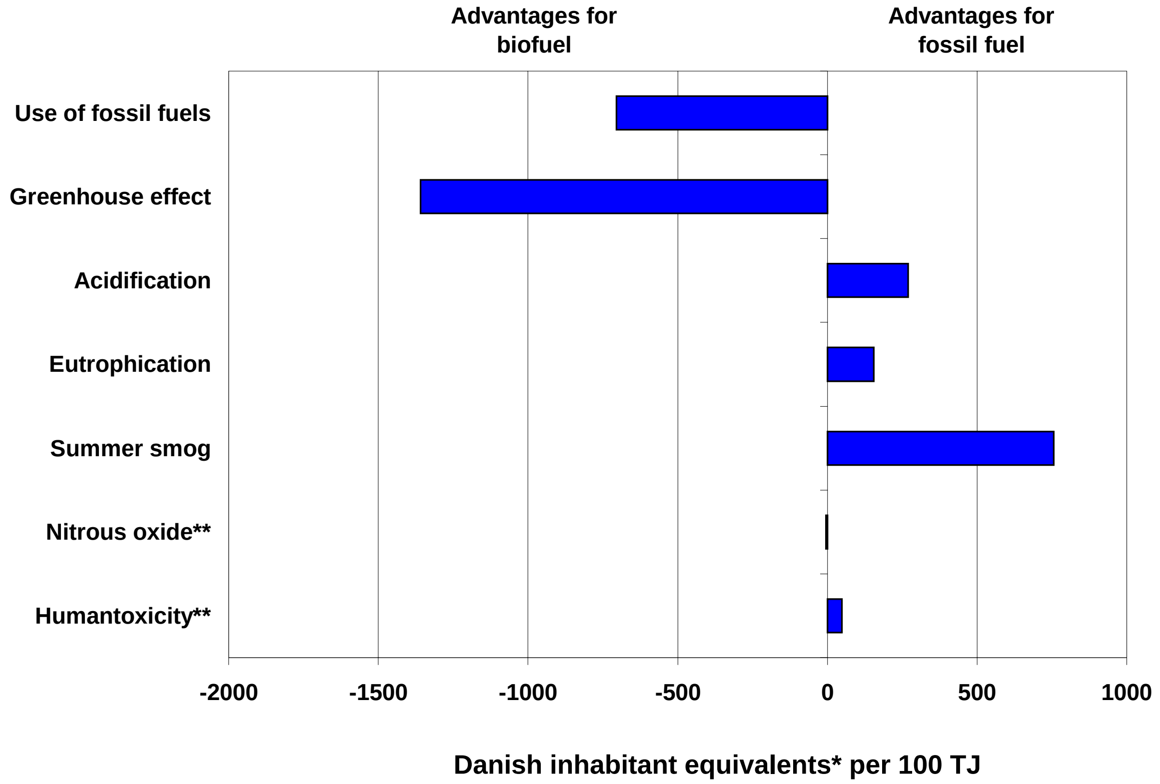
The figure shows the results of comparisons between complete life cycles where light oil (blue) or natural gas (light blue) is substituted by wheat straw for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 4,700 inhabitants of Denmark in one year or a wheat straw production of about 2,200 ha/a.

Conclusion

The results show that both wheat straw as well as light oil/natural gas have certain ecological advantages and disadvantages, depending on the parameters given highest priority. Thus for example, wheat straw has significant environmental advantages over the fossil fuels with regard to the parameters greenhouse effect and use of fossil fuels but on the other hand light oil and natural gas is superior with regard to nitrous oxide, summer smog and human toxicity. The other parameters show less significant result in favour of fossil fuel. As mentioned, the data for human toxicity tend to have a uncertainty higher than average, and should therefore not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against wheat straw or light oil/natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required. Whether wheat straw is assessed as better or worse than light oil depends upon the focus and priorities of the decision makers. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, wheat straw will be better suited. If on the other hand the parameter nitrous oxide is deemed to be most important, then light oil or natural gas would be preferred.

Biogas versus natural gas for energy production – Denmark



* How to interpret the diagram

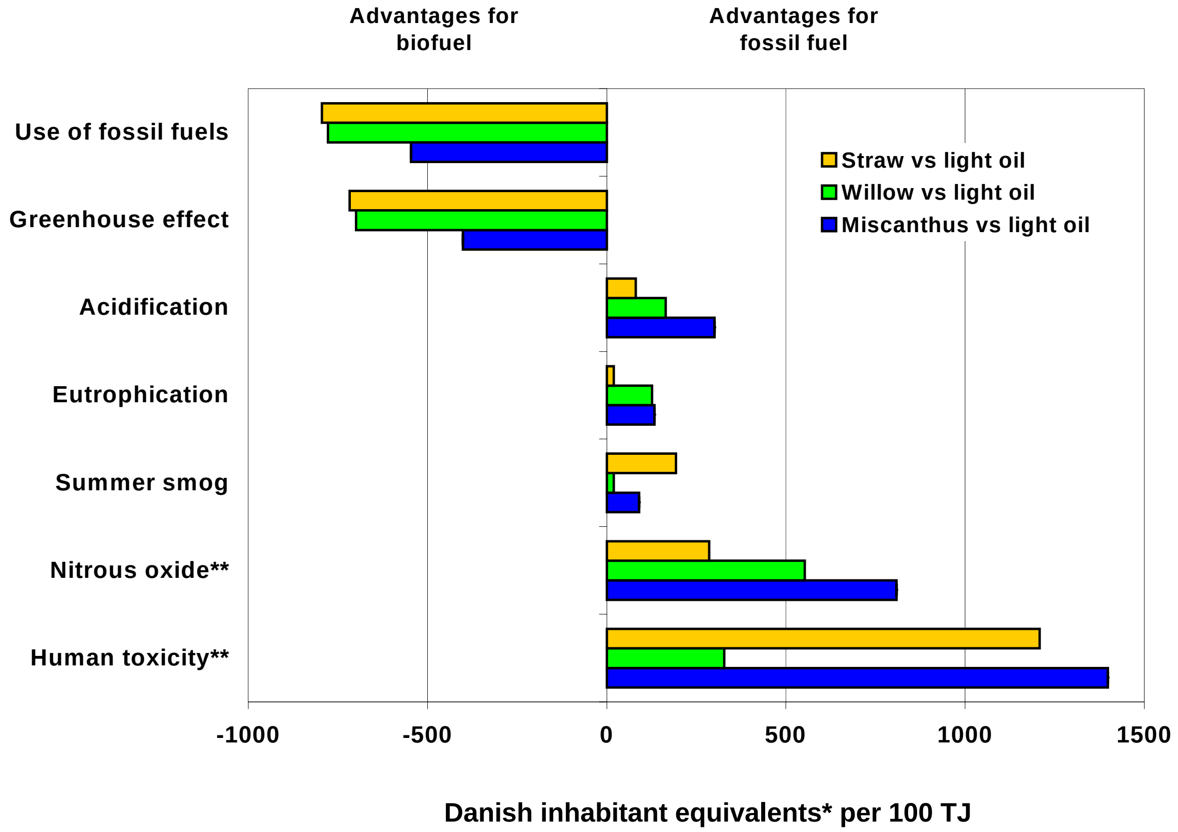
The figure shows the results of comparisons between complete life cycles where natural gas is substituted by biogas for energy (heat and power) production. The unit refers to an amount of 100 TJ of energy. This is equivalent to the average energy requirement of about 4,700 inhabitants of Denmark in one year.

Conclusion

The results show that both biogas as well as natural gas have certain ecological advantages and disadvantages, depending on the parameters given highest priority. Biogas has significant environmental advantages over natural gas with regard to the parameters greenhouse effect and use of fossil fuels but on the other hand natural gas is superior with regard to acidification and eutrophication and summer smog. The parameter human toxicity shows a less significant result in favour of fossil fuel, but it should be noted that these data tend to have a high uncertainty, and should not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against biogas or natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required. Whether biogas is assessed as better or worse than natural gas depends upon the focus and priorities of the decision makers. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, biogas will be better suited. If on the other hand the parameters acidification and eutrophication are deemed to be most important, then natural gas would be preferred.

Technical applications: heat production – Denmark



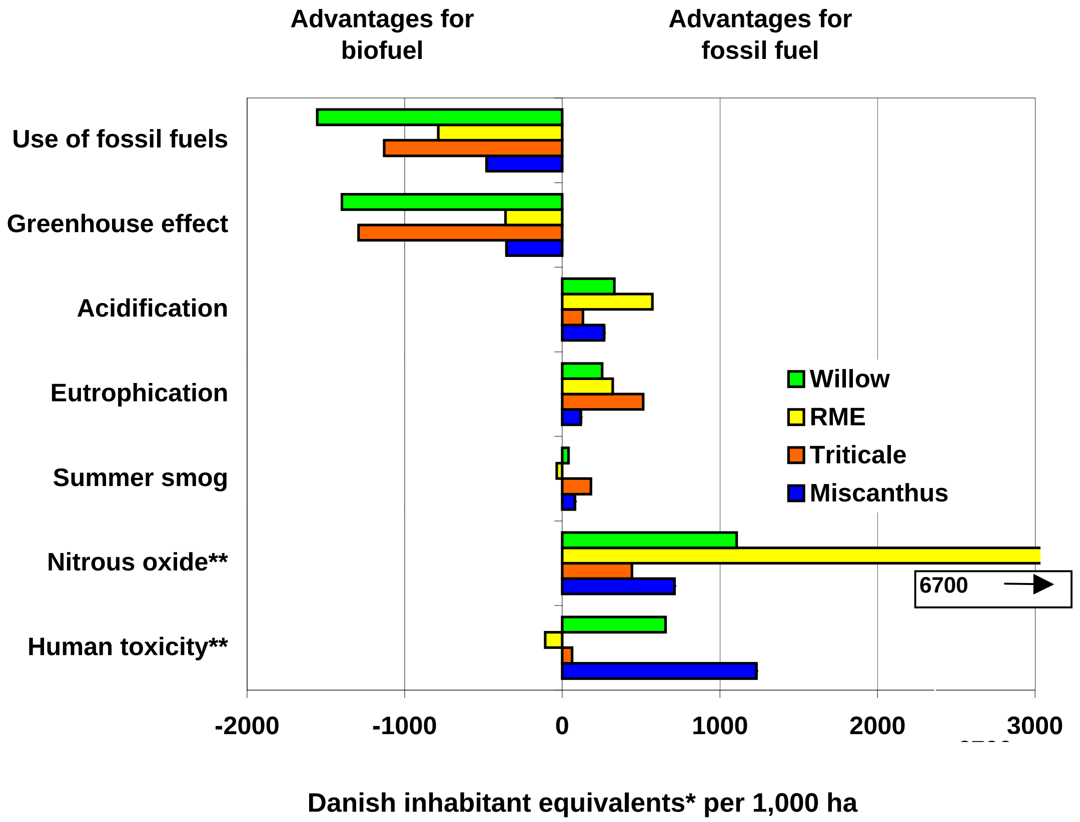
* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where straw, willow and Miscanthus respectively are used for heat production instead of light oil. The results are given for an amount of 100 TJ. This is equivalent to the average heat requirement of 4,700 Danes. In this case for example the amount of greenhouse gas emissions that is being saved by substituting light oil by willow is equal to the amount which about 750 Danish citizens would on average generate in one year. (This is what is meant by “Danish inhabitant equivalents”).

Conclusion

Comparing the three investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges: Straw show the greatest advantages in all categories apart from summer smog and human toxicity. Willow has similar big advantages with regard to use of fossil fuels and greenhouse effect, and comes out second best regarding nitrous oxide, acidification and eutrophication. Miscanthus is the worst choice in all categories apart from summer smog, and is therefore not recommendable for heat production, if the categories here reflect the interest of the decision-maker. However, whether straw or willow should be recommended depends on the subjective judgements and priorities of the individual decision maker with regard to the environmental categories under study, and other interests.

Ecological aspects I: land use efficiency – Denmark



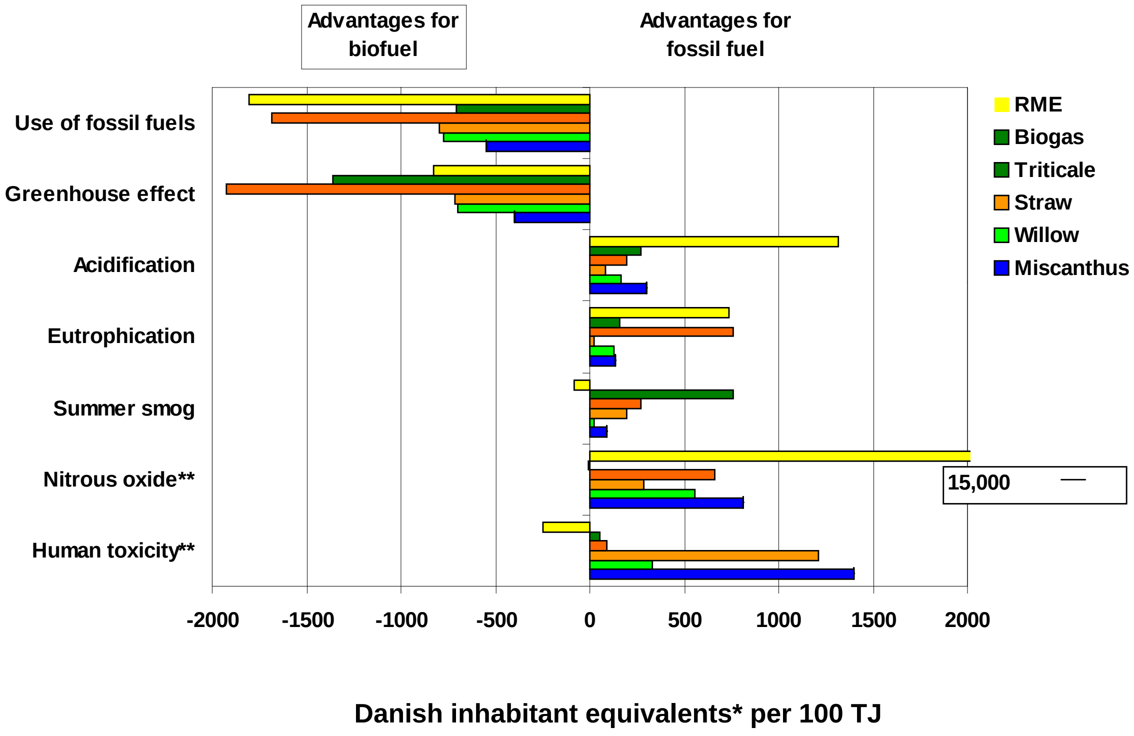
* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where willow, RME, triticale and Miscanthus respectively are used for energy production instead of their respective fossil counterparts. The results are given for an area of 1,000 ha being cultivated with the respective crop. In this case for example the amount of greenhouse gas emissions that is being saved when 1,000 ha of Miscanthus are cultivated and used to substitute light oil, is equal to the amount which about 350 Danish citizens would on average generate in one year. (This is what is meant by “Danish inhabitant equivalents”).

Conclusion

Comparing the four investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges: Growing 1000 ha of willow or triticale will give the greatest advantages in the categories use of fossil fuels and greenhouse effect. Triticale furthermore shows the best results with regard to nitrous oxide and acidification. RME shows the worst or second worst results in all categories, except from an insignificant advantage with regard to summer smog. Miscanthus shows the smallest advantages with regard to use of fossil fuels and greenhouse effect and has average disadvantages with regard to all other categories than human toxicity, and these data should not be included in the final assessment because of a relatively high uncertainty. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.) It is important to realise that the final assessment of which biofuel is to be preferred depends on the subjective judgements and priorities of the individual decision maker.

Ecological aspects II: impacts related to saved energy – Denmark



* How to interpret the diagram

The figure can be used to give an answer in the situation where a decision maker wants to support a given amount of bioenergy measured in Joule, and wants to know which energy will give maximum environmental benefits from this support.

The figure shows the results of complete life cycle comparisons where RME, biogas, triticale, straw, willow and Miscanthus respectively are used for energy production instead of their respective fossil counterparts (light oil is chosen for Miscanthus, willow and straw). The results are given for an amount of 100 TJ. This is equivalent to the average heat requirement of 4,700 Danes. In this case for example the amount of greenhouse gas emissions that is being saved by substituting light oil by RME is equal to the amount which about 800 Danish citizens would on average generate in one year. (This is what is meant by “Danish inhabitant equivalents”).

Conclusion

Comparing the six investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges: RME shows the greatest advantages with regard to use of fossil fuels, summer smog, and human toxicity. Triticale has greatest advances with regard to greenhouse effect, and for use of fossil fuels the advantage is almost as big as for RME. Straw show the smallest disadvantages with regard to nitrous oxide, acidification and eutrophication. A further assessment of what biofuel is most environmental advantageous cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

7.1.3 Country specific results – France

The bioenergy strategy in France is depending on the existing energy producers and the availability of raw materials from the forestry and agriculture sectors. Traditional fuelwood for domestic use is the most important source of bioenergy in France (about 8-10 Mtoe per year). A large scale programme, managed by ADEME, is promoting a better use efficiency for this fuel wood and also a utilisation in industries and collectivities. More recently, at the beginning of the 1990's, liquid biofuels for transportation have been implemented at a large scale level according to the Levy's mission (1991). This project is based upon two chains : a) RME – rape seed oil methyl ester – from rape seed oil blended with diesel (5 % in volume without labelling, up to 30 % in urban captive fleets), today this chain represents roughly 300 000 tons of RME per year (~300 000 ha of rape seed grown on set-aside areas) and b) ETBE – ethyl tertiobutyl ether – (47 % ethanol and 53 % isobutylen) from ethanol produced from sugar beet or wheat blended with gasoline (15 % in volume), this chain represents today 100 000 tons of alcohol per year and extension based upon alcohol ex sugar beet is planned. These chains benefit from temporary tax exemption: 0.50 Euro per litre of alcohol and 0.35 Euro per litre of RME. These bioenergy chains, fuelwood and mainly liquid biofuels, are now mature and implemented on an industrial scale. Other bioenergy chains based on lignocellulosic raw materials for electricity and heat production are today in France at the experimental or demonstration level. Specific experiments exist at the agricultural level (Miscanthus, fibre sorghum, Arundo etc.) but agricultural dry residues such as cereal straw represent a high potential of lignocellulosic raw material for these chains.

While the results for the whole of Europe are presented in Chapter 4, in the following section are presented the results of all life cycle comparisons that were investigated in France:

- Triticale versus coal
- Miscanthus versus natural gas
- Wheat straw versus natural gas
- Rape seed oil methyl ester (RME) versus fossil diesel fuel
- Sunflower methyl ester (SME) versus fossil diesel fuel
- ETBE from sugar beet versus MTBE

For more information on these comparisons the reader is referred to Chapter 2. As for the European chains, the life cycle comparisons were carried out with regard to specific environmental impact parameters. These were:

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog (Photochemical Ozone Creation Potential)
- Nitrous oxide
- Human toxicity

The criteria according to which these were selected as well as an explanation of their meanings can be found in the Chapters 3.3 and 3.4. For reasons of clarity of presentation, the results of minimum-maximum evaluations have not been presented in the result graphs. For more information on this the reader is referred to Chapter 4.1.3.

How to interpret the diagrams

The seven following diagrams show the results of comparisons between complete life cycle of the bioenergy chains studied in France versus their corresponding fossil energy chain. Each of the seven diagrams is concerning a specific impact: primary energy requirements, global warming potential, acidification and eutrophication, summer smog (photochemical ozone creation potential), nitrous oxide (N_2O emissions) and finally human toxicity.

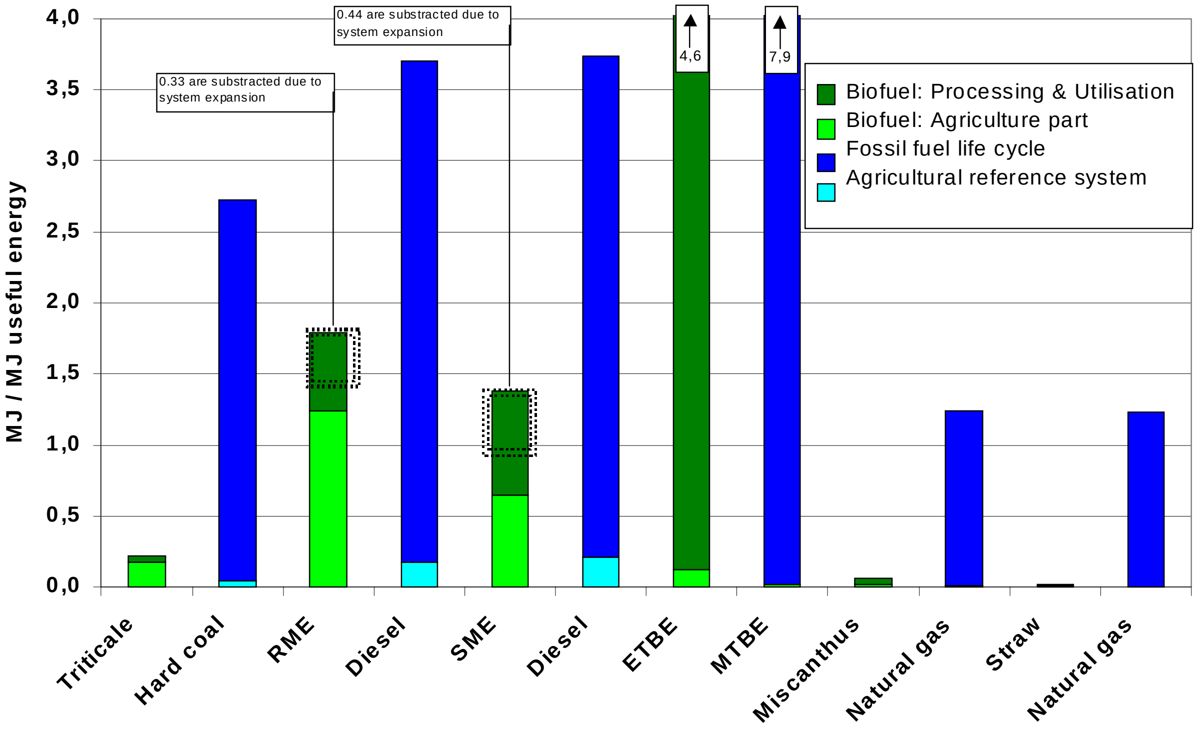
For each of the 7 diagrams, the abscissa represents a series of 6 comparable couples of energy (1 bioenergy and 1 fossil energy) for example: triticale versus hard coal, RME versus diesel etc.

Useful energy is electrical energy for the comparison triticale-hard coal, mechanical energy for the comparisons RME-diesel, SME-diesel and ETBE-MTBE and finally calorific energy for the comparisons Miscanthus-natural gas and straw-natural gas.

A direct comparison between bioenergy chains is only correct if the useful energy or energy vector is similar. So, we can compare Miscanthus versus straw , RME versus SME.

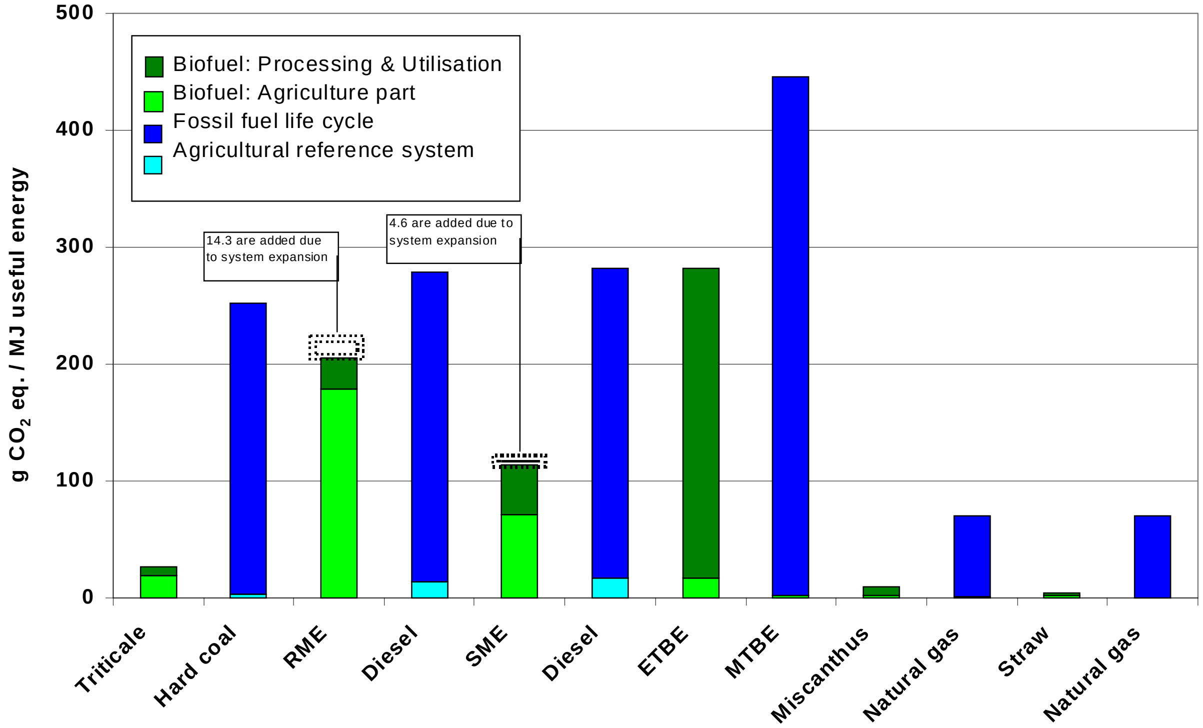
Primary energy requirements – France

In comparison with fossil energy, all the bioenergy chains represent a significant advantage. This advantage is maximum with electricity and heat production respectively from triticale, Miscanthus and straw. The advantage with liquid biofuels (RME, SME & ETBE) is less important but liquid biofuel is a more sophisticated source of energy, especially well adapted to transportation. RME and SME are more efficient than ETBE as the fossil content (methanol) and the industrial transformation (esterification) are less important. The apparent low contribution of agriculture to ETBE versus RME or SME is due to the higher productivity per hectare of sugar beet.

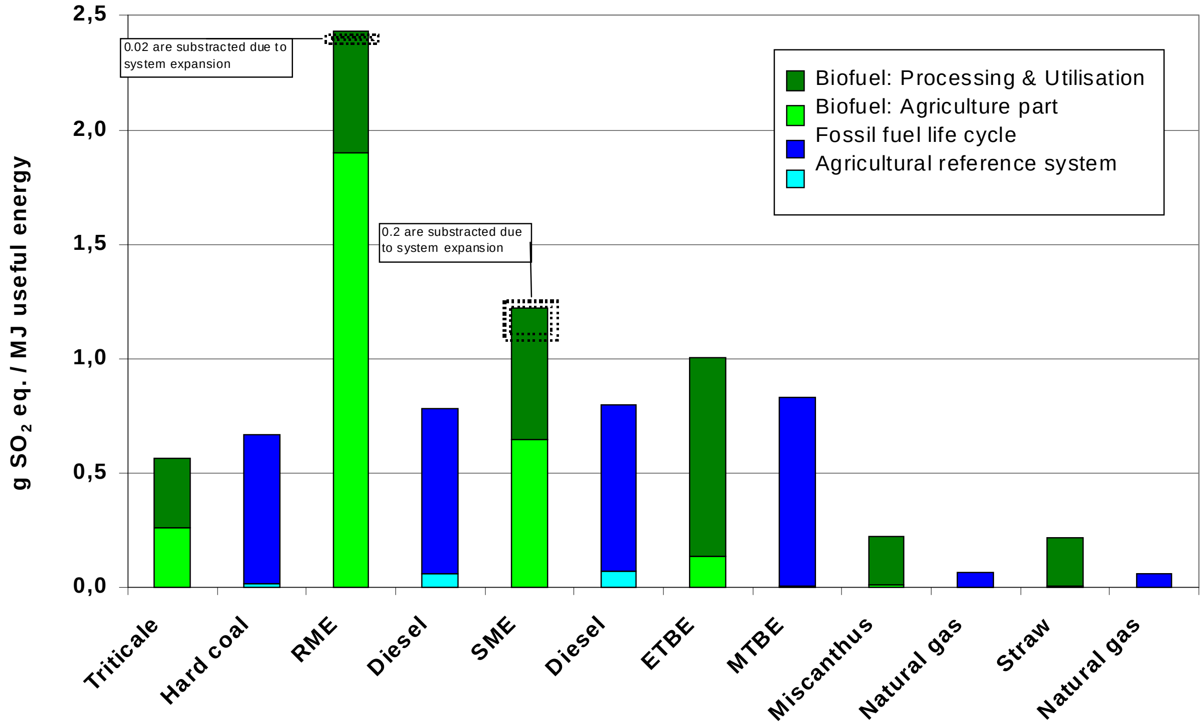


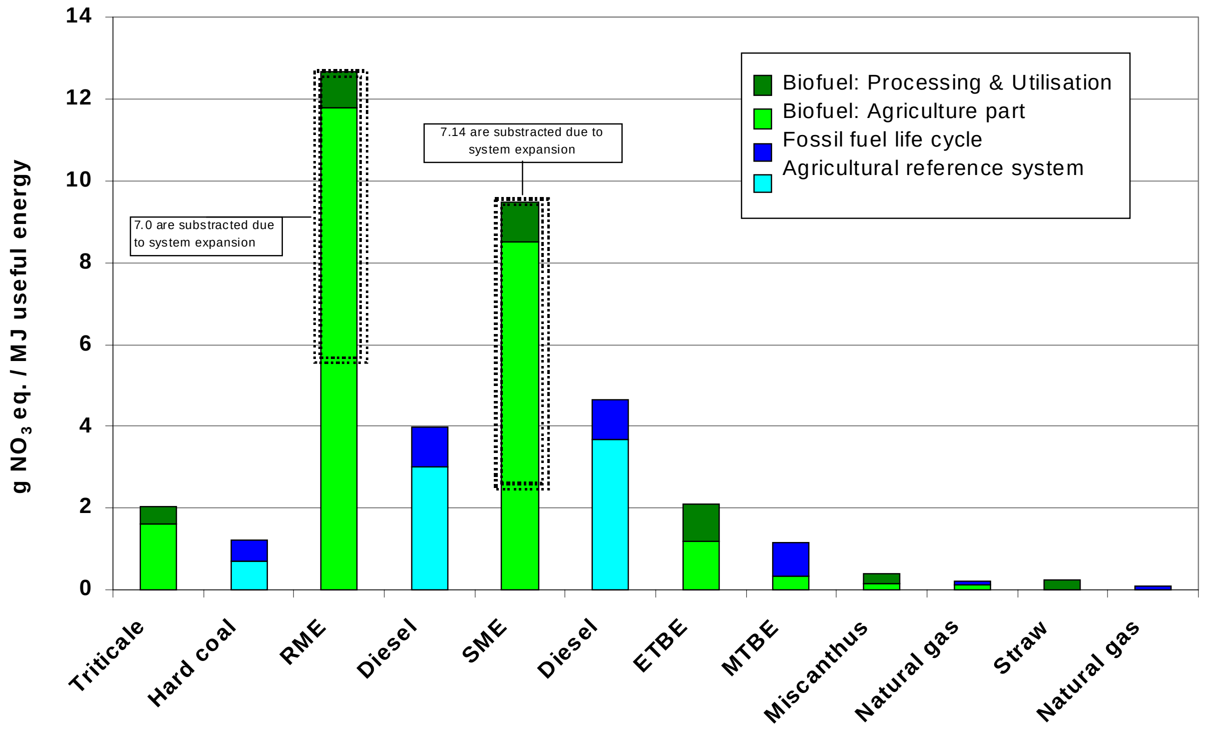
Global warming potential – France

The previous comments concerning primary energy can be applied to the global warming potential. But, the following comment may be added in order to explain the difference between the agriculture contribution to RME and SME. Rape seed and sunflower have a similar productivity per hectare with a nitrogen input very different, respectively 180 and 50-60 units N/ha. As the N_2O emission is a fixed percentage of the N fertiliser applied, it explains the difference in GWP.



Acidification and Eutrophication – France

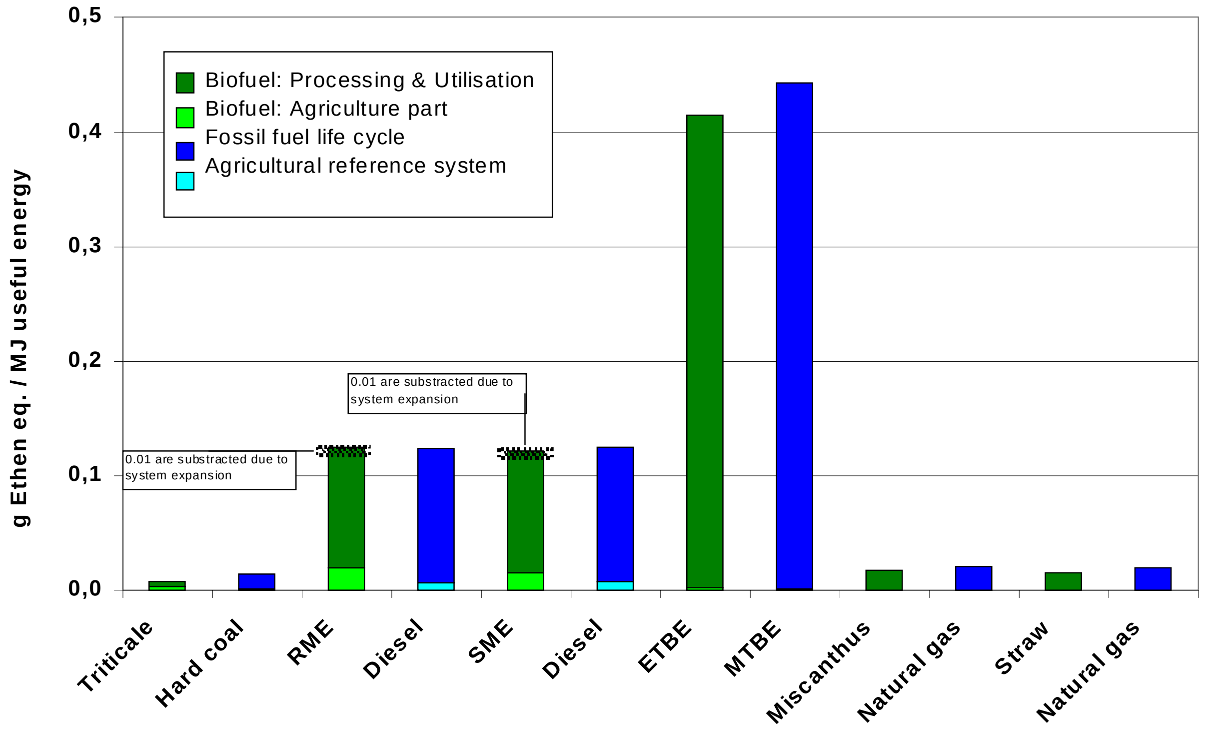



7.0 are substracted due to system expansion

7.14 are substracted due to system expansion

Generally, the biofuels have higher emission values than the corresponding fossil fuels. This is mainly due to the influence of the agricultural inputs, particularly nitrogen fertilisers. In the case of RME and SME this effect is particularly strong because of their high nitrogen fertiliser demands. The fact that ETBE has lower emission values than the vegetable oil methylesters is mainly explained by the higher productivity per hectare of sugar beet.

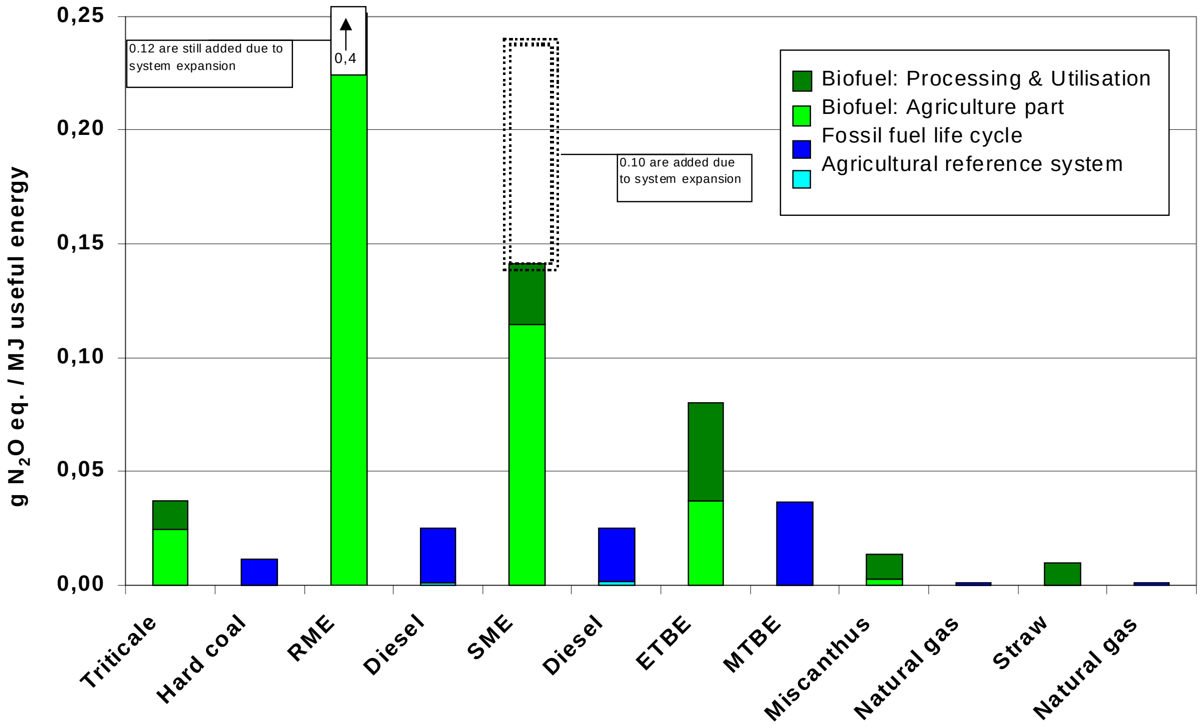
Summer smog (photochemical ozone creation potential) – France


0.01 are substracted due to system expansion

0.01 are substracted due to system expansion

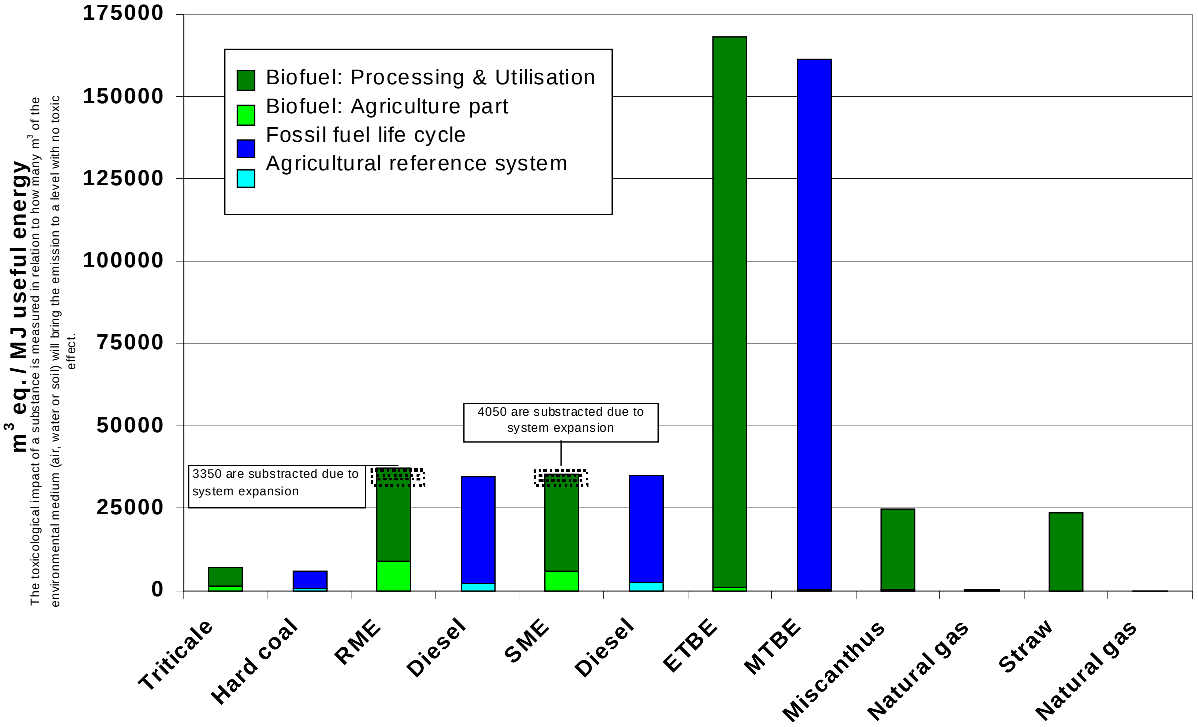
This graph shows there is no significant difference between biofuels and their respective fossil equivalents. For RME, SME and ETBE, the POCP ranges between 0 and 7 % less than diesel or MTBE. For the biofuels used to produce electricity or heat, the POCP is significantly lower than for those used to produce liquid biofuels, and the advantages for biofuels are still important: 15 to 20 % less POCP for Miscanthus or straw compared to natural gas, and more than 50 % less POCP for triticale compared to hard coal.

Nitrous oxide (N_2O emissions) – France



The large differences in N_2O emissions are mainly due to fertiliser production and application (see section on GWP).

Human toxicity – France



Concerning human toxicity, except for Miscanthus and straws, there is no significant difference between biofuels and their respective fossil equivalents. For RME, SME and ETBE, it ranges between 0 and 8 % more than diesel or MTBE, and for triticale it's 25 % more than for hard coal, but very low values in comparison to other chains. For the biofuels used to produce heat, the human toxicity is significantly higher than that natural gas, which is the best fossil source of energy concerning this impact.

Conclusion

In comparison with fossil energy, all the bioenergy chains represent a significant advantage in term of global impact: resources depletion such as primary energy, global warming potential. This advantage is higher with biomass as raw material for electricity and heat than with liquid biofuels. But liquid biofuels are today the single source of energy for transportation. The advantage of bioenergy at the global scale is sometimes weighted by the local or regional impacts such as eutrophication or acidification. In terms of environment, the use of bioenergy is prevailing on an optimum between global and local impacts on environment. Moreover, these different impacts represent a partial view of the environmental impacts such as landscape, which are directly related to the spatial distribution of the energy crops at the national scale and land use.

7.1.4 Country specific results – Germany

Within the context of this project, the various participating countries investigated different biofuels in comparison to their respective fossil counterparts, as was explained in Chapter 2. While the results for the whole of Europe are presented in Chapter 4, in this chapter the results for the individual countries are presented, on which the German results are based. In the following section the results for all those life cycle comparisons are presented that were investigated in Germany. These are:

- Triticale versus coal
- Willow versus light oil and natural gas
- Miscanthus versus light oil and natural gas
- Rape seed oil methyl ester versus fossil diesel fuel
- ETBE from sugar beet versus MTBE
- Wheat straw versus light oil and natural gas

In addition, for each country comparisons between its various biofuels have been carried out in order to assess which one is the most suitable in ecological terms for a specific objective. This lead to a number of different questions, in the light of which the various biofuels were compared. Germany looked at four of these, namely:

- Technical applications
    - Heat production: willow, Miscanthus and straw
    - Transport: RME and ETBE
- Ecological aspects
    - Efficiency of land use: triticale, willow, Miscanthus, RME and ETBE
    - Impacts related to saved energy: triticale, willow, Miscanthus, RME, ETBE and straw

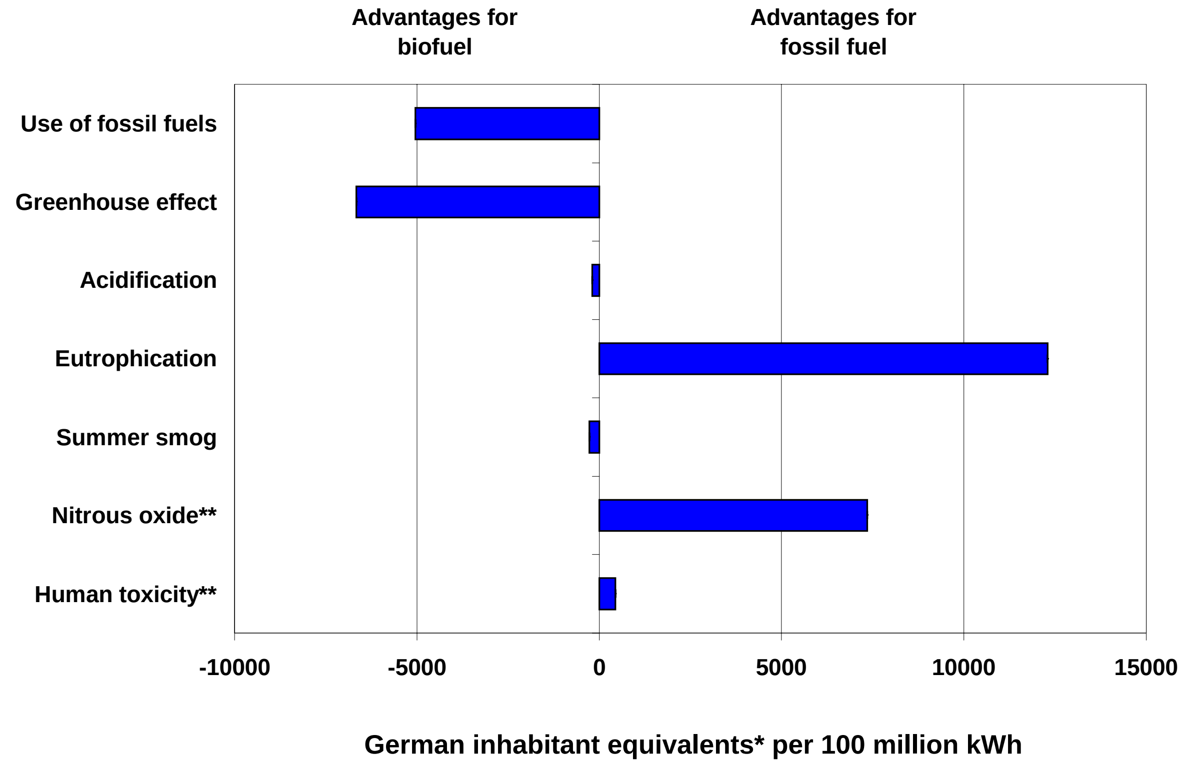
For more information on these comparisons the reader is referred to Chapter 2. As for the German chains, the life cycle comparisons were carried out with regard to specific environmental impact parameters. These were:

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Nitrous oxide
- Human toxicity

The criteria according to which these were selected as well as an explanation of their meanings can be found in the Chapters 3.3 and 3.4.

For reasons of clarity of presentation, the results of minimum-maximum evaluations have not been presented in the result graphs. For more information on this the reader is referred to Chapter 4.1.3.

Triticale versus hard coal for electricity production – Germany



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where hard coal is substituted by triticale for electricity generation. The unit refers to an amount of one hundred million kWh of electricity. This is equivalent to the average electricity requirement of about 15,000 inhabitants in Germany in one year, or a triticale production of about 5,500 ha/a. In this case for example the amount of fossil fuel saved is equal to the amount which about 5,000 German citizens would on average consume in one year (this is what is meant by “German inhabitant equivalents”).

Remarks and conclusions

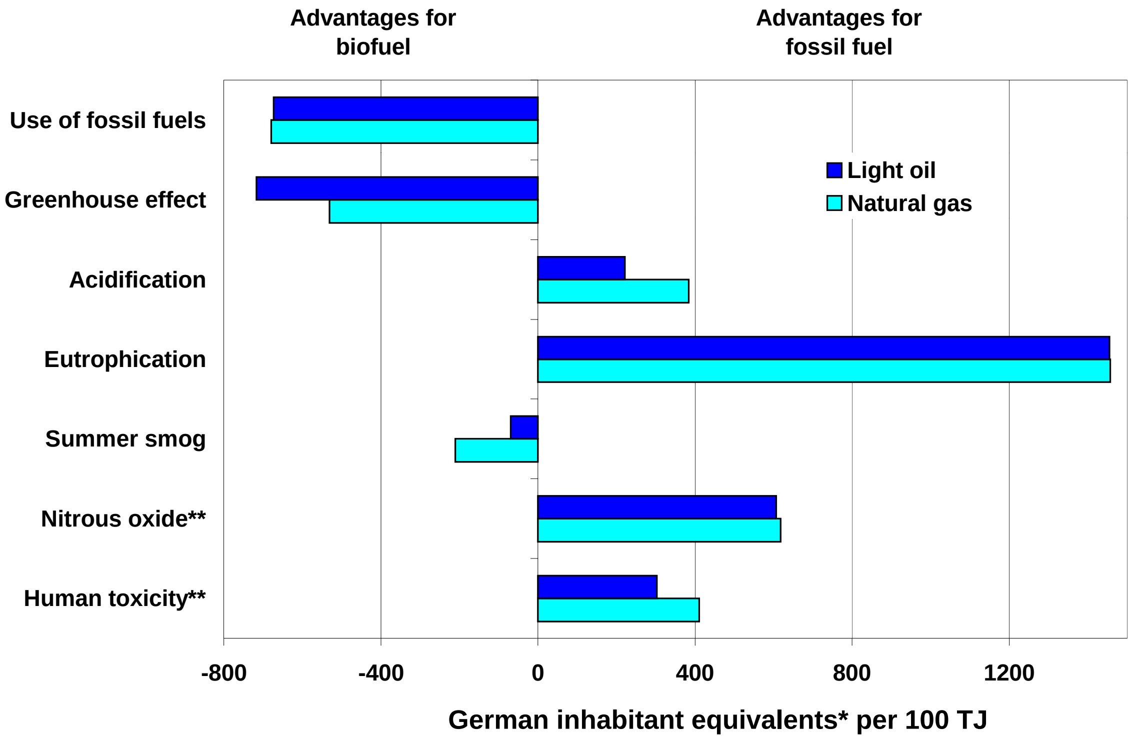
The results show that both triticale as well as hard coal have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect and summer smog (small)
- Advantages of the fossil fuel: eutrophication
- Low or no significance: acidification

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

A further assessment in favour of or against triticale or hard coal cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

Willow versus light oil / natural gas for district heat production – Germany



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where light oil and natural gas respectively are substituted by willow for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 25,000 inhabitants of Germany in one year or a willow production of about 900 ha/a. In this case for example the amount of fossil fuel saved if Miscanthus replaces either of the fossil fuels is equal to the amount which about 700 German citizens would on average consume in one year (this is what is meant by “German inhabitant equivalents”).

Remarks and conclusions

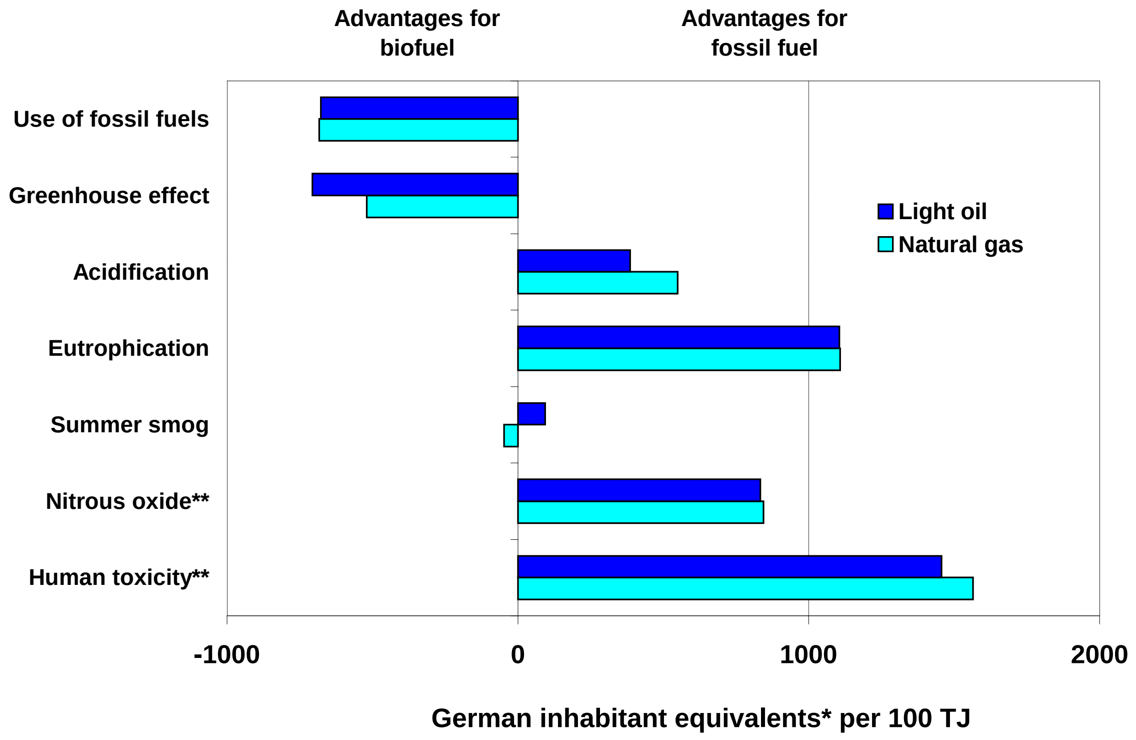
The results show that both willow as well as light oil and natural gas have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, summer smog
- Advantages of the fossil fuel: acidification, eutrophication
- Low or no significance: –

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

A further assessment in favour of or against willow or light oil / natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

Miscanthus versus light oil / natural gas for district heat production – Germany



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where light oil and natural gas respectively are substituted by Miscanthus for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 25,000 inhabitants of Germany in one year or a Miscanthus production of about 450 ha/a. In this case for example the amount of fossil fuel saved if light oil is substituted by Miscanthus is equal to the amount which nearly 700 German citizens would on average consume in one year (this is what is meant by “German inhabitant equivalents”).

Remarks and conclusions

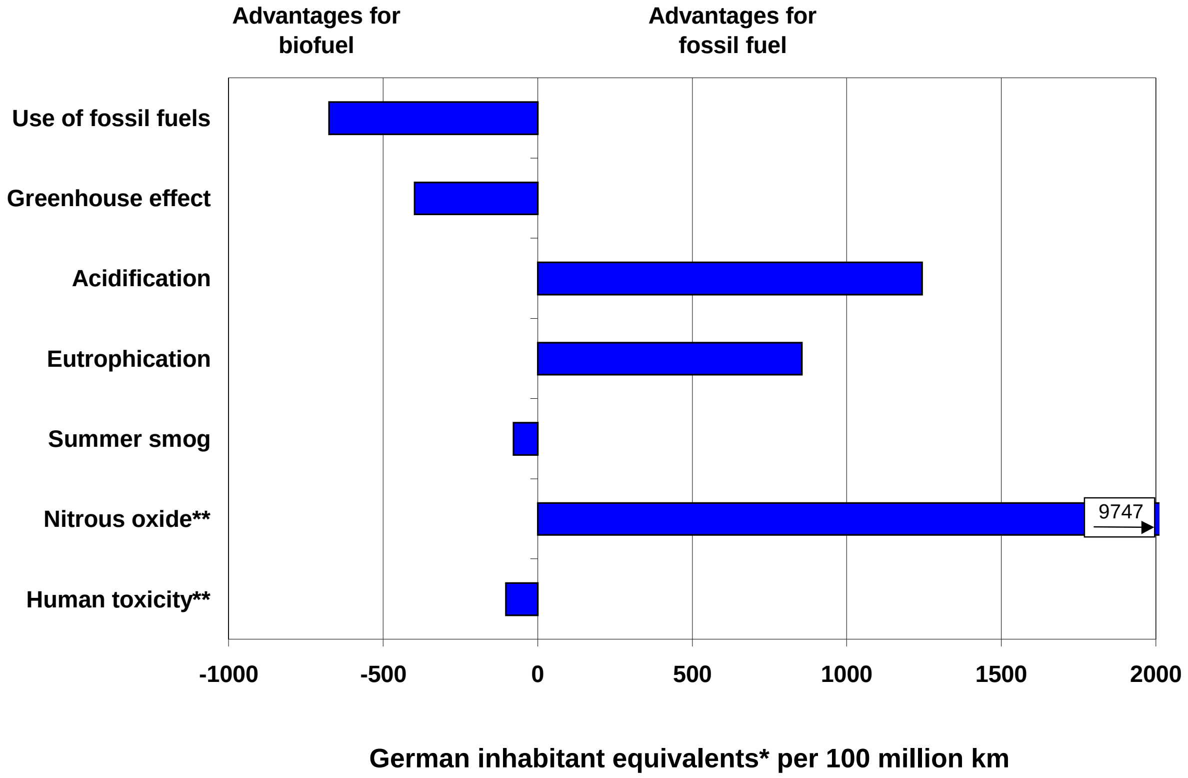
The results show that both Miscanthus as well as light oil and natural gas have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, compared to natural gas also summer smog (small)
- Advantages of the fossil fuel: acidification, eutrophication, compared to light oil also summer smog (small)
- Low or no significance: –

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

A further assessment in favour of or against Miscanthus or light oil / natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

RME versus diesel fuel for transportation – Germany



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where RME is used in passenger cars instead of diesel fuel. The results are given for a distance of 100 million km being covered by passenger cars using the biofuel instead of fossil fuel. This is equivalent to the average annual mileage of about 7,000 inhabitants of Germany. In this case for example the amount of greenhouse gas emissions that is being saved by substituting diesel fuel by RME is equal to the amount which about 700 German citizens would on average generate in one year (this is what is meant by "German inhabitant equivalents").

Remarks and conclusions

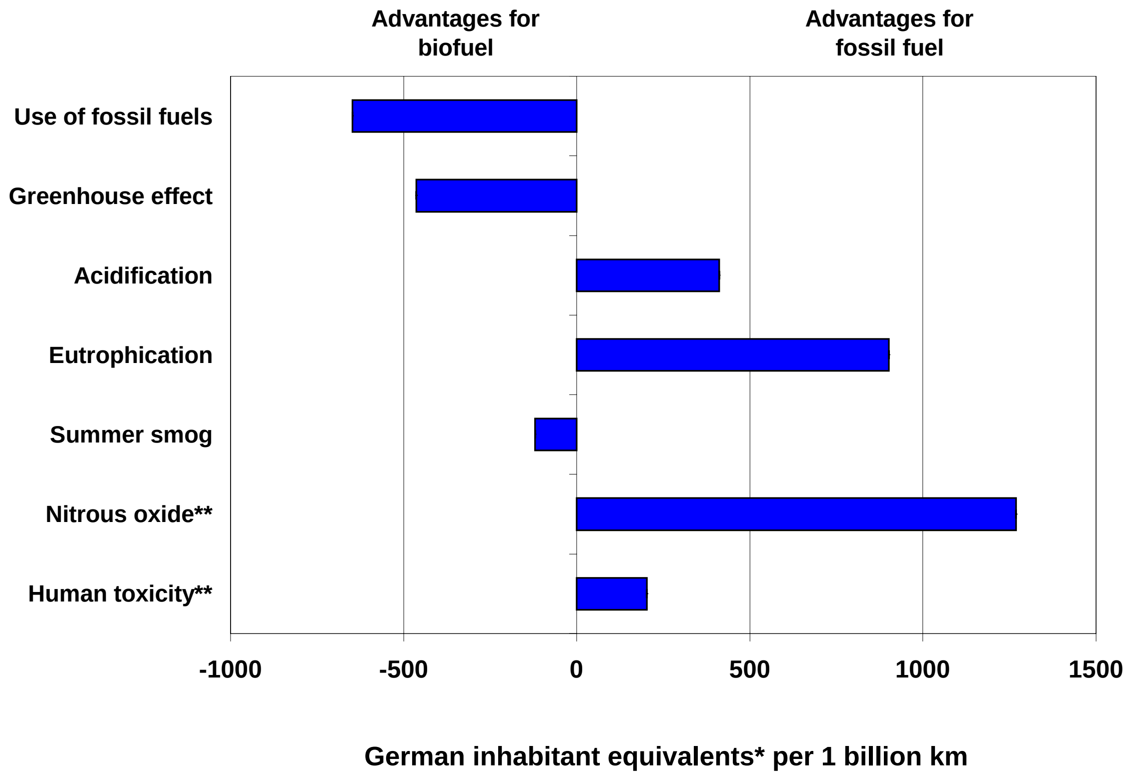
The results show that both RME as well as diesel fuel have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect
- Advantages of the fossil fuel: acidification, eutrophication
- Low or no significance: summer smog

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

A further assessment in favour of or against RME or diesel fuel cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

ETBE versus MTBE for transportation – Germany



* How to interpret the diagram:

The figure shows the results of complete life cycle comparisons where gasoline with component ETBE from sugar beet (12 vol. % = 10 % of energy content) is used in passenger cars instead of gasoline with fossil MTBE (12 vol. %). The results are given for a distance of 1 billion km being covered by passenger cars using the gasoline with the bio-component instead of fossil component. This is equivalent to the average annual mileage of about 70,000 Germans. In this case for example the amount of greenhouse gas emissions that is being saved by substituting diesel fuel by ETBE is equal to the amount which nearly 700 German citizens would on average generate in one year (this is what is meant by "German inhabitant equivalents").

Remarks and conclusions

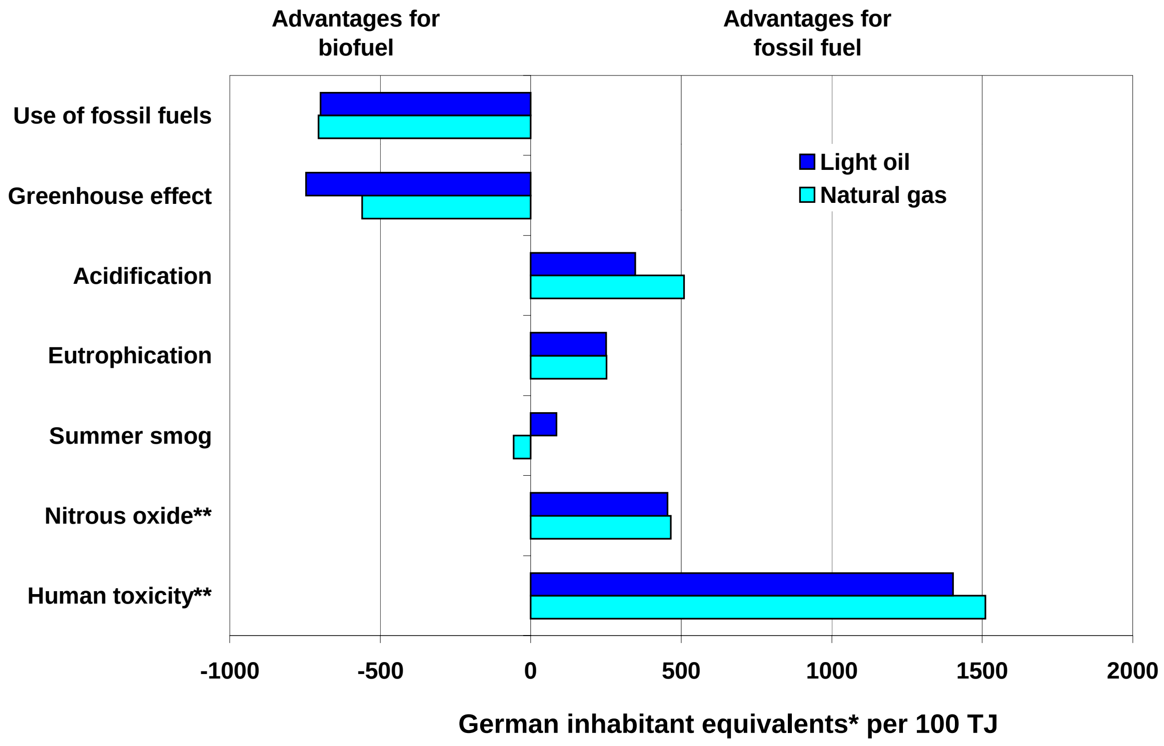
The results show that both ETBE as well as MTBE have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect
- Advantages of the fossil fuel: acidification, eutrophication
- Low or no significance: summer smog

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

A further assessment in favour of or against ETBE or MTBE cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

Wheat straw versus light oil / natural gas for district heat production – Germany



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where light oil and natural gas respectively are substituted by wheat straw for heat production. The unit refers to an amount of 100 TJ of heat. This is equivalent to the average heat requirement of about 25,000 inhabitants of Germany in one year or a wheat straw production of about 1,300 ha/a. In this case for example the amount of fossil fuel saved if light oil is substituted by wheat straw is equal to the amount which more than 700 German citizens would on average consume in one year (this is what is meant by “German inhabitant equivalents”).

Remarks and conclusions

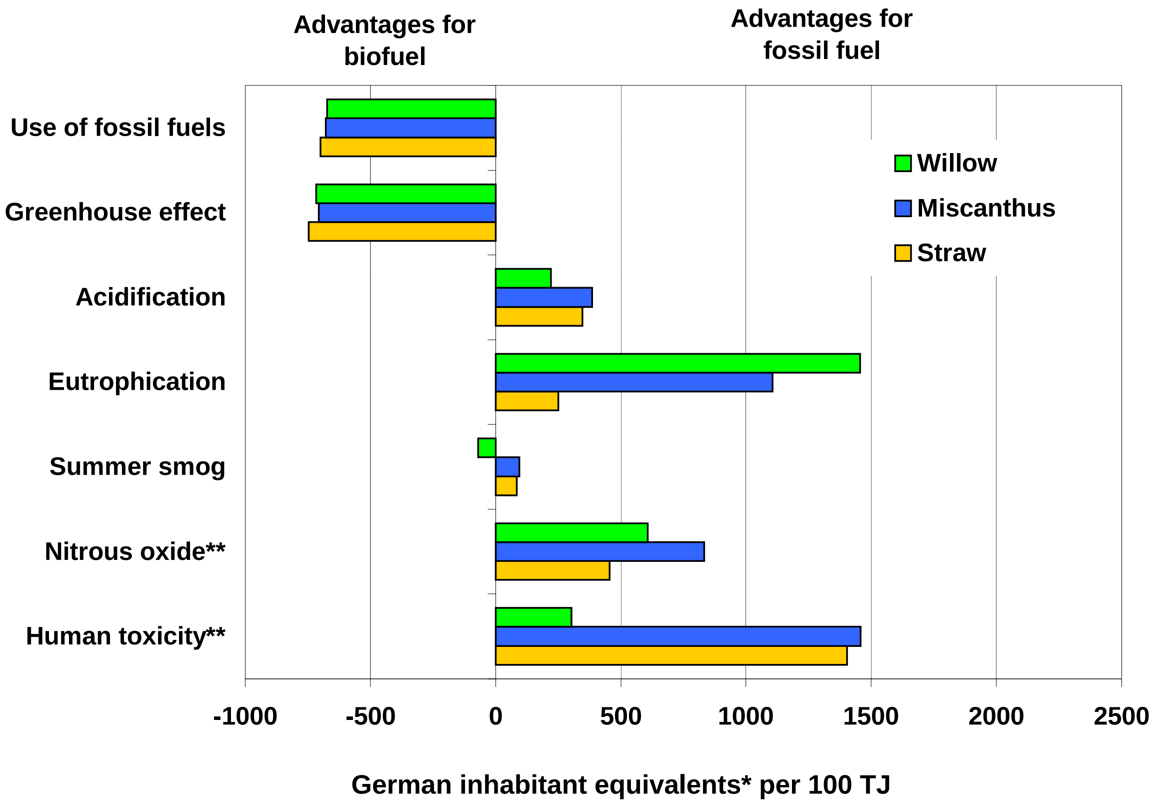
The results show that both wheat straw as well as light oil and natural gas have certain ecological advantages and disadvantages.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, compared to natural gas only: summer smog (small)
- Advantages of the fossil fuel: acidification, eutrophication, light oil only: summer smog
- Low or no significance: –

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

A further assessment in favour of or against wheat straw or light oil / natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

Technical applications I: heat production – Germany



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where straw, willow and Miscanthus respectively are used for heat production instead of light oil. The results are given for an amount of 100 TJ. This is equivalent to the average heat requirement of 25,000 inhabitants of Germany in one year. In this case for example the amount of greenhouse gas emissions that is being saved by substituting light oil by Miscanthus is equal to the amount which about 700 German citizens would on average generate in one year. (This is what is meant by “German inhabitant equivalents”.)

Remarks and conclusions

Comparing the four investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:

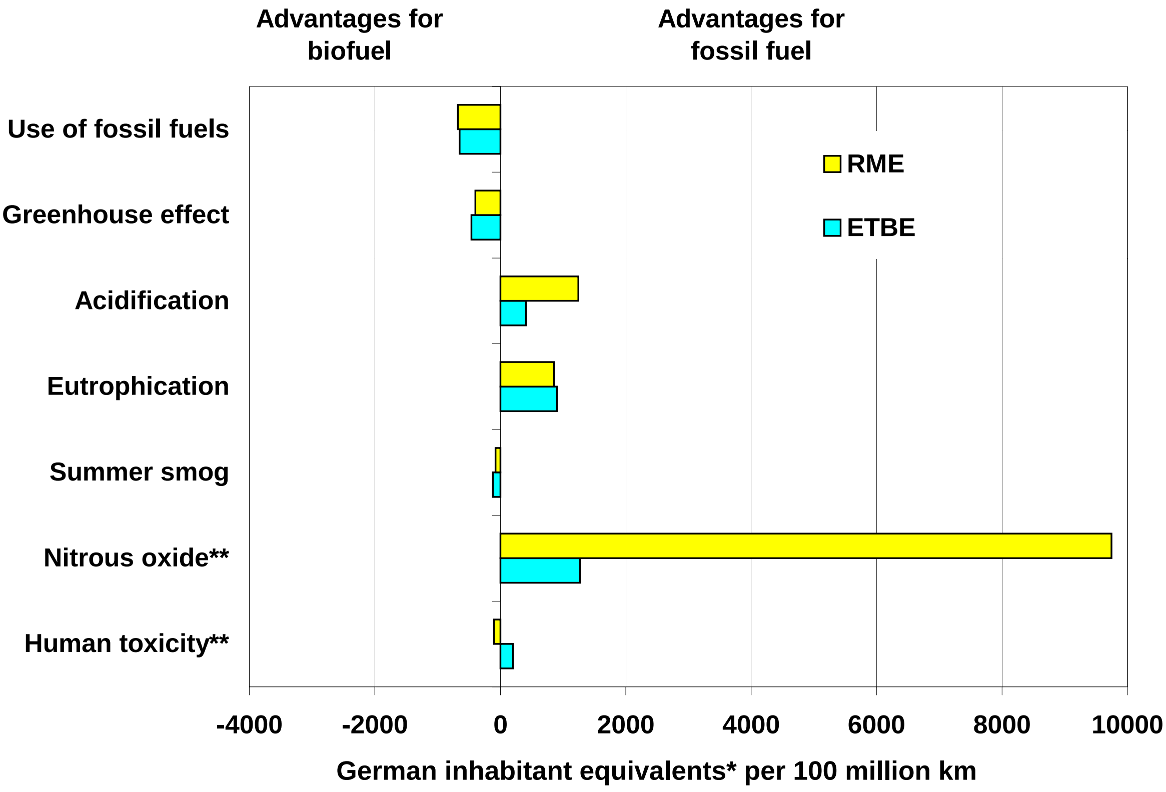
- Use of fossil fuels and greenhouse effect: all biofuels show quite similar advantages.
- Acidification: all biofuels show disadvantages, willow the smallest, straw and Miscanthus similar.
- Eutrophication: straw shows a small, the cultivated biofuels much bigger disadvantages.
- Summer smog: willow shows a small advantage, straw and Miscanthus small disadvantages.

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

Overall, Miscanthus has the least favourable results apart from the category eutrophication.

A further assessment in favour of or against one of the biofuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

Technical applications II: transport – Germany



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where RME, SME and ETBE respectively are used in passenger cars instead of their respective fossil counterparts. The results are given for a distance of 100 million km being covered by passenger cars using the biofuel instead of fossil fuel. This is equivalent to the average annual mileage of 7,000 Germans. In this case for example the amount of greenhouse gas emissions that is being saved by substituting MTBE by ETBE is equal to the amount which about 700 German citizens would on average generate in one year. (This is what is meant by "German inhabitant equivalents".)

Remarks and conclusions

Comparing the three investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:

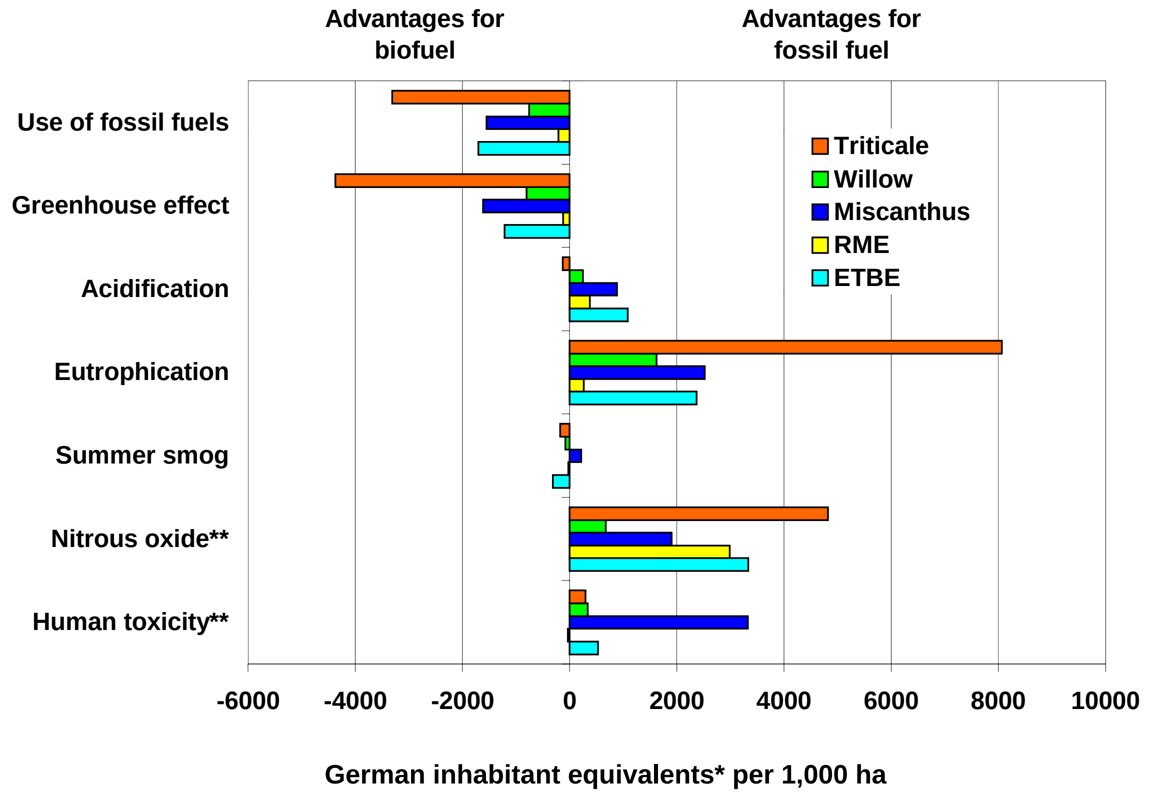
- Use of fossil fuels: the biofuels show quite similar advantages (better: RME).
- Greenhouse effect: the biofuels show quite similar advantages (better: ETBE).
- Acidification: the biofuels show disadvantages of very different magnitude with ETBE having the lower and RME the higher impacts.
- Eutrophication: ETBE and RME have similar disadvantages.
- Summer smog: the results are non-significant.

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

The differences between the results of RME and ETBE respectively are very small, but due to its much larger disadvantage regarding acidification, RME shows the less favourable results overall.

A further assessment in favour of or against one of the biofuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

Ecological aspects I: land use efficiency – Germany



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where willow, Miscanthus, ETBE, RME and triticale respectively are used for energy production instead of their respective fossil counterparts. The results are given for an area of 1,000 ha being cultivated with the respective crop. In this case for example the amount of greenhouse gas emissions that is being saved when 1,000 ha of Miscanthus are cultivated and used to substitute light oil is equal to the amount which about 1,500 German citizens would on average generate in one year. (This is what is meant by “German inhabitant equivalents”.)

Remarks and conclusions

Comparing the six investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:

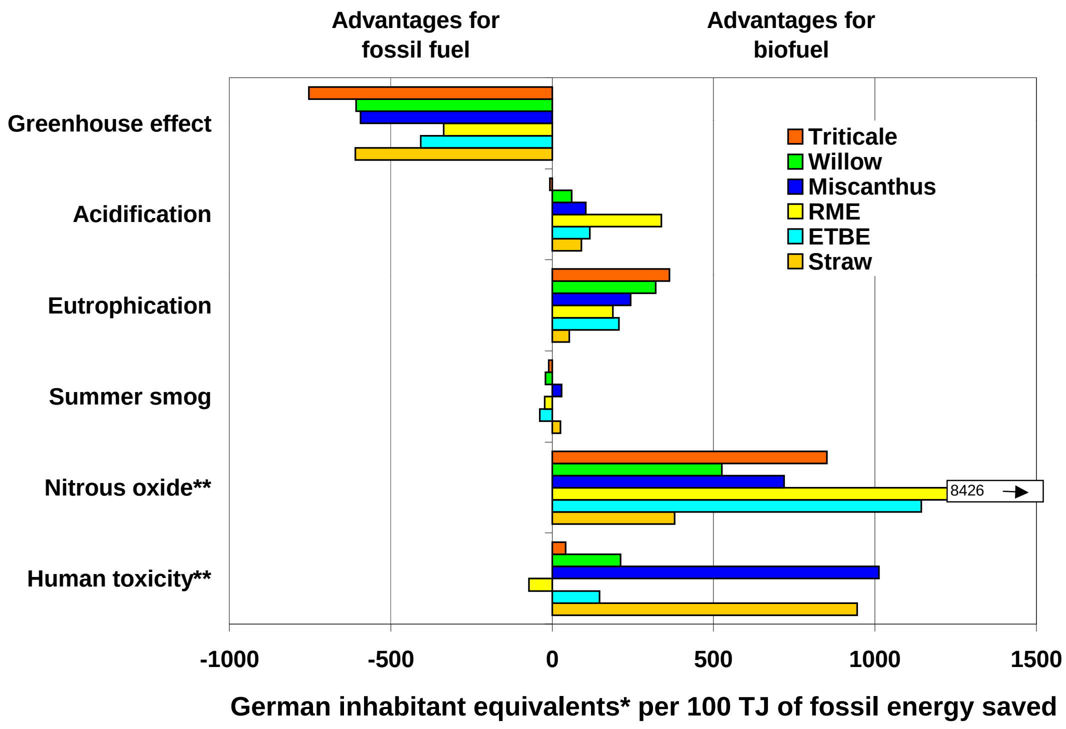
- Use of fossil fuels and greenhouse effect: all biofuels are advantageous. triticale reveals by far the highest benefits. RME shows the smallest advantages.
- Acidification: Nearly all biofuels show disadvantages, ETBE the greatest, willow the smallest. The result for triticale is non-significant.
- Eutrophication: all biofuels show disadvantages, triticale the greatest, willow the smallest.
- Summer smog: triticale and willow show advantages, Miscanthus show a disadvantage. The results for RME and ETBE are non-significant.

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

In this case there appears to be no clear overall ranking of the biofuels, as they all have certain advantages and disadvantages.

A further assessment in favour of or against one of the biofuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

Ecological aspects II: impacts related to saved energy – Germany



* How to interpret the diagram

The figure shows the results of complete life cycle comparisons where all biofuels investigated by Germany are used for energy production instead of their respective fossil counterparts. The results for the various categories are given with reference to the category use of fossil fuels, i.e. 100 TJ of fossil energy saved. For example, for every 100 TJ of fossil energy saved through the substitution of diesel fuel by RME, the amount of greenhouse gas emissions avoided is equal to those on average generated by about 300 inhabitants of Germany in one year. (This is what is meant by “German inhabitant equivalents”.) On the other hand, in this case for every 100 TJ of energy saved an amount of N_2O is emitted that is equal to that on average generated by 8,400 German inhabitants in one year. Note that in this diagram the advantages of the fossil fuels are on the left hand side and vice versa.

Remarks and conclusions

Comparing the investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:

- Greenhouse effect: for all biofuels ensue. This effect is the greatest for triticale and lowest for RME.
- Acidification: apart triticale all biofuels have negative impacts in this category, particularly RME. For triticale the results are non-significant.
- Eutrophication: all biofuels show disadvantages.
- Summer smog: willow and triticale show slight advantages, wheat straw and Miscanthus show slight disadvantages. The results of RME and ETBE are non-significant.

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**See Chapter 4.1.2 and for details on all impact categories 3.3 and 3.4.)

For most of the biofuels a negative “side-effect” results compared to the fossil fuels regarding most of the categories apart from the greenhouse effect.

Taking the land use efficiency of the various biofuels into account (see previous section), triticale appears to achieve the best overall results and RME the worst.

A further assessment in favour of or against one of the biofuels cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

7.1.5 Country specific results – Greece

Within the context of this project, the various participating countries investigated different biofuels in comparison to their respective fossil counterparts, as was explained in Chapter 2. While the results for the whole of Europe are presented in Chapter 4, in this chapter the results for the individual countries are presented, on which the European results are based. In the following section the results for all those life cycle comparisons that were investigated in Greece are presented:

- Wheat straw versus light oil and natural gas for district heating.
- Sunflower seed oil methyl ester (SME) versus fossil diesel fuel for transportation.
- Biogas from liquid swine manure versus natural gas for combined heat and power production.

In addition, for each country comparisons between its various biofuels have been carried out in order to assess which one is the most suitable in ecological terms for a specific objective. This lead to a number of different questions, in the light of which the various biofuels were compared. Greece looked at one of these and namely: Saving of energy resources: SME, biogas and straw.

For more information on these comparisons the reader is referred to Chapter 2. As for the European chains, the life cycle comparisons were carried out with regard to specific environmental impact parameters. These were:

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Nitrous oxide
- Human toxicity

The criteria according to which these were selected as well as an explanation of their meanings can be found in the Chapters 3.3 and 3.4.

How to interpret the diagrams

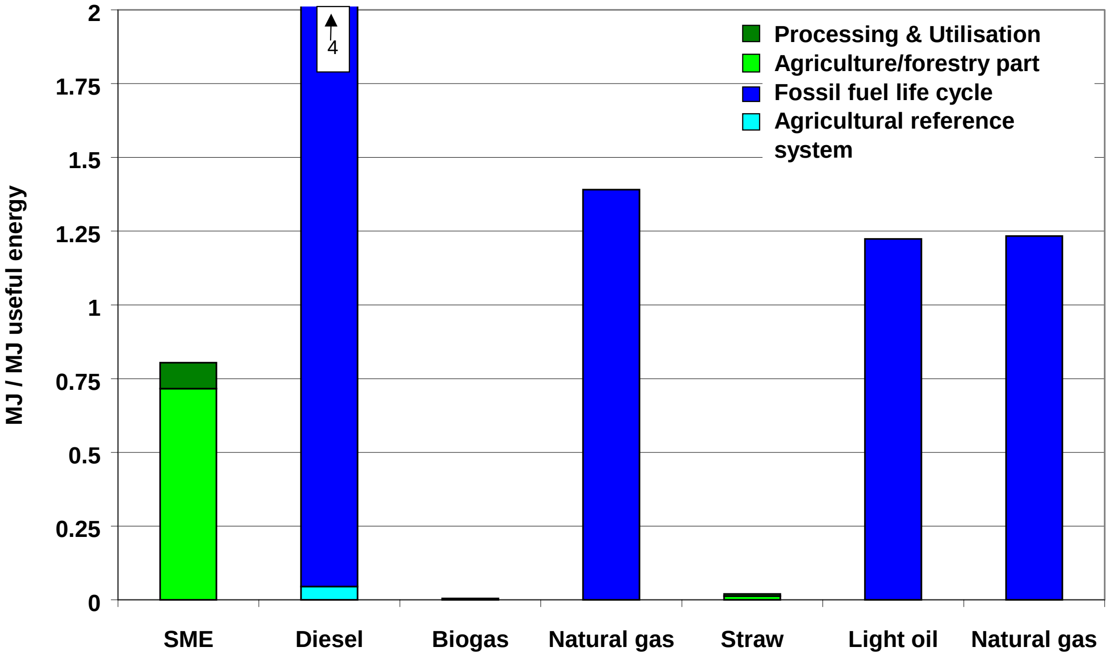
Each diagram corresponds to one environmental parameter for which the results for the biofuels and their fossil counterparts are presented in different columns side by side. The values are expressed per MJ useful energy, namely the net energy that is available to the end user. Each column is divided in two differently coloured parts that correspond to different phases in the life cycles of the fuels under study. *Agriculture/forestry part* includes all processes connected to the production of the raw material until harvesting of the energy crop or collection of the residue while *agricultural reference system* includes the reference use of the land or the residue. *Processing & utilisation* includes all processes after harvesting/collection until energy production and waste disposal on the biofuel’s side and *fossil fuel life cycle* the whole life cycle (production, use and waste disposal) of the fossil fuels . In the case of biogas all processes are included in the *agriculture/forestry* part.

For reasons of clarity of presentation, the minimum-maximum evaluations have not been presented in the result graphs. For more information on this the reader is referred to Chapter 4.1.3.

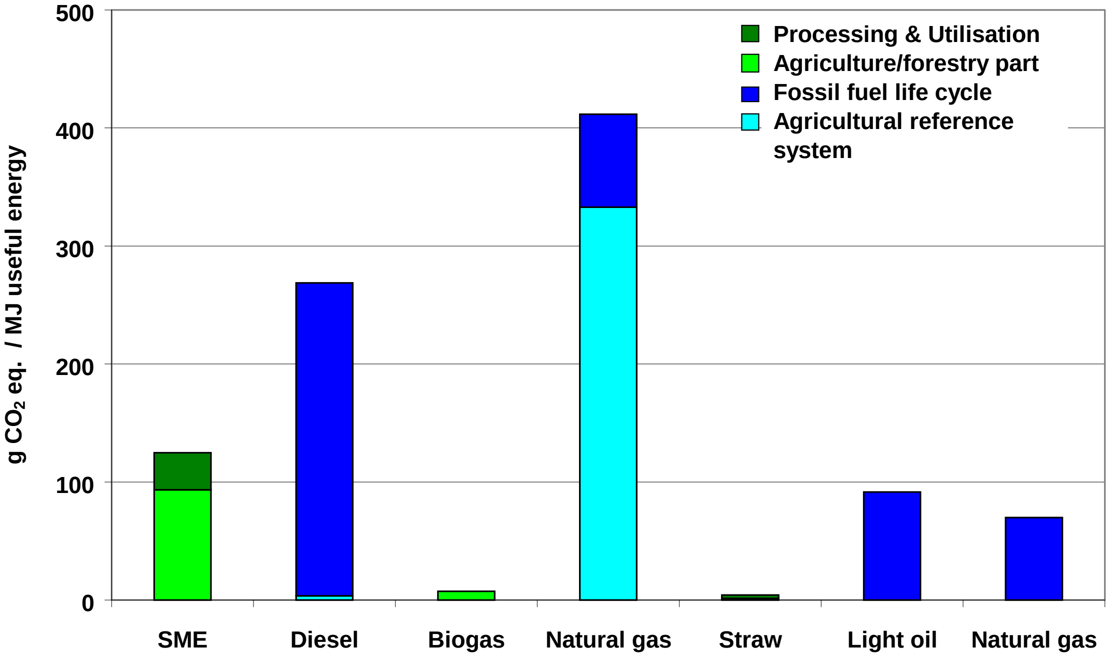
Use of fossil fuels – Greece

The production and use of all biofuels under study instead of their fossil counterparts result in net savings of fossil fuels. The substitution of diesel oil with SME results in a net finite energy gain of 2.8 MJ/MJ useful energy while the respective value for biogas is 1.4 MJ/MJ useful energy. In the case of wheat straw energy savings are up to 1.2 MJ/MJ useful energy when it replaces light oil and 1.4 MJ/MJ useful energy when it replaces natural gas.

The energy requirements per MJ of useful energy are higher in the SME chain compared to the other two biofuels mainly due to increased energy demand during the production of the raw material (sunflower seed). However, SME proves to be the most favourable biofuel in this impact category saving twice as much energy as the other two biofuels.



Greenhouse effect – Greece

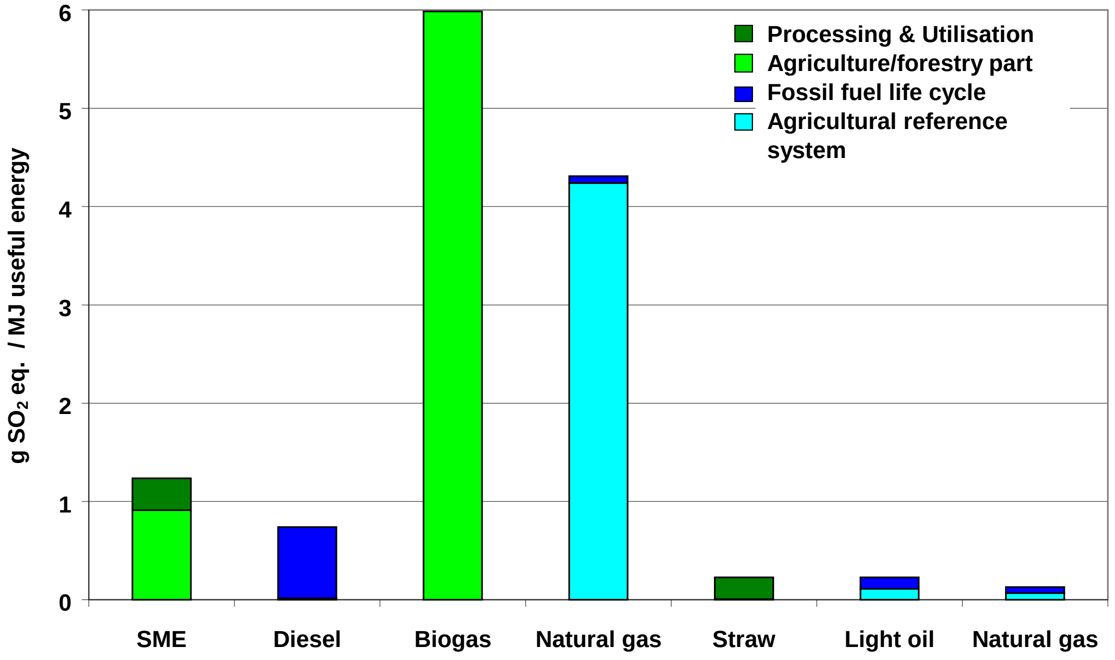


All biofuels under study result in savings of greenhouse gas emissions. The substitution of natural gas with biogas saves 404 g CO_2 eq./MJ useful energy, diesel oil with SME 144 g CO_2 eq./MJ useful energy and light oil with straw 87 CO_2 eq./MJ useful energy. Straw instead of natural gas saves 74 CO_2 eq./MJ useful energy.

The advantage of biogas in this impact category can be attributed to CH_4 use as a fuel in the biogas chain instead of its uncontrolled release to the environment in the reference system as well as the avoided CO_2 emissions from the substitution of a fossil fuel with a biofuel.

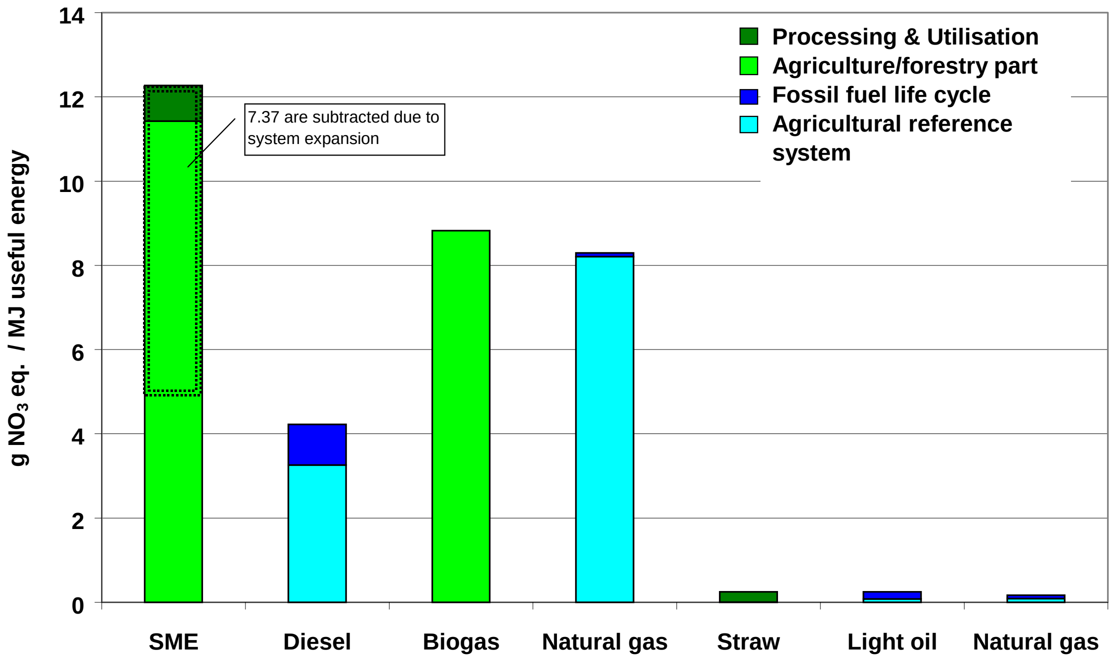
Acidification – Greece

Acidification is an impact category in which all biofuels under study present worse results than the reference fossil fuel. The least favourable biofuel is biogas emitting 1.7 g SO_2 eq./MJ useful energy more than natural gas due to increased SO_2 and NO_x emissions from biogas combustion. The increased acidifying emissions in the SME chain (0.5 g SO_2 eq./MJ useful energy) are in the agricultural part mainly due to NH_3 emissions from nitrogen fertilisation while in the case of straw increased emissions are due to straw combustion.



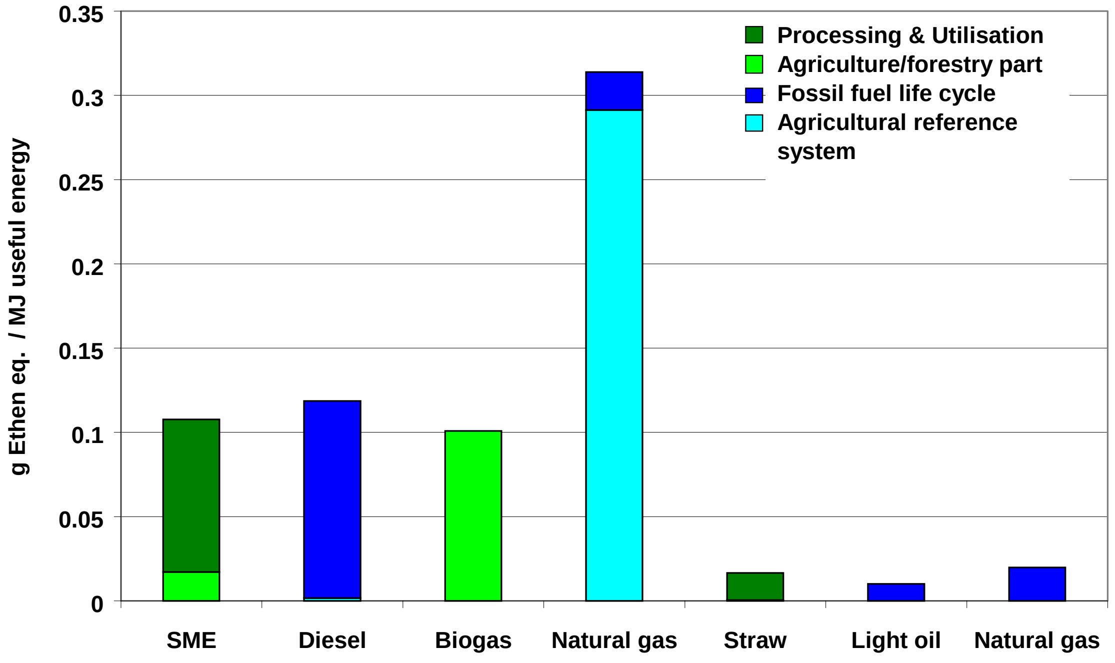
Eutrophication – Greece

In the impact category eutrophication all biofuels present worse results compared to their fossil counterparts. In the biogas chain NOx emissions from biogas combustion are mainly responsible for the increased emissions of the biogas chain (0.52 g NO_3 eq./MJ useful energy more than in the natural gas chain).In the SME chain as shown in the above figure 7.37 g NO_3 eq./MJ useful energy are subtracted from the total emissions of the chain due to system expansion (see Chapter 3.2.4., glycerine and sunflower meal) and therefore SME emits 0.67 g NO_3 eq./MJ useful energy more than diesel oil through its life cycle due to increased emissions in the *agriculture/forestry* part. Wheat straw proves to be the least disadvantageous biofuel in this impact category emitting 0.16 NO_3 eq./MJ useful energy more than light oil and natural gas.



Summer smog – Greece

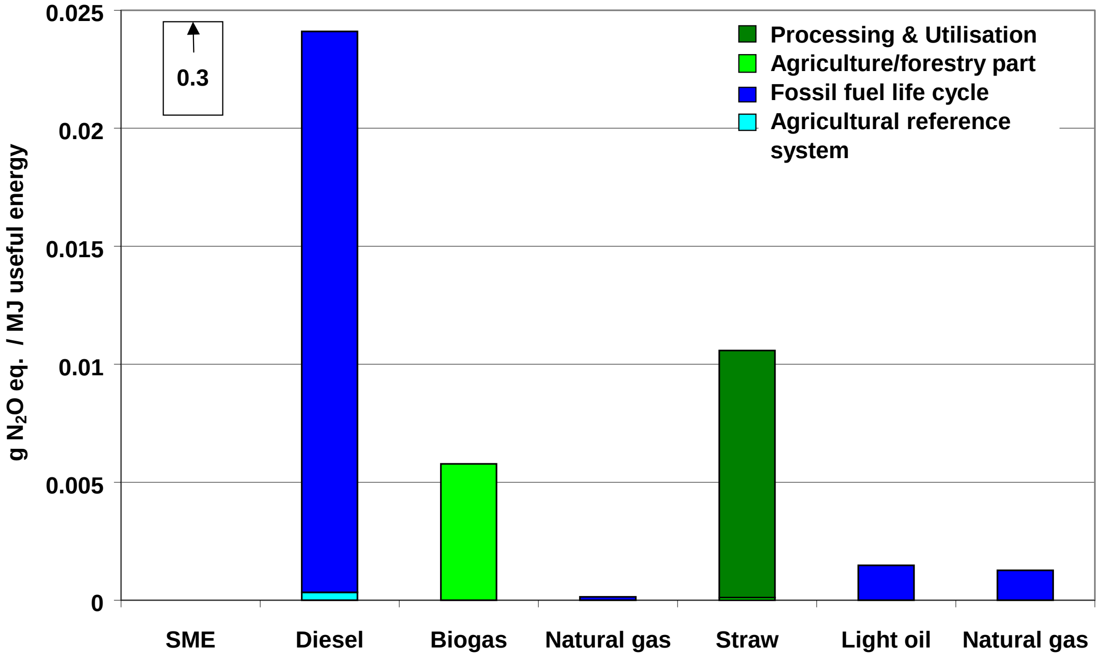
Concerning summer smog creation all biofuels under study prove to be advantageous compared to their fossil counterparts with the exception of straw versus light oil. Savings in the related emissions are 0.2 g Ethen eq./MJ useful energy in the case of biogas versus natural gas and 0.01 g Ethen eq./MJ useful energy in the case of SME versus diesel oil. Straw when it replaces natural gas results in savings of 0.006 g Ethen eq./MJ useful energy, while compared to light oil it emits 0.006 g Ethen eq./MJ useful energy more. Biogas proves to be the most favourable biofuel in this impact category.



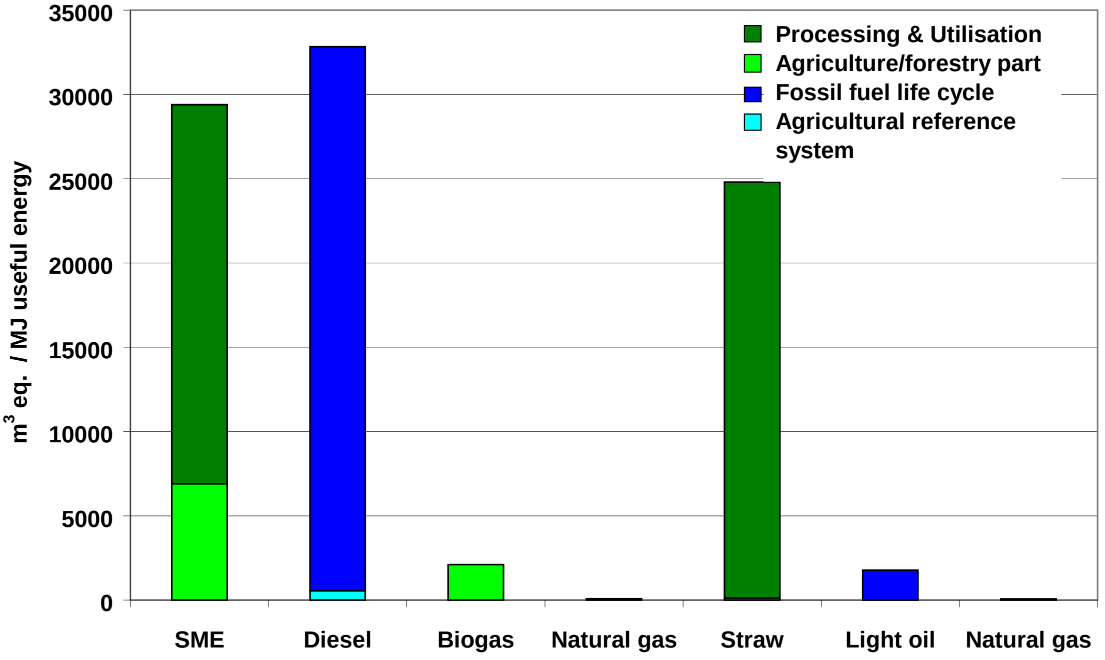
Nitrous oxide – Greece

All biofuels under study appear disadvantageous compared to their fossil counterparts concerning N_2O emissions. The most disadvantageous one is SME, emitting 0.3 g N_2O eq./MJ useful energy more than diesel oil mainly due N_2O emissions from the application of nitrogen fertilisers and SME combustion. Straw results in increased emissions of 0.009 g N_2O/MJ useful energy compared to both light oil and natural gas due to increased emissions during combustion. The least disadvantageous biofuel in this impact category is biogas, emitting 0.004 g N_2O/MJ useful energy more than natural gas.

The data for ozone depletion tend to have a high uncertainty (see chapter 4.1.2) and there fore these impact categories should not be included in the final assessment.



Human toxicity – Greece



In the impact category human toxicity the only biofuel that contributes to savings in the related emissions is SME with net savings of 3,430 m^3 eq./MJ useful energy. Both biogas and straw present worse results than their fossil counterparts. The least favourable for this impact category is straw emitting more than 20,000 m^3 eq./MJ useful energy higher than light oil or natural gas due to increased benzene and dioxins emissions from straw combustion. The respective value for biogas versus natural gas is 2,014 m^3 eq./MJ useful energy. It is clear that SME is the most advantageous biofuel in this impact category and straw the most disadvantageous.

The data for human toxicity tend to have a high uncertainty (see chapter 4.1.2) and there fore these impact categories should not be included in the final assessment.

Country summary and conclusions

All biofuels studied for Greece (SME, straw and biogas) present advantages and disadvantages compared to the reference systems, while the comparison of biofuels among one another does not come to a final conclusion. However the following remarks might be useful:

In the impact categories *Use of fossil fuels* and *Greenhouse effect* all the biofuels under study present better results than their fossil reference system. Net savings in finite energy are higher when SME replaces diesel oil while biogas instead of natural gas saves more than two times higher global warming related emissions than the other two biofuels under study.

In the impact categories *Acidification, Eutrophication* and *Nitrous oxide* all biofuels appear disadvantageous compared to their fossil counterparts. Biogas proves to be the least disadvantageous in terms of N_2O emissions and straw concerning acidification and eutrophication related emissions.

Concerning *Summer smog* creation all biofuels appear more favourable than their fossil counterparts with the exception of wheat straw versus light oil. Savings in the related emissions are higher in the biogas chain.

All biofuels with the exception of SME give worse results than the fossil fuels they are compared with in the impact category *Human toxicity*, indicating that SME is the most favourable biofuel in this impact category.

Impact categories	SME	Wheat straw vs. light oil	Wheat straw vs. nat. gas	Biogas
Use of fossil fuels	+	+	+	+
Greenhouse effect	+	+	+	+
Acidification	-	-	-	-
Eutrophication	-	-	-	-
Summer smog	+	-	+	+
Nitrous oxide**	-	-	-	-
Human toxicity**	+	-	-	-

(+) advantage for the biofuel (-) disadvantage for the biofuel
** The data for ozone depletion and human toxicity tend to have a high uncertainty (see chapter 4.1.1) and there fore these impact categories should not be included in the final assessment.

Taking into account the above remarks no further assessment in favour or against the use of the biofuels under study instead of their fossil counterparts or one biofuel instead of another can be carried out on a scientific basis. Subjective value judgements regarding the individual environmental categories are required for this purpose, which differ from person to person.

7.1.6 Country specific results – Italy

Within the context of this project, the various participating countries investigated different biofuels in comparison to their respective fossil counterparts, as was explained in Chapter 2. While the results for the whole of Europe are presented in Chapter 4, in this chapter the results for the individual countries are presented, on which the European results are based. In the following section the results for all those life cycle comparisons are presented that were investigated in Italy. These are:

- Sunflower oil methyl ester versus fossil diesel fuel
- Traditional firewood versus heating oil and natural gas
- Biogas versus natural gas

In addition, for each country comparisons between its various biofuels have been carried out in order to assess which one is the most suitable in ecological terms for a specific objective. This lead to a number of different questions, in the light of which the various biofuels were compared. Of these, Italy looked at one ecological aspect, namely impacts related to saved energy, comparing SME, traditional firewood and biogas.

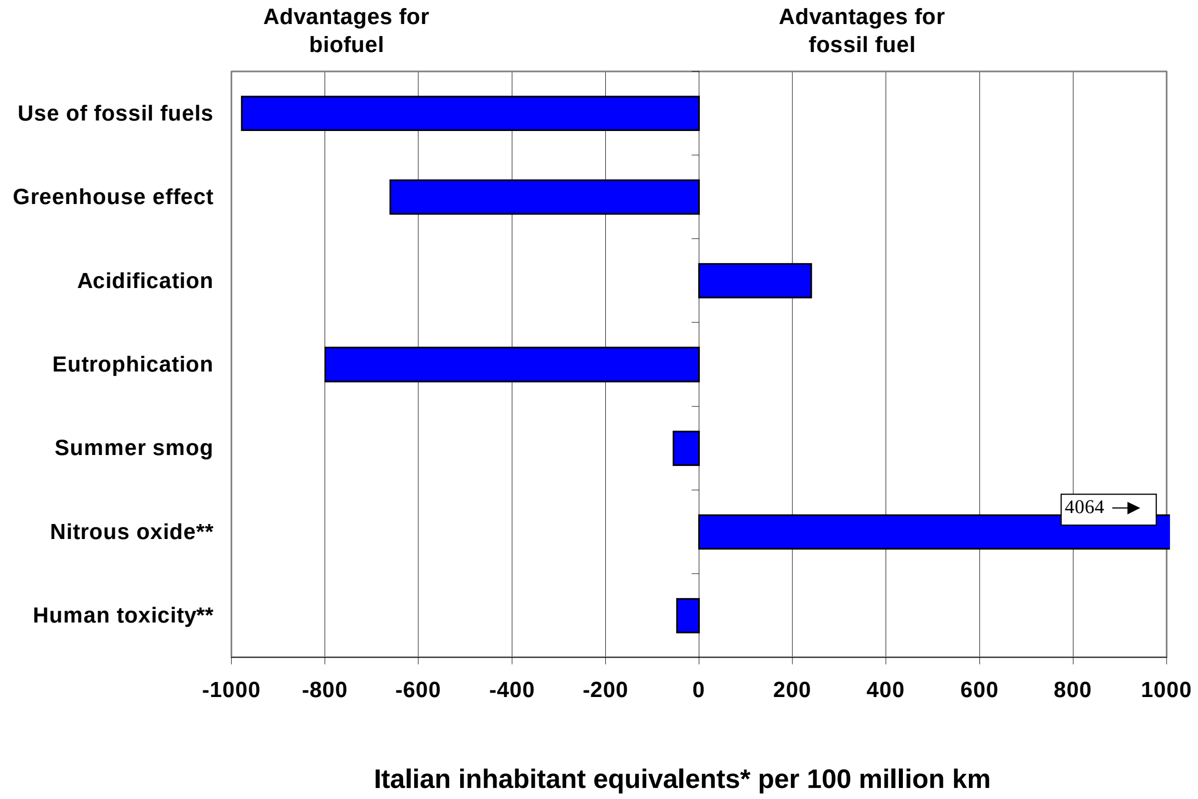
For more information on these comparisons the reader is referred to Chapter 2. As for the European chains, the life cycle comparisons were carried out with regard to specific environmental impact parameters. These were:

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Nitrous oxide
- Human toxicity

The criteria according to which these were selected as well as an explanation of their meanings can be found in the Chapters 3.3 and 3.4.

For reasons of clarity of presentation, the results of minimum-maximum evaluations have not been presented in the result graphs. For more information on this the reader is referred to Chapter 4.1.3.

SME versus diesel fuel for transportation – Italy



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where SME is used in a diesel engine instead of diesel. The unit refers to an amount of 100 million km. This is equivalent to the average annual mileage of about 4,000 Europeans. In this case for example the amount of fossil fuel saved is equal to the amount which about 1,000 Italian citizens would on average consume in one year (this is what is meant by "Italian inhabitant equivalents"). Again, the use of SME leads to a reduction of greenhouse effect equal to that that 660 Italian citizen would cause in one year.

Conclusion

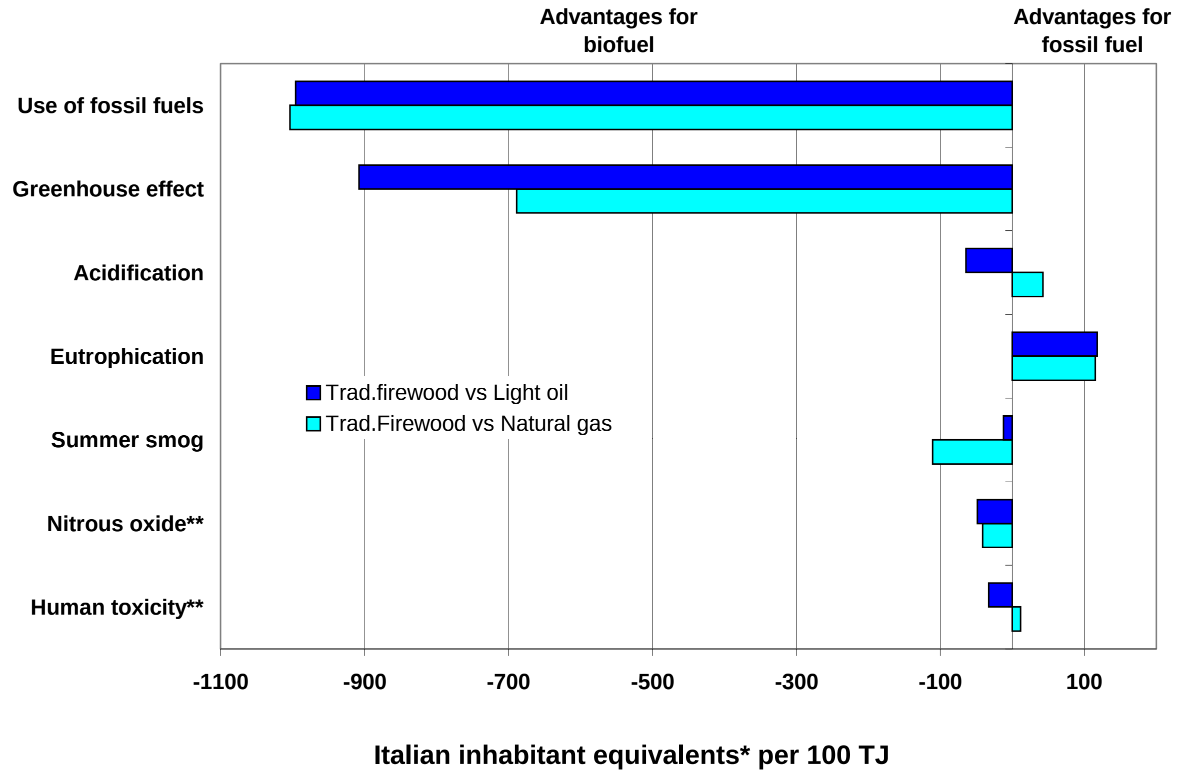
The results show that both SME as well as Diesel fuel have certain ecological advantages and disadvantages, depending on the parameters given highest priority, even if SME seems to be more advantageous from a general point of view.

- Advantages of the biofuel: use of fossil fuels, greenhouse effect, eutrophication, summer smog (small)
- Advantages of the fossil fuel: acidification (small)

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against SME or diesel cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. Whether SME is assessed as better or worse than diesel depends upon the focus and priorities of the decision makers. If the main focus of the decision maker is for example on the reduction of the greenhouse effect and the saving of energy resources, SME will be better suited. If on the other hand the parameter acidification is deemed to be most important, then diesel would be preferred.

Traditional firewood versus light oil and natural gas for heat production – Italy



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where traditional firewood is used for heating purposes instead of Light oil and Natural Gas. The unit refers to an amount one hundred TJ. This is equivalent to the average heat requirement of about 4,000 inhabitants of Europe in one year. In this case for example the amount of fossil fuel saved using traditional firewood instead of Light oil is equal to the amount which about 1,000 Italian citizens would on average consume in one year (this is what is meant by “Italian inhabitant equivalents”). Again the use of traditional firewood instead of light oil leads to a reduction of acidification equal to that that 50 Italian citizens would cause in one year.

Conclusion

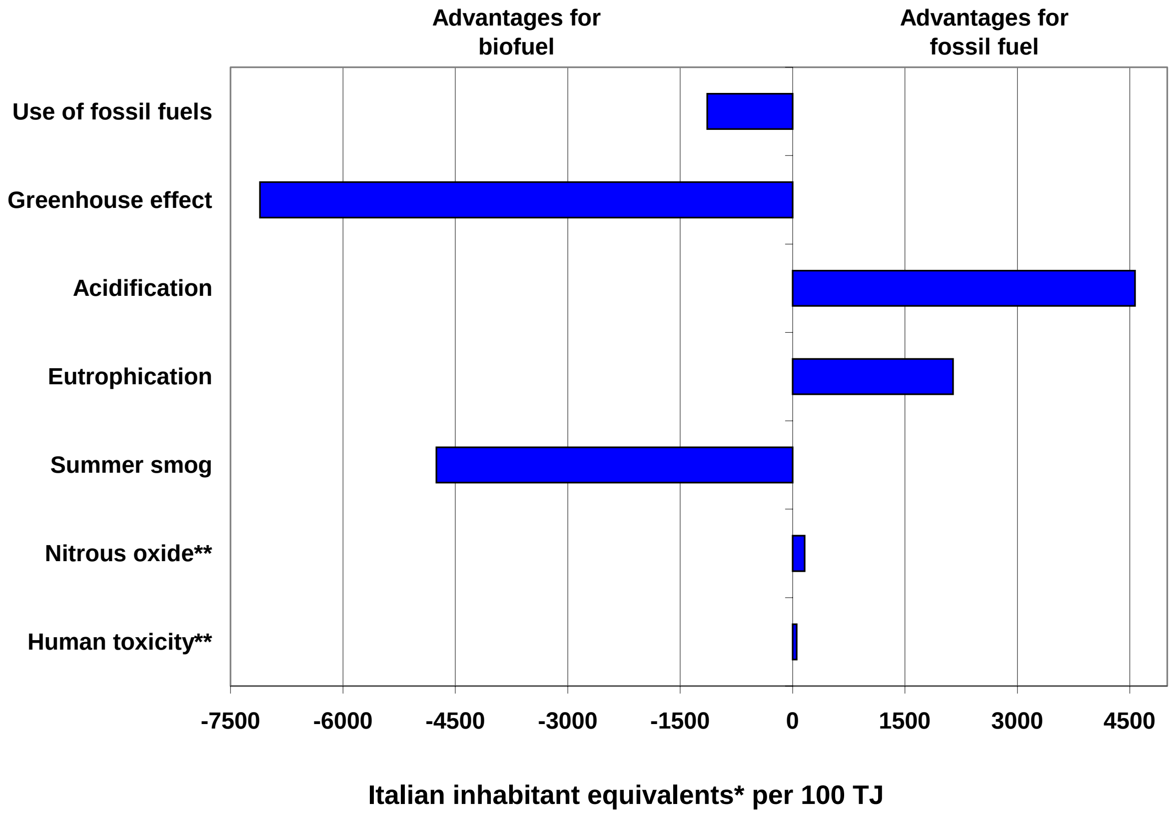
The results show that traditional firewood has a good advantage over light oil and natural gas:

- Advantage for traditional firewood: use of fossil fuels, greenhouse effect, summer smog, acidification versus light oil
- Advantages for fossil fuel: eutrophication, acidification versus natural gas

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against firewood or light oil cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. Whether firewood is assessed as better or worse than light oil or natural gas depends upon the focus and priorities of the decision makers.

Biogas versus natural gas for combined heat and power production – Italy



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where natural gas is substituted by biogas from swine manure for heat and electricity generation. The unit refers to an amount one hundred TJ. This is equivalent to the average heat requirement of about 4,000 inhabitants of Europe in one year. In this case for example the amount of fossil fuel saved is equal to the amount which about 1,100 Italian citizens would on average consume in one year (this is what is meant by "Italian inhabitant equivalents"). Again the use of biogas leads to a reduction of summer smog equal to that that 4700 Italian citizens would cause in one year.

Conclusion

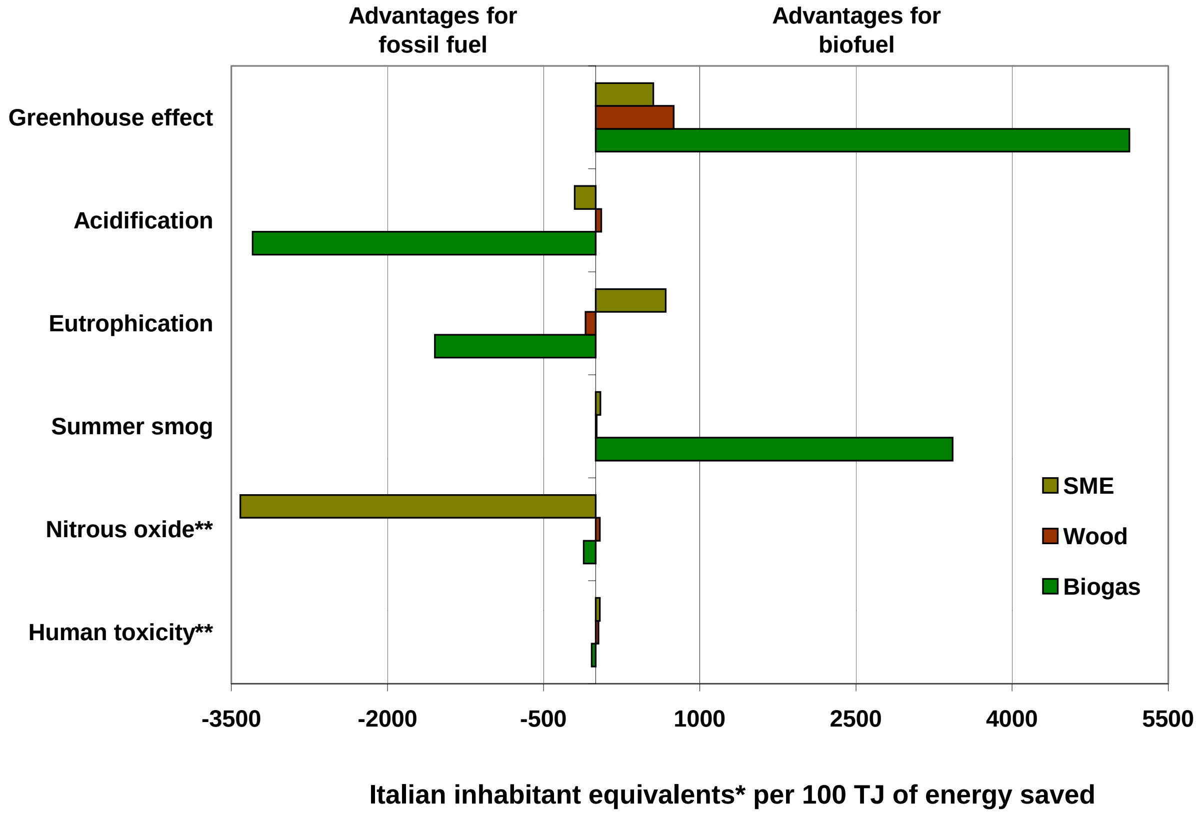
The results show that both biogas as well as natural gas have certain ecological advantages and disadvantages:

- Advantages of the biofuel: use of fossil fuels, greenhouse effect and summer smog
- Advantages of fossil fuel: acidification and eutrophication

The data for ozone depletion and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.)

A further assessment in favour of or against biogas or natural gas cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person. Whether biogas is assessed as better or worse than natural gas depends upon the focus and priorities of the decision makers.

Ecological aspects: impacts related to saved energy – Italy



* How to interpret the diagram

The figure shows the results of comparisons between complete life cycles where each biofuel under study (SME, Traditional Firewood, Biogas) is substituted to a conventional energy carrier (respectively light oil, diesel, natural gas) for energy production. The results for the various categories are given with reference to the category use of fossil fuels, i.e. 100 TJ of fossil energy saved. For example for every 100 TJ of fossil energy saved through the substitution of diesel fuel by SME the amount greenhouse gas emissions avoided is equal to those on average generated by about 550 Inhabitants of Italy in one year (this is what is meant by “Italian inhabitant equivalents”). On the other hand, in this case for every 100 TJ of energy saved an amount of N_2O is emitted that is equal to that on average generated by 3400 Italian inhabitants in one year. Note that in this diagram the advantages of the fossil fuels are on the left hand side and vice versa.

Conclusion

Comparing the investigated bioenergy carriers (in turn compared to their fossil counterparts) against each other, the following result emerges:
Greenhouse effect: for all biofuels a clear advantage over the fossil counterparts can be pointed out. The effect is the greatest for Biogas and lowest for SME.
Acidification: Wood has a very low positive impact, whereas SME and Biogas have a negative impact.
Eutrophication: SME has a good advantage, whereas Wood and Biogas show disadvantages.
Summer smog: all the biofuels show advantages, but the results of SME and Wood are non significant.
The data for nitrous oxide and human toxicity tend to have a high uncertainty. Therefore these categories should not be included in the final assessment. (**For more information on this and the other environmental parameters investigated see Chapters 3.3 and 3.4 as well as 4.1.2.).
A further assessment in favour of a specific biofuel cannot be carried out on a scientific basis, because for this purpose subjective value judgements regarding the individual environmental categories are required which differ from person to person.

7.1.7 Country specific results – The Netherlands

In the following section the results for all those life cycle comparisons are presented that were investigated for The Netherlands.

The figures in this section show the results of the comparisons between the complete life cycles where a fossil fuel is substituted by a biofuel. CLM studied the life cycles of:

- Willow and Miscanthus versus natural gas (heat production);
- Hemp versus natural gas (electricity production);
- ETBE from sugar beet versus MTBE;
- Biogas versus natural gas (electricity and heat production).

In order to assess which biofuel is the most suitable in ecological terms for different objectives we will make the following comparisons:

- Heat production with perennial crops: willow, Miscanthus;
- Different types of bioenergy with annual crops: hemp, sugar beet for ETBE;
- Electricity: biogas, hemp;
- Bioenergy: annual crops, perennial crops.

Bullet 3 gives a comparison between life cycles which do not exclude each other. Both biofuels can be produced without affecting the other chain. This is not the case for the other comparisons as arable land is needed for the crops.

The life cycle comparisons were carried out with regard to specific environmental impact parameters. These were:

- Use of fossil fuels
- Greenhouse effect
- Acidification
- Eutrophication
- Summer smog
- Nitrous oxide
- Human toxicity

Per environmental impact parameter a short impression of the most notable results is given. In the conclusions the four comparisons are discussed and a summary of the results and discussion is given.

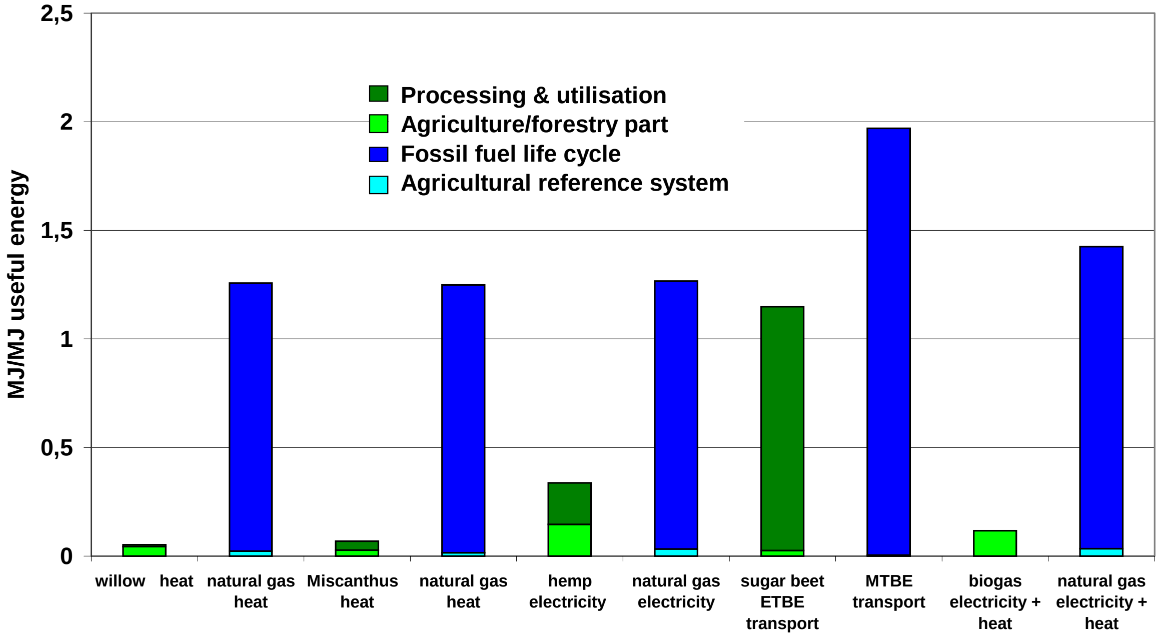
How to interpret the diagrams

For each environmental parameter a figure is shown with the impact of the biofuels and the accompanying fossil fuel on that specific environmental theme. The impact on an environmental parameter is expressed per MJ useful energy. This is the net energy which is usable for the consumer. The difference in height between the columns for the biofuel and accompanying fossil fuel shows the effect on an environmental parameter when the fossil fuel is substituted by the biofuel.

The columns for the biofuels and accompanying fossil fuels are divided into an agricultural and a energy production part to show and compare the effect on the environmental parameters of the different stages in the life cycles.

For biogas no distinction is made for the agricultural and energy production part. In its graph, the bar for the agricultural part also includes the energy production due to fermentation.

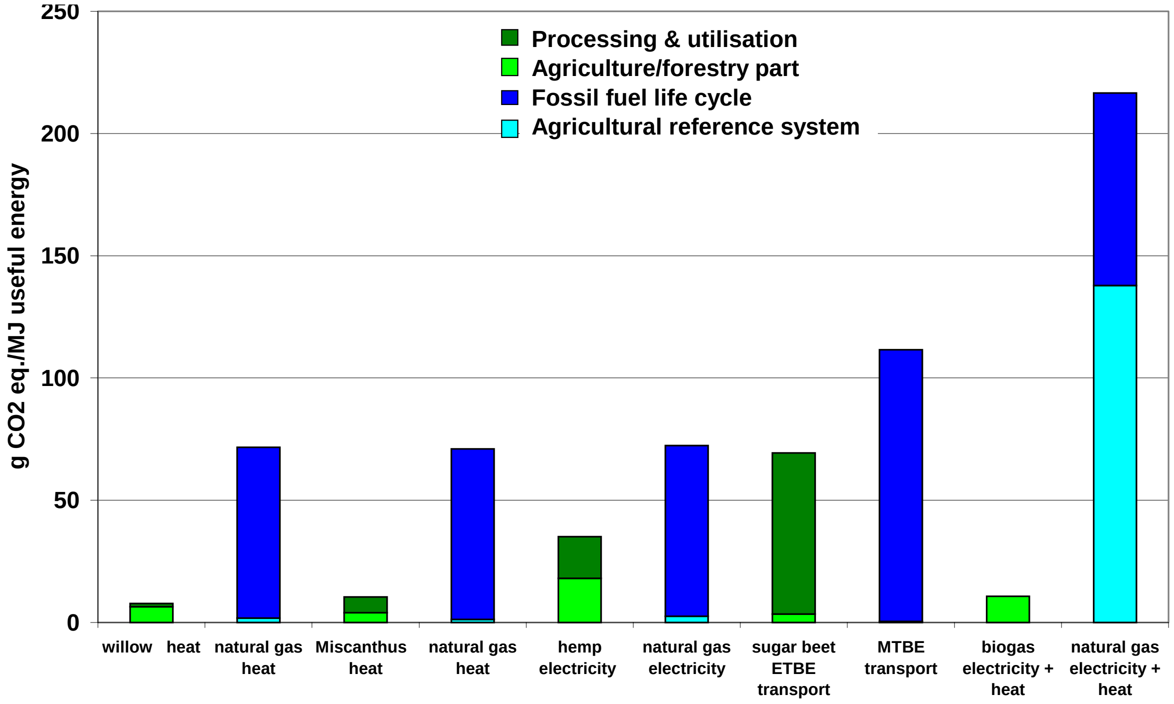
Use of fossil fuels – The Netherlands



As shown in the figure less energy (as fossil fuels) is needed when energy is produced with biofuels than with fossil fuels. The difference in energy demand between biofuel and fossil fuel varies around 1 MJ/MJ useful. Obviously this is caused by the use of biomass for the production of biofuel in stead of using fossil resources.

Growing perennials costs less fossil fuel than growing annuals. This difference between annuals and perennials is due to a much more intensive cultivation of the annuals.

Greenhouse effect – The Netherlands



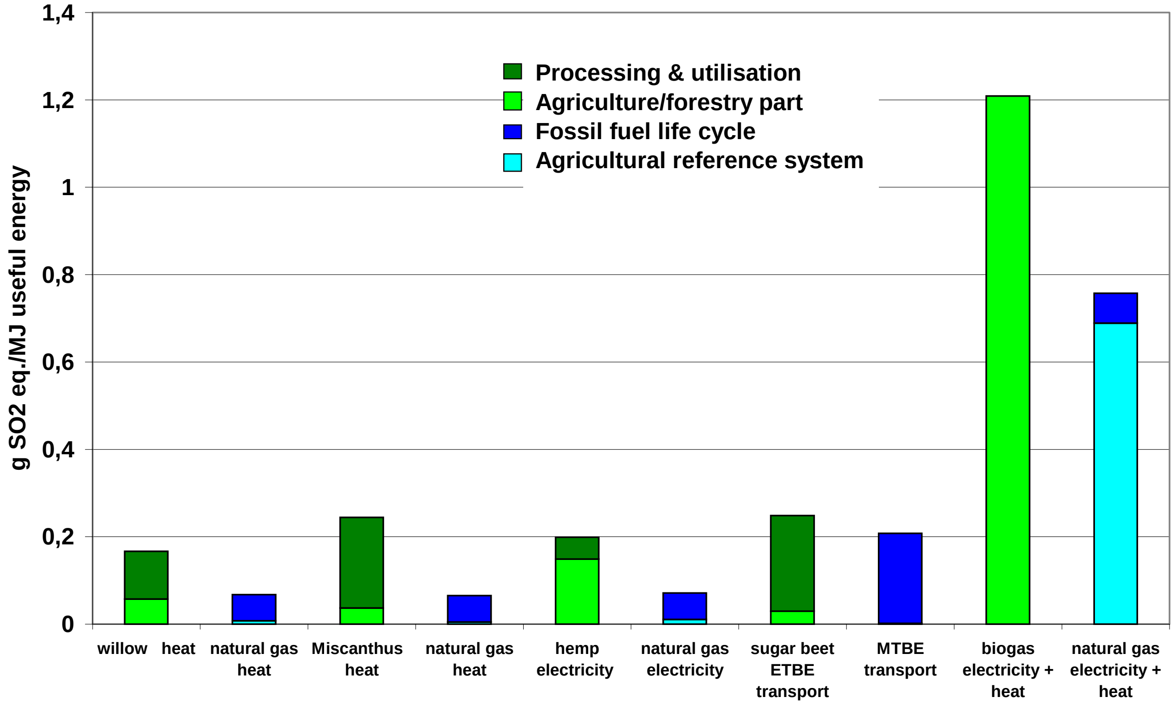
In all studied chains, the biofuel chains cause less impact on the greenhouse warming effect than the fossil fuel chains. Clearly this relates to the difference in use of primary fossil energy (see previous diagram). Another important issue which affects the results is the amount of useful energy per ha produced by each energy crop, because a high production of useful energy per ha can result in a high saving of CO_2 emission. For the different energy crops the following useful energy productions per ha have been determined: ETBE 125 GJ/ha, Miscanthus 212 GJ/ha, willow 140 GJ/ha and hemp 197 GJ/ha.

For biogas the difference between the emission of CO_2 equivalents for the biofuel and the fossil fuel system is the biggest of all studied biofuels. This significant difference is mainly caused by the difference in emission of CH_4 in the biofuel and reference system. In the biofuel system we assumed that all CH_4 formed in the manure was used in the fermentation process to produce biogas. For the reference system we assumed that all CH_4 formed due to spontaneous fermentation was emitted to air. This has a large effect as the greenhouse effect of CH_4 is 8 times the effect of CO_2 (with a 500 year time horizon, 25 with a 100 year time horizon).

The agricultural part of the bioenergy chains results in a higher emission of global warming pollutants than the fallow land in the fossil fuel chains. The reason for this is the more intensive use of the land in the bioenergy chains.

The difference in impact on the greenhouse effect for the four energy crops compared with the accompanying fossil fuels is about the same. Only for hemp the difference is smaller. This is partly due to a more intensive use of the land compared with the perennials willow and Miscanthus.

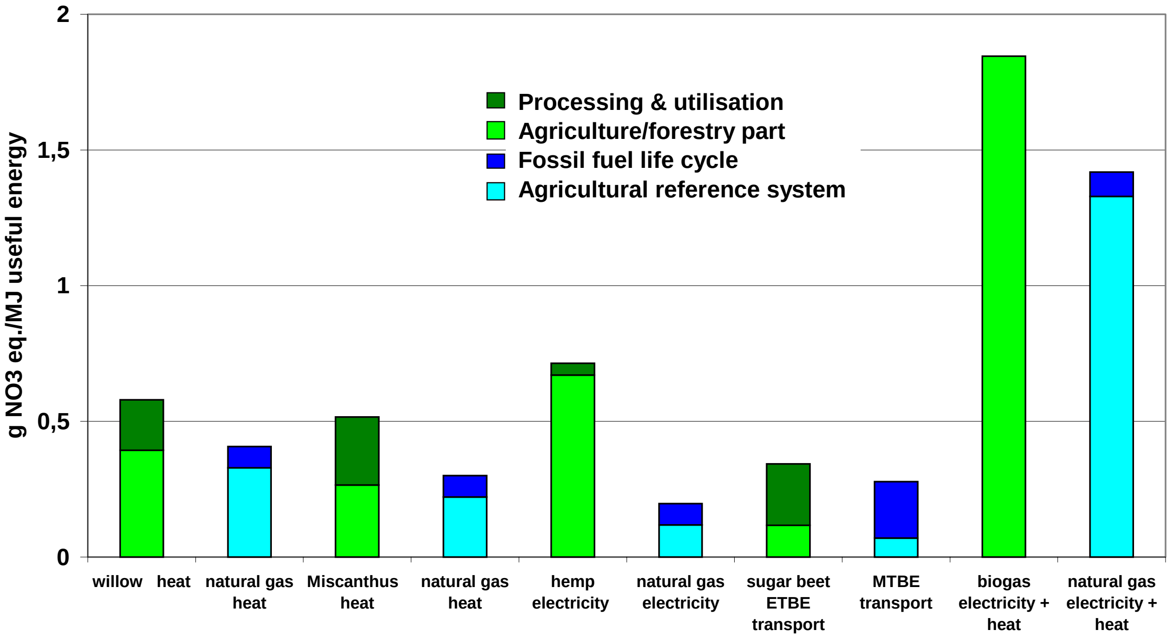
Acidification – The Netherlands



All biofuels cause a higher effect on acidification than the fossil fuels. For the energy crops this is mainly or partly due to a bigger effect on acidification during the agricultural part. This can be explained by the more intensive fertilisation for these crops compared with fallow, and its accompanying emission of ammonia.

The results of Miscanthus show an obvious higher effect on acidification due to the energy production part compared to the energy production part of natural gas. This is partly explained by a 3 times higher NO_x emission during the combustion of Miscanthus. The large difference in effect on acidification between biogas and its reference can be explained by a higher volatilisation of ammonia during spreading of the fermented manure compared with non-fermented manure. The reason for this is the higher concentration of mineral nitrogen in fermented manure compared to non-fermented manure. The mineral nitrogen concentration in manure rises due to fermentation. Another reason for acidification is the high NO_x emission for combustion of biogas.

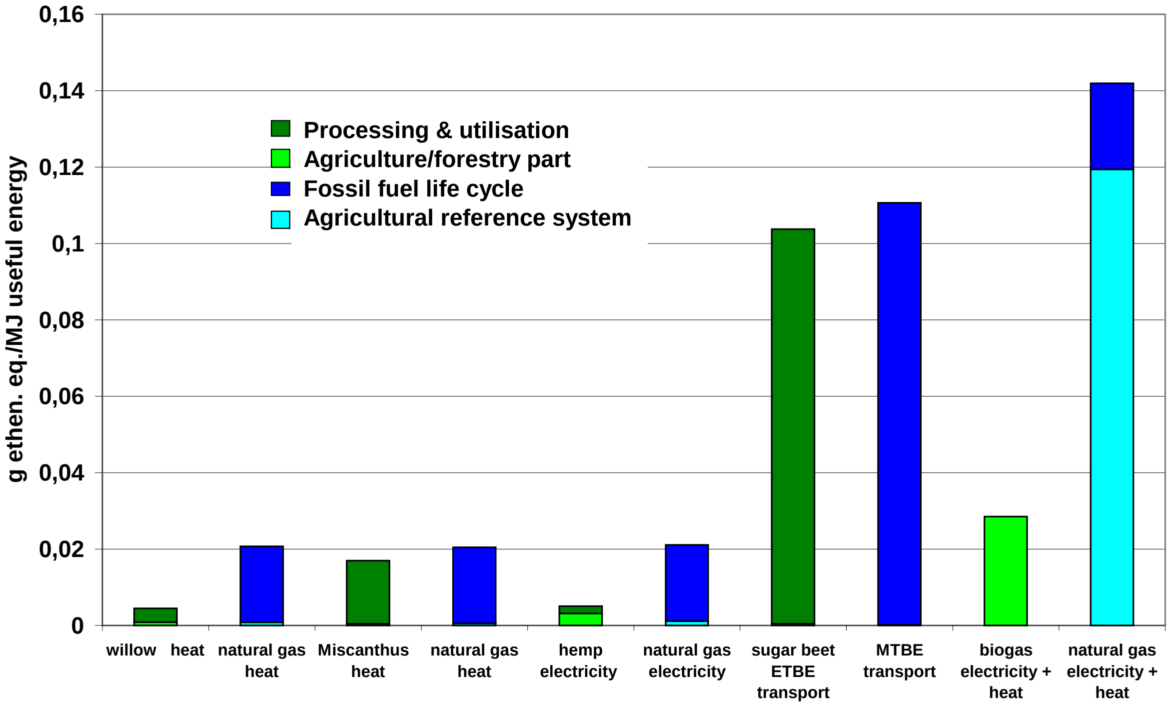
Eutrophication – The Netherlands



All biofuels cause a higher effect on eutrophication than the reference system. Hemp has the largest difference in eutrophication compared with the reference system and sugar beet for ETBE the smallest. For Miscanthus the eutrophication score during the energy production part with the fossil reference system is remarkable. This is related with the NO_x emissions from combustion (see previous graph). For sugar beet and especially hemp the difference is mainly caused during the agricultural part. This can be explained by the more intensive fertilising for these crops compared with fallow.

The difference between biogas and its reference is caused by a higher ammonia volatilisation due to the application of fermented swine manure and a higher NO_x emission in the chain of biogas compared with the reference. Compared with the other biofuels, biogas has a larger impact on eutrophication.

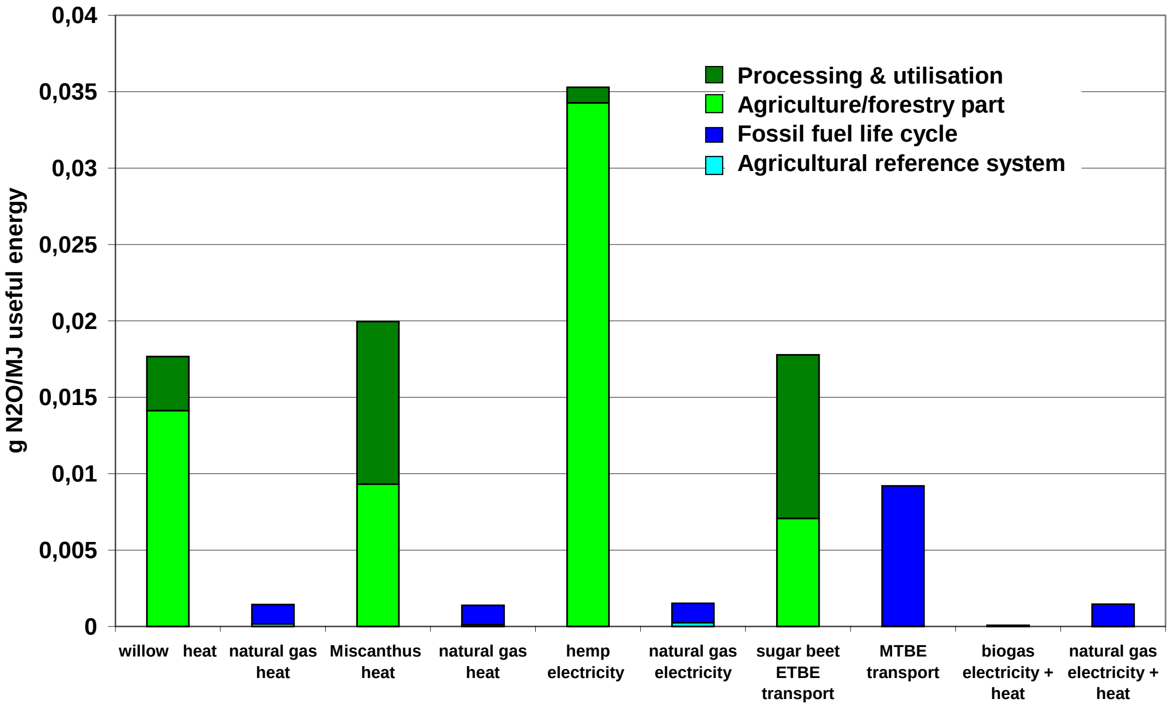
Summer smog – The Netherlands



All biofuels cause a smaller effect on summer smog than the reference system. In general, this is caused by a higher emission of VOC (Volatile Organic Compounds) in the fossil fuel chain. Replacing natural gas by biogas as an energy source gives the largest result in lowering summer smog. In the agricultural part of the reference for biogas the impact on summer smog is very high compared to the impact of biogas and to other chains. This is caused by the emission of methane during storage and spreading of non-fermented manure which does not occur when the manure is fermented to biogas.

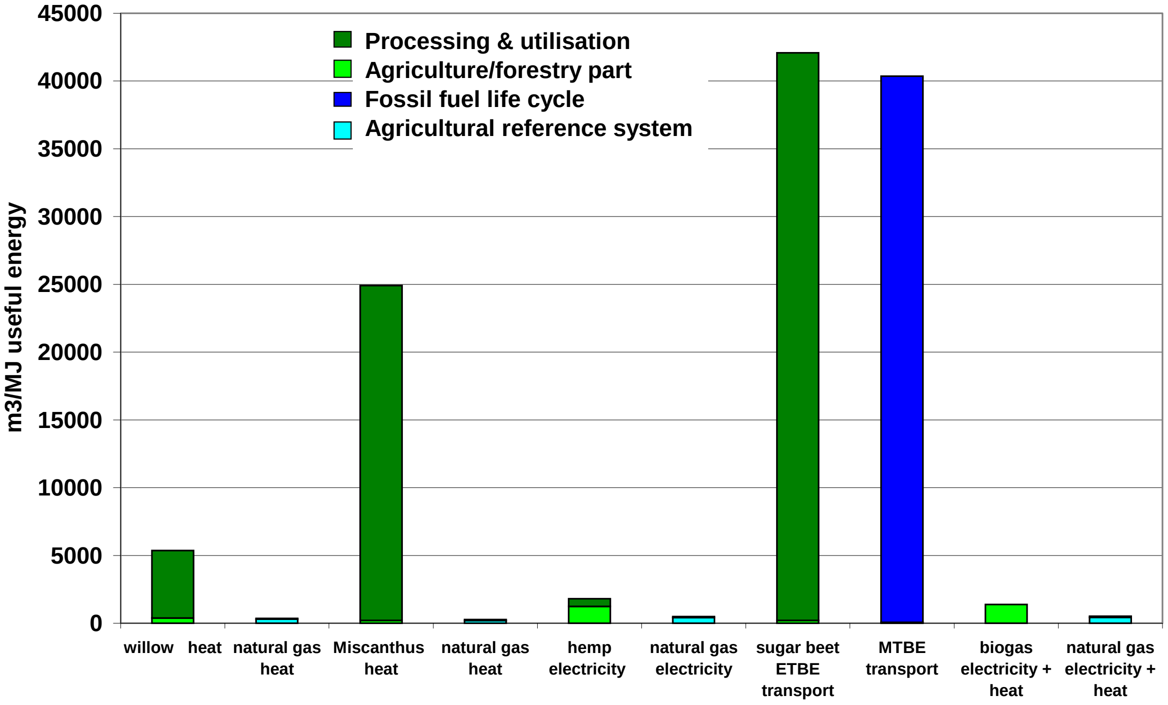
Compared with the other energy crops, Miscanthus gives only a minor advantage compared with the reference. This is due to a higher emission of pollutants like VOCs and benzene during the combustion of Miscanthus compared with the combustion of willow and hemp.

Nitrous oxide – The Netherlands



The figure shows that using energy crops as biofuel causes more ozone depletion by N_2O than using fossil fuels. Especially for hemp, which causes a ten times higher emission of N_2O than using natural gas for producing electricity. For willow, hemp and sugar beet for ETBE this difference is mainly due to a high N_2O emission during the agricultural part. This is caused by more intensive fertilisation of the energy crops in comparison with fallow. For Miscanthus the difference is caused by the agricultural part as well as the energy production part. Combustion of Miscanthus causes a 10 times higher N_2O emission than the combustion of the cleaner natural gas. Finally, the use of biogas leads to zero emission of N_2O.

Human toxicity – The Netherlands



A remarkable difference between the chains is the high impact on human toxicity for both ETBE and MTBE which is due to the energy production part. Using ETBE instead of MTBE gives slightly more impact on human toxicity. The energy production out of Miscanthus and willow has a much higher impact on human toxicity compared to the impact of the fossil fuel counterpart. This difference is partly caused by a significant higher emission of dioxines during the combustion of Miscanthus and willow compared with combustion of natural gas. This emission is much higher than the emission of dioxines from combustion of biogas and hemp.

The use of pesticides in energy crops is limited and for willow and Miscanthus even (close to) zero. For human toxicity the effect of pesticides is only reflected in the hemp chain. Due to its complexity, persistent toxicity and ecotoxicity have been left out of the quantitative assessment. In case they would have been included, the use of pesticides in general would have shown a worse score for energy crops as compared to fallow land.

Four comparisons

In this part, the four comparisons described in the introduction will be discussed.

Heat production with perennial crops: willow, Miscanthus

Summarising the results, it is obvious that the perennials willow and Miscanthus have in general comparable results. Both biofuels have advantages on the use of fossil fuels and the greenhouse effect. The energy production per ha of Miscanthus is higher than willow, which indicates that Miscanthus uses the land more efficient. Both biofuels also have a positive result on summer smog but this advantage is larger for willow than for Miscanthus. This is caused by a higher emission of VOC with combustion of Miscanthus.

For ozone depletion, acidification and eutrophication willow and score worse than natural gas for the production of heat. The can partly be explained by the more intensive use of the land (fertilisation) compared with fallow. Besides that, the energy production part of Miscanthus causes a high effect on ozone depletion and acidification compared to the reference and willow. Miscanthus combustion has a higher N_2O and NO_x emission which affects the ozone depletion and acidification.

Miscanthus has an obvious disadvantage for human toxicity whereas this disadvantage is smaller for willow. This is due to dioxine emission from Miscanthus combustion.

Different types of bioenergy with annual crops: hemp, sugar beet for ETBE

In general the results for the annuals sugar beet and hemp are comparable. Like willow and Miscanthus both biofuels score well on the use of fossil fuels, greenhouse effect and summer smog. The production of useful energy per ha is larger from hemp then from sugar beet for ETBE.

Hemp has larger disadvantages for ozone depletion and eutrophication compared to ETBE. Especially the more intensive fertilisation of hemp causes a larger effect on ozone depletion and eutrophication.

For acidification ETBE has a minor disadvantage compared with the disadvantage of. For hemp, the relatively high score for acidification due to the agricultural part relates to ammonia emission.

If we compare the level of impact for human toxicity it can be seen that ETBE has a much higher impact than hemp. Nevertheless the difference between the fossil fuel and the biofuel is comparable for ETBE and hemp. The minor disadvantage of hemp is caused by the use of pesticides. The disadvantage of sugar beet for ETBE is due to the energy production part.

Electricity: biogas, hemp

The results for biogas and hemp are comparable for all the environmental parameters except for ozone depletion. Both biofuels have a positive result for the use of fossil fuels, greenhouse effect and summer smog. Nevertheless the advantages for biogas for greenhouse effect and summer smog are higher than for hemp. This is partly caused by the reduction of methane emission because biogas out of manure is used as a biofuel instead of applying non-treated manure on the field.

For acidification and eutrophication biogas and hemp have disadvantages compared to the fossil fuels. For hemp this is due to the more intensive fertilisation. For it is due to the higher emission of ammonia during spreading of the fermented manure and the higher emission of NO_x during the combustion of the biogas.

Both biofuels have a comparable minor disadvantage on human toxicity.

A large difference between hemp and biogas is the highly negative effect of hemp and the positive effect of biogas on ozone depletion. The agricultural part of hemp causes a high emission of N2O whereas biogas leads to less emission of N2O compared to the fossil fuel reference.

Bioenergy: annual crops, perennial crops

The perennials willow and Miscanthus and the annuals sugar beet for ETBE and hemp have advantages for the use of fossil fuels , greenhouse effect and summer smog. For the use of fossil fuels and greenhouse effect the perennial crops have a larger impact than the annuals.

The perennial and annual crops both have disadvantages for ozone depletion and eutrophication. With regard to eutrophication by ETBE, this is only minor compared to the disadvantage of willow, Miscanthus and hemp.

For acidification and human toxicity, the annuals and perennials differ but the picture is not clear. ETBE has a minor disadvantage which is mainly caused by a bigger effect in the energy production part for human toxicity and by a bigger effect in the agricultural part for acidification. The disadvantage of hemp can be explained with the more intensive fertilisation (eutrophication) and pesticide use (human toxicity). The negative scores of perennials on these themes do not relate to the relative clean agricultural production part, but to the emissions in the energy production phase.

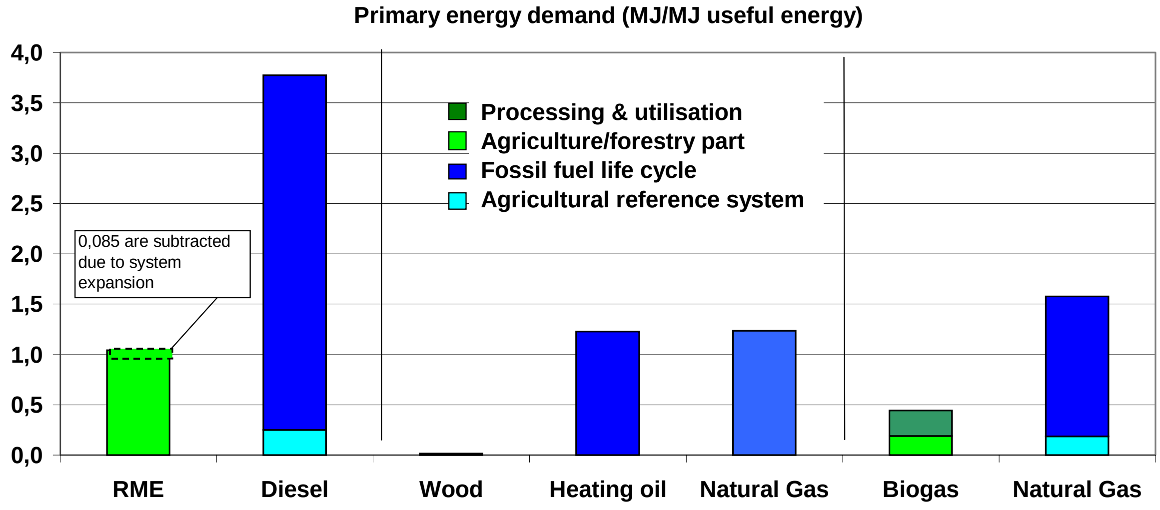
7.1.8 Country specific results – Switzerland

Introduction

The three Swiss biofuels RME, wood and biogas are shown in comparison with their fossil counterparts. The results are presented per MJ useful energy, which means that efficiency factors (0.36 for diesel engine, 0.75 for a wood boiler, 0.9 for oil and gas boiler and 0.8 for gas in order to produce electricity and heat) are already taken into account. The contributions of the agricultural/forestry parts and the energy production are shown in detail to enhance a clear assessment. The agricultural/forestry part contains all processes on the fields, on the farm or in the forest until farm gate for the biofuel crop as well as for the reference crop. Energy production for biofuels starts with transport from farm and contains all subsequent processes, whereas in energy production of fossil fuels all processes are included. The biogas plant belongs to the energy production, the distribution of the slurry belongs to the agricultural part. It is unfortunately possible to assess the influence of the allocation procedures for RME only partly, although the contributions of the substituted systems for glycerine and rape seed meal can be bigger than the absolute values shown. The – negative or positive – consequences on soil ecotoxicity (due to wood decay for example), which can play an important role from an environmental point of view, could not be assessed in the project.

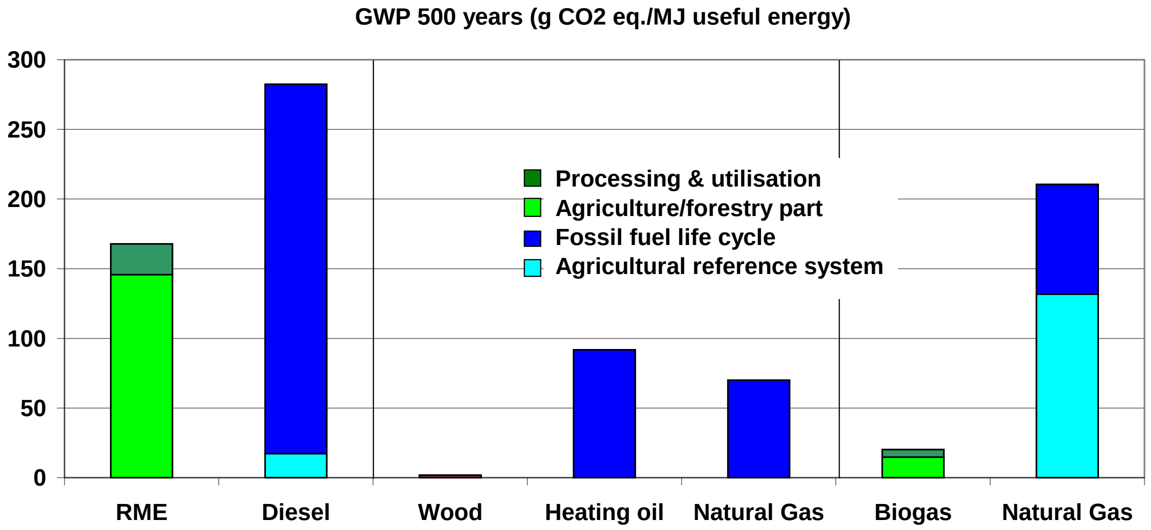
Use of fossil fuels – Switzerland

All biofuels consume less fossil fuels per MJ useful energy produced than their fossil counterparts (see result diagram below). The fossil energy demand from RME results mainly from the machinery and fertilisers used in the rape seed growing. Due to the system expansion with soy beans there is even a small bonus in the transesterification step. The diesel system needs almost four times as much fossil energy although the fallow does hardly consume any. Heating oil and natural gas need around 80 times more fossil energy than wood logs for heating. The natural gas system for electricity and heat uses about 3.5 times more fossil energy than the biogas system (with both times the same energy demand for the distribution of the slurry). The biofuel needing the least fossil energy per MJ useful energy is by far wood logs for heat with only 0.01 MJ (see result diagram below). Biogas needs roughly 40 times more energy with 0.4 MJ and RME even 70 times more with 0.96 MJ. The latter fact is not only due to the energy consuming required for growing of rape seed, but also due to the much lower efficiency of the diesel engine compared to the wood boiler. For comparisons between the biofuels one would have to take into account the different system boundaries.



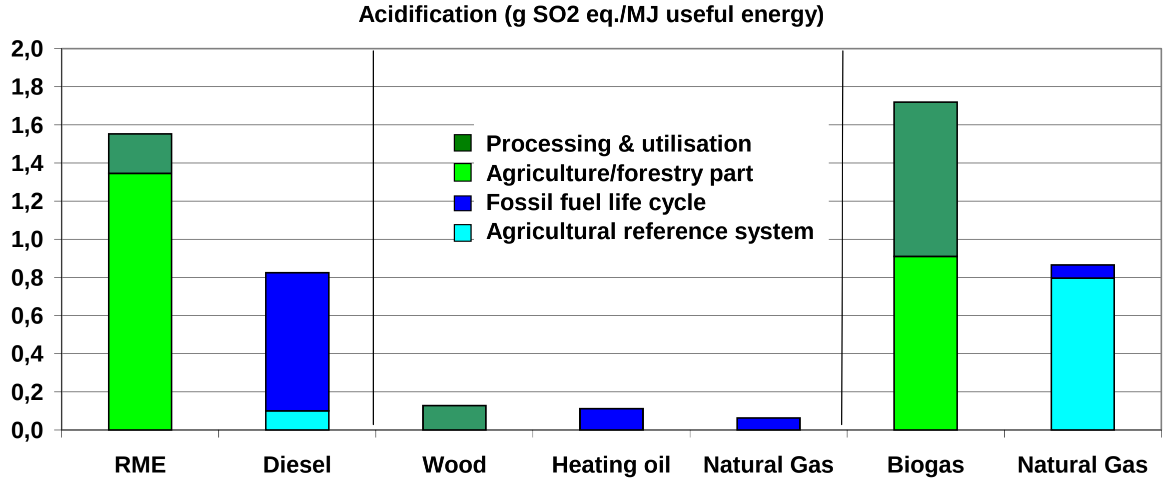
Greenhouse effect (greenhouse warming potential GWP) for 500 years – Switzerland

All biofuels have a lower GWP than their respective fossil reference systems (see result diagram below) The GWP for RME origins mostly from the nitrous oxide (N_2O) formed due to fertilisation, whereas the burden for diesel is almost entirely due to the fossil carbon dioxide (CO_2) at combustion. The difference between the three heating systems stems entirely from the fossil CO_2 emissions at combustion. As the energy source of biogas consists mostly of methane, there is a double reduction of GWP compared with its reference system, since the latter emits not only methane during slurry storage but also fossil CO_2 at gas combustion.



Acidification – Switzerland

All biofuels cause slightly more acidification than the fossil fuel systems compared (see diagram below). Although diesel has a higher sulphur content than RME, the agricultural part of RME is more decisive for the overall impact. The spreading of mineral fertilisers results in ammonia (NH_3) – emissions which contribute to acidification. The differences between the wood, heating oil and natural gas systems are based on due to the different burning emissions, namely due to higher NH_3 and HCl emissions of wood. Biogas burning emits a lot more sulphur oxides (SO_2) than natural gas burning, which explains the higher score for the biogas system.



Eutrophication – Switzerland

The score for RME is smaller than for the diesel system (see result table below) in spite of more leaching of nitrate (NO_3^-) and higher ammonia (NH_3) emissions due to fertilisation. But the system expansion with soy beans gives such a large reduction that the overall result is in favour of the RME system.

Eutrophication potential for wood is larger because of the higher NH_3 emissions at combustion. Slurry from the biogas plant contains a bit more nitrogen in the mineral form, which increases the risk of NH_3 emissions and NO_3^- leaching and consequently causes a worse result for the biogas system.

Summer smog (photochemical ozone creation potential POCP) – Switzerland

POCP not only depends on hydrocarbons, included as NMVOC emissions, but also on methane. This is important for the biogas system in which no methane is emitted during slurry storage, resulting in a lower score than that of its reference system (see result table below). For the two other investigated biofuels systems, the differences of the NMVOC emissions explain the results.

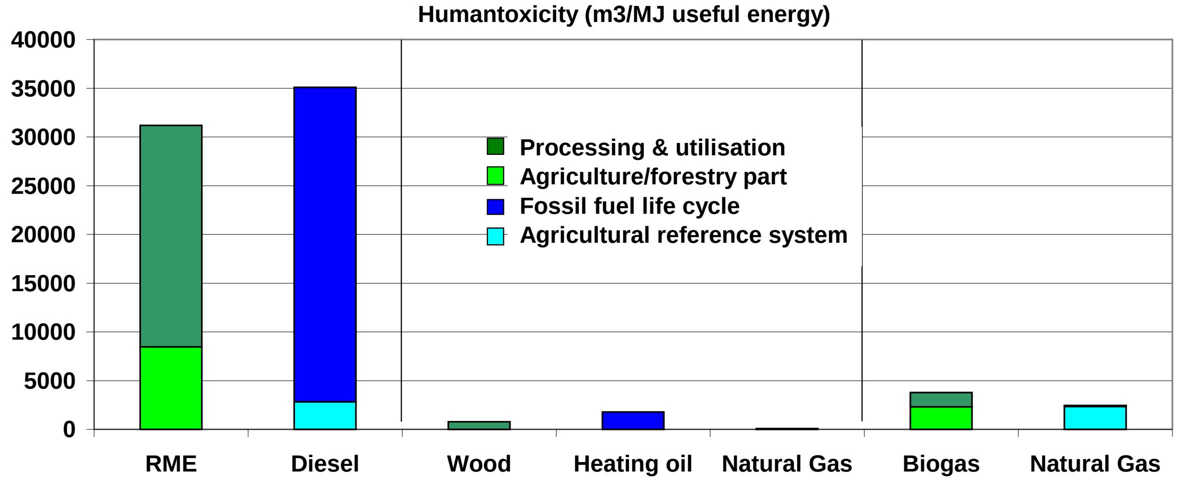
Impact category	RME	Diesel	Wood	Light oil	Natural gas	Biogas	Natural gas
Summer smog g ethen eq./MJ	0.11	0.12	0.02	0.01	0.02	0.05	0.1
Eutrophication g NO_3^- eq. /MJ	4.1	7.6	0.2	0.1	0.1	0.5	0.1
Ozone depletion by nitrous oxide in g N_2O /MJ	0.437	0.020	0.001	0.001	0.001	0.003	0.001
MJ refers to MJ of useful energy							

Ozone depletion by nitrous oxide – Switzerland

For this impact category only the N_2O emissions are included. RME has a considerably higher potential than its fossil alternative because of the possible denitrification of the fertiliser used (see result table above).

Human toxicity – Switzerland

The impact on human toxicity depends mainly on heavy metals, pesticides, NO_x, SO_2 and particles. Biogas has a higher score than CHP from natural gas because of higher SO_2 emissions. In spite the fact that wood burning causes more particles, the toxicity potential for heating oil is higher due to more heavy metals emitted in different processes (see result diagram below).



Summary and conclusion

In the result table below there is an overview of the advantages and disadvantages from the biofuels compared to their fossil counterparts. The scheme for determining and assessing the significance of the results for each impact category was published in Wolfensberger and Dinkel (1997).

Impact category	RME	Wood vs. oil	Wood vs. gas	Biogas
Use of fossil fuels	Very favourable	Very favourable	Very favourable	Very favourable
Greenhouse effect	Favourable	Very favourable	Very favourable	Very favourable
Acidification	Unfavourable	Comparable	Unfavourable	Unfavourable
Eutrophication	Favourable	Unfavourable	Unfavourable	Comparable
Human toxicity	Comparable	Favourable	Very unfavourable	Unfavourable
Summer smog	Comparable	Favourable	Unfavourable	Favourable

Regarding the major reasons of the authorities for promoting biofuels (saving of fossil fuels and reduction of global warming), all three investigated biofuels are highly recommendable. But one has to be aware of the fact that for biogas these advantages have to be partly paid with higher potentials in acidification and human toxicity. Moreover, the outcome for RME, which is more favourable as it was the case in previous studies (the results are unfavourable here only for acidification), partly depends on the procedure applied for taking into account the contribution of rape seed meal (this comment is valid first of all for eutrophication and the use of fossil fuels). Research is needed concerning the real relevance of these negative environmental aspects in the whole assessment. The results indicate that the probably best biofuel is wood compared to oil heating, because there only the impact potential eutrophication is unfavourable and the result does not depend on a methodological choice.

7.2 Comparisons between the countries for each biofuel

7.2.1 Introduction

Within this project, the various participating countries investigated several biofuels as explained in detail in Chapter 2. Each biofuel was investigated by at least three countries (with the exception of hemp which was only investigated by the Netherlands). The various countries carried out their life cycle comparisons individually, taking into account country specific conditions and data. Thus certain differences are bound to exist in the results, caused by different climatic conditions as well as socio-economic and technological ones. These include for example soil fertility and rain fall, topography, field size and crop yields, which together lead to differences in agricultural practices and the ratio of input to crop yield. The following chapters show chain by chain the results for the individual countries and the EU together and give short remarks on the differences.

For the result presentation of the biofuel comparisons between the countries a different format has been chosen than for the European and the country specific results: the relative differences of the impacts related to the fossil fuel. The respective figures regarding the environmental effects of the fossil fuels were subtracted from those of the biofuels, and this value was divided by the figures for the fossil fuels (in this case the reference unit was 1 MJ). This procedure allows a comparison of country specific results and of the relative advantages and disadvantages of the biofuels compared to the fossil fuels.
The differences between the impacts of the biofuels can be categorised as follows:

1. For a certain country *various* input data for *several* processes are greater/smaller than for the other countries, so that the sum of the effects of these processes and their aggregation leads to significant differences between the countries.
2. For a certain country *a few* input data of *one* process are much greater/smaller than for the other countries, so that this process dominates the balance of the inventory and impact assessment.

Only the second category of differences will be discussed.

Table 7-2 summarises the various life cycle comparisons investigated.

Table 7-2 life cycle comparisons investigated

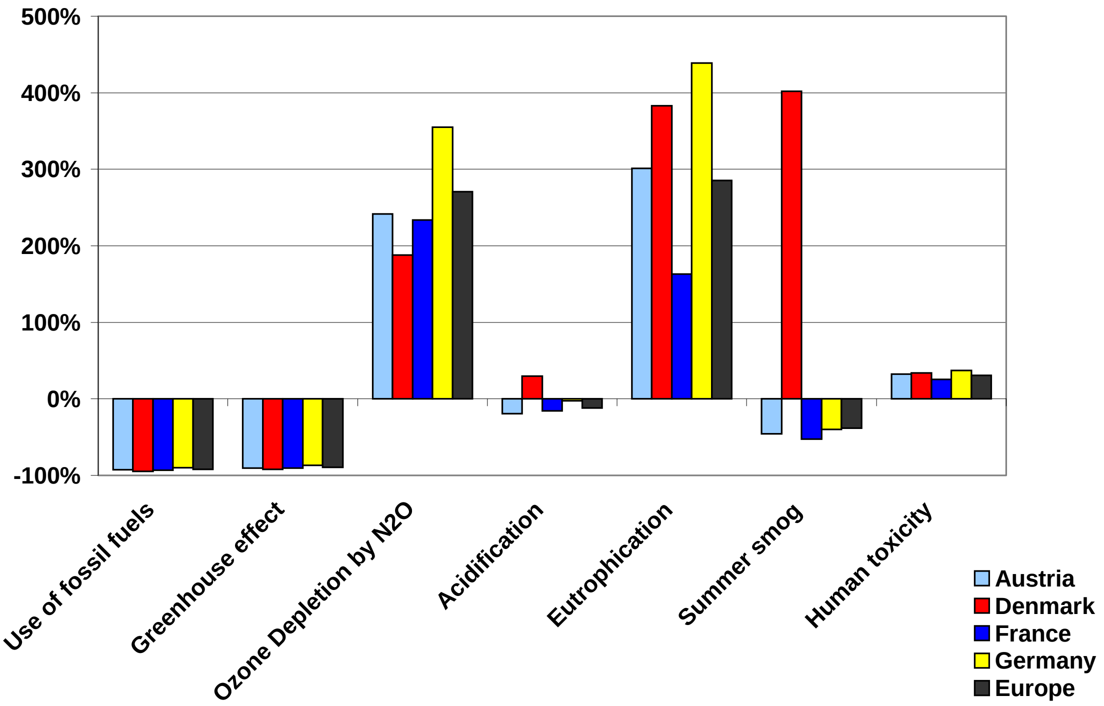
Life cycle comparison	Countries involved
Traditional firewood vs. light oil	Austria, Italy, Switzerland
Triticale vs. coal	Austria, Denmark, France, Germany
Miscanthus vs. light oil	Denmark, France, Germany, Netherlands
Willow vs. light oil	Denmark, Germany, Netherlands
Wheat straw vs. light oil	Austria, Denmark, France, Germany, Greece
Biogas from swine excrements vs. natural gas	Austria, Denmark, Greece, Italy, Netherlands, Switzerland
Rape seed oil methyl ester vs. fossil diesel fuel	Austria, Denmark, France, Germany, Switzerland
Sunflower oil methyl ester vs. fossil diesel fuel	France, Greece, Italy
ETBE from sugar beet vs. MTBE	France, Germany, Netherlands

With regard to the life cycle comparisons concerning traditional firewood, Miscanthus, willow and wheat straw, only light oil was considered here. The differences between the comparisons with natural gas can be deduced from the relevant sections in Chapters 4.3 and 7.1 respectively.

The impact categories human toxicity and nitrous oxide will be shown without remarks because of the high uncertainty of the individual results and therefore coincidental character of differences among the countries.

For more information on the life cycle comparisons carried out see Chapter 2. For information regarding the selected impact parameters the reader is referred to the Chapters 3.3 and 3.4 as well as Chapter 4.1.2.

7.2.2 Triticale versus hard coal for electricity production: relative impact differences related to fossil fuels



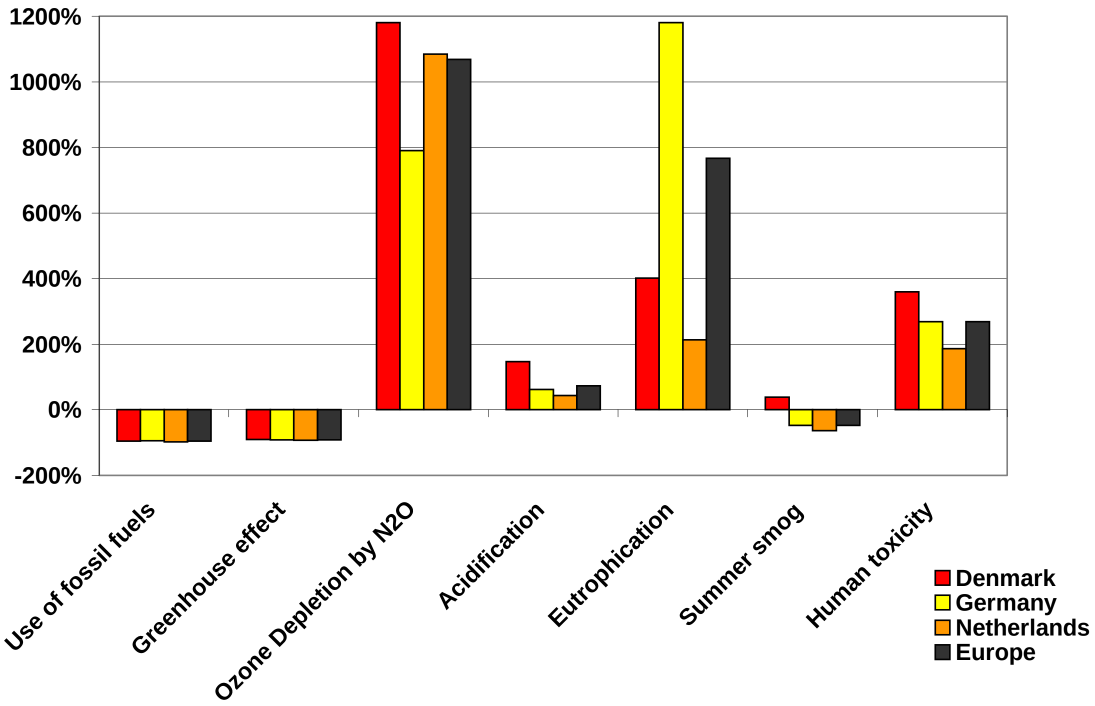
How to interpret the diagram

Environmental advantages and disadvantages of triticale compared to hard coal for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuels. The zero line indicates the level for fossil fuels. Therefore negative values indicate advantages for triticale and positive ones represent advantages for hard coal. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

Regarding the parameters use of fossil fuels and greenhouse effect, the results are similar for all four countries. Regarding ozone depletion and eutrophication, Germany shows the highest value and Denmark and France respectively the lowest. The overall pattern of ozone depletion is determined by the ratio N fertiliser/yield. That of eutrophication is caused by the nitrate emissions to water (very low in France) and the NO_X emission factors of the combustion (very high in Denmark). For summer smog Denmark stands out with an exceptionally high impact. This is due to extremely high methane and NMHC emissions from combustion. Since this cannot be regarded as being typical for other countries in Europe, the results of the Danish chain have been used only for Denmark but not as defaults for other countries (like Finland or the Netherlands) for calculating the European means. Most of the other differences are rather small and to be regarded as less significant.

7.2.3 Willow versus light oil for district heat production: relative impact differences related to fossil fuels



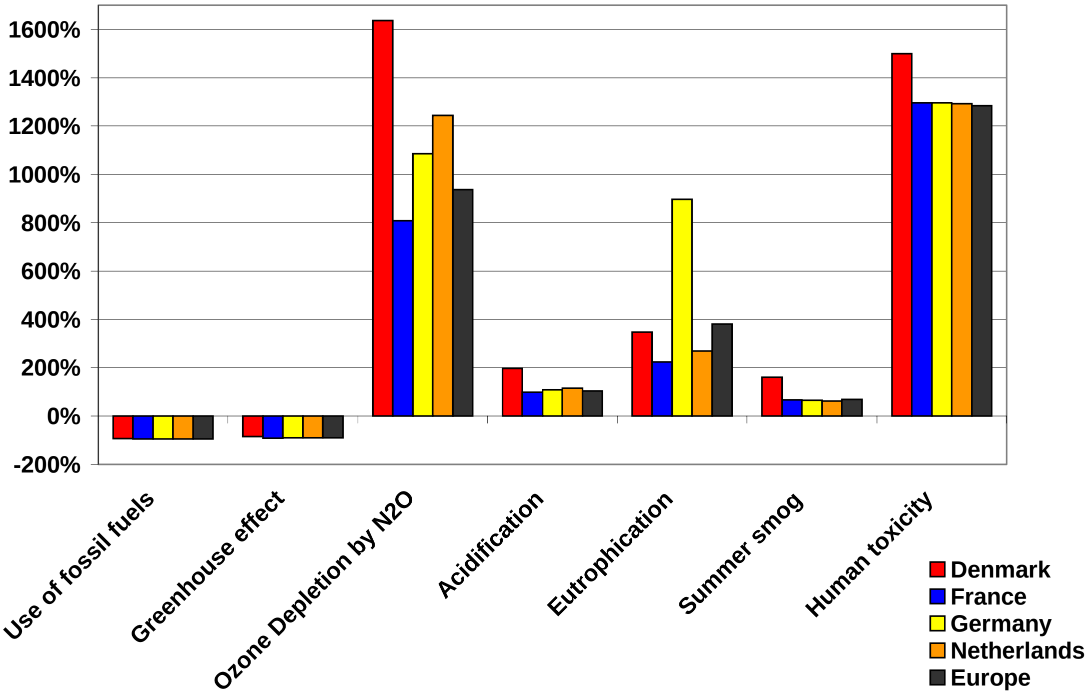
How to interpret the diagram

Environmental advantages and disadvantages of willow compared to light oil for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuels. Therefore negative values indicate advantages for willow and positive ones represent advantages for light oil. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

Regarding the parameters use of fossil fuels and greenhouse effect, the results are similar for all three countries. For eutrophication Germany stands out with an exceptionally high impact by using the defaults from the data collection guideline for nitrate emissions to water; for the other countries a more complex model was used (the Netherlands) or other assessments were done (Denmark); for both countries higher nitrate emissions from fallow than from the crop were observed. For summer smog Denmark stands out with an quite high impact. This is due to extremely high methane and NMHC emissions from combustion. Since this cannot be regarded as being typical for other countries in Europe, the results of the Danish chain have been used only for Denmark but not as defaults for other countries (like Finland or the Netherlands) for calculating the European means. Most of the other differences are rather small and to be regarded as less significant.

7.2.4 Miscanthus versus light oil for district heat production: relative impact differences related to fossil fuels



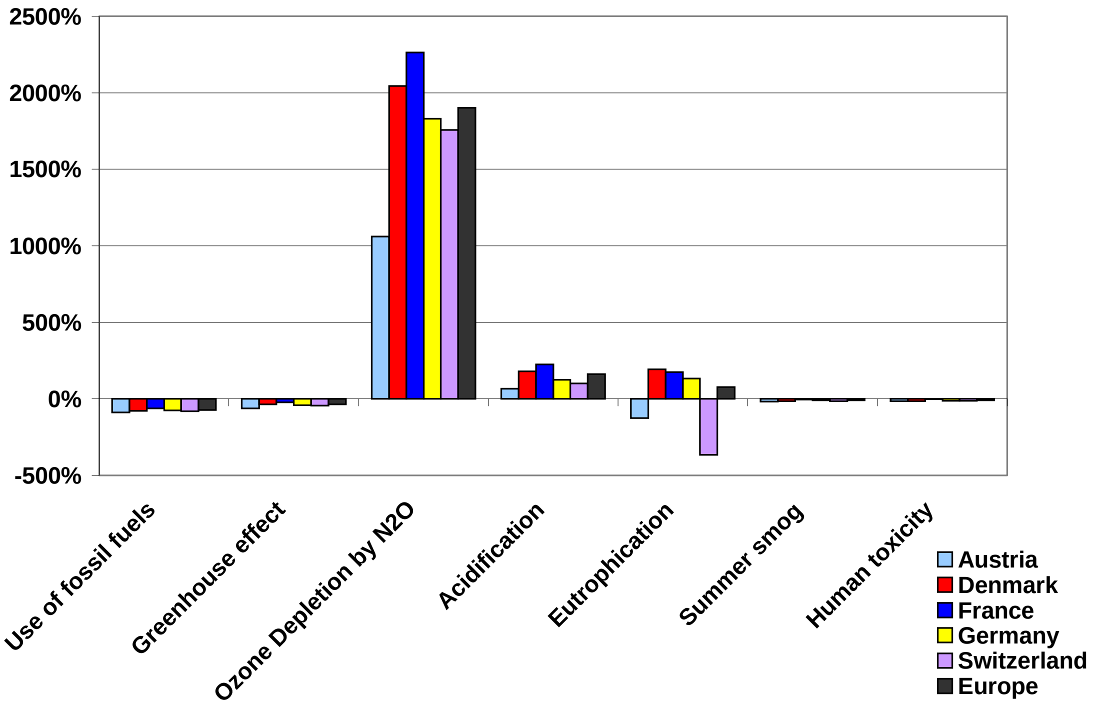
How to interpret the diagram

Environmental advantages and disadvantages of Miscanthus compared to light oil for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuels. Therefore negative values indicate advantages for Miscanthus and positive ones represent advantages for light oil. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

Regarding the parameters use of fossil fuels and greenhouse effect, the results are similar for all four countries. Regarding ozone depletion, caused by very different ratios N fertiliser/yield Denmark shows the highest value and France the lowest. For eutrophication Germany stands out with an exceptionally high impact by using the defaults from the data collection guideline for nitrate emissions to water; for the other countries a more complex model was used (the Netherlands) or other assessments were done (all of these countries: higher nitrate emissions from fallow than from the crop). Most of the other differences are rather small and to be regarded as less significant.

7.2.5 Rape seed oil methyl ester (RME) versus fossil diesel fuel for transportation: relative impact differences between biofuels and fossil fuels



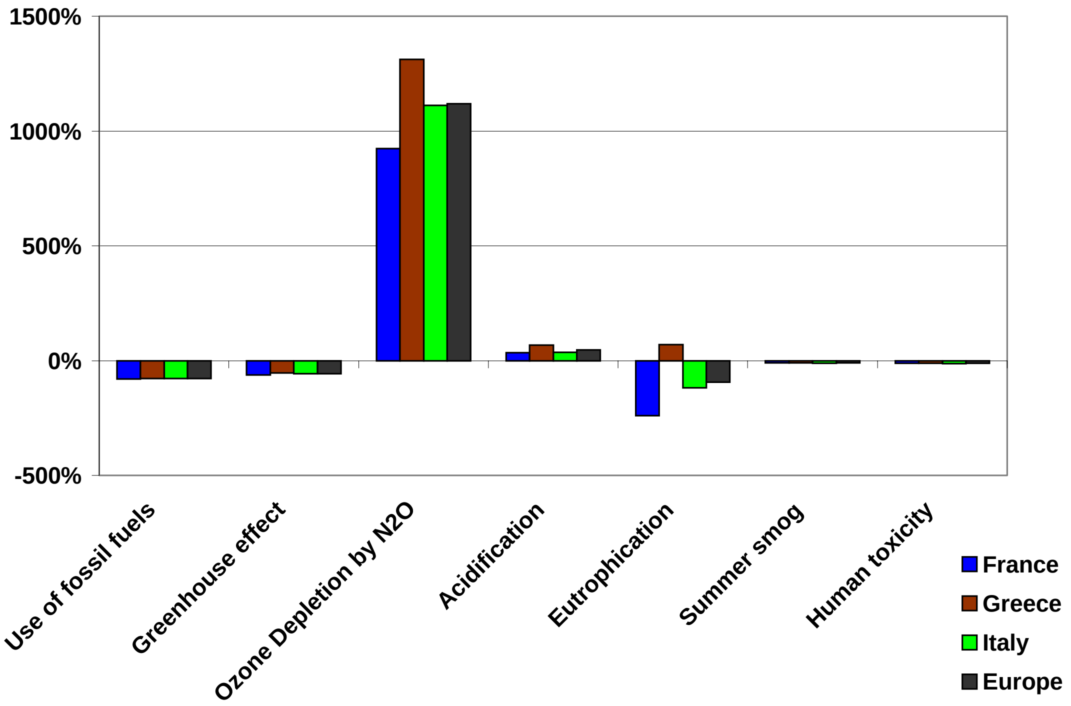
How to interpret the diagram

Environmental advantages and disadvantages of RME compared to diesel fuel for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuels. Therefore negative values indicate advantages for RME and positive ones represent advantages for diesel fuel. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

The results show relatively large differences between the countries for the most of the impacts. Also in the case of the greenhouse effect there are big differences with France showing the lowest benefits and Austria the highest benefit. Regarding ozone depletion, the highest impacts are recorded in France and the lowest in Austria; the pattern is determined by the ratio N fertiliser/yield. In the case of eutrophication, for Austria the sum of several smaller factors leads to certain credits, resulting in a negative value (advantage compared to diesel fuel), while for Switzerland the reason is that in the case of the agricultural reference system (fallow) higher PO_4^{3-} emissions to water occur than for RME, giving a very high credit. The results on acidification is affected by credits of SO_2 emissions to air in Austria and Switzerland.

7.2.6 Sunflower oil methyl ester (SME) versus fossil diesel fuel for transportation: relative impact differences between biofuels and fossil fuels



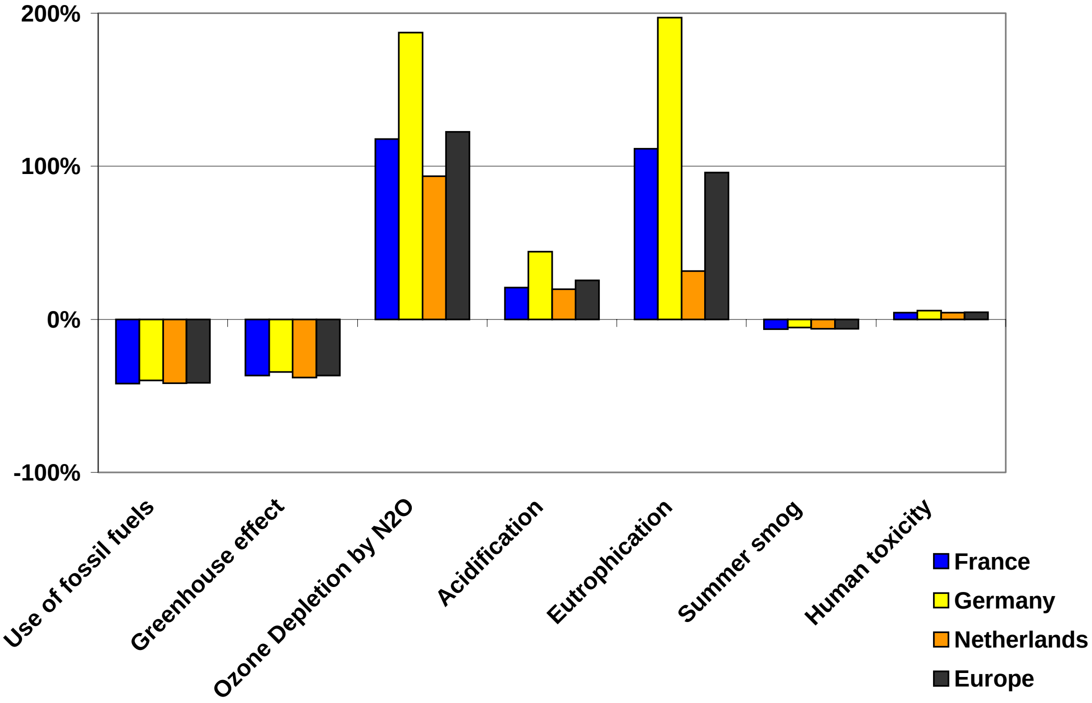
How to interpret the diagram

Environmental advantages and disadvantages of SME compared to diesel fuel for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuels. Therefore negative values indicate advantages for SME and positive ones represent advantages for diesel fuel. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

The results give a uniform picture regarding use of fossil fuels, greenhouse effect and also regarding ozone depletion and acidification. The large differences regarding eutrophication are due to different PO_4^{3-} emissions to water and different yields, which together lead to very different credits. Most of the other differences are rather small and to be regarded as less significant.

7.2.7 ETBE from sugar beet versus fossil MTBE for transportation: relative impact differences between biofuels and fossil fuels



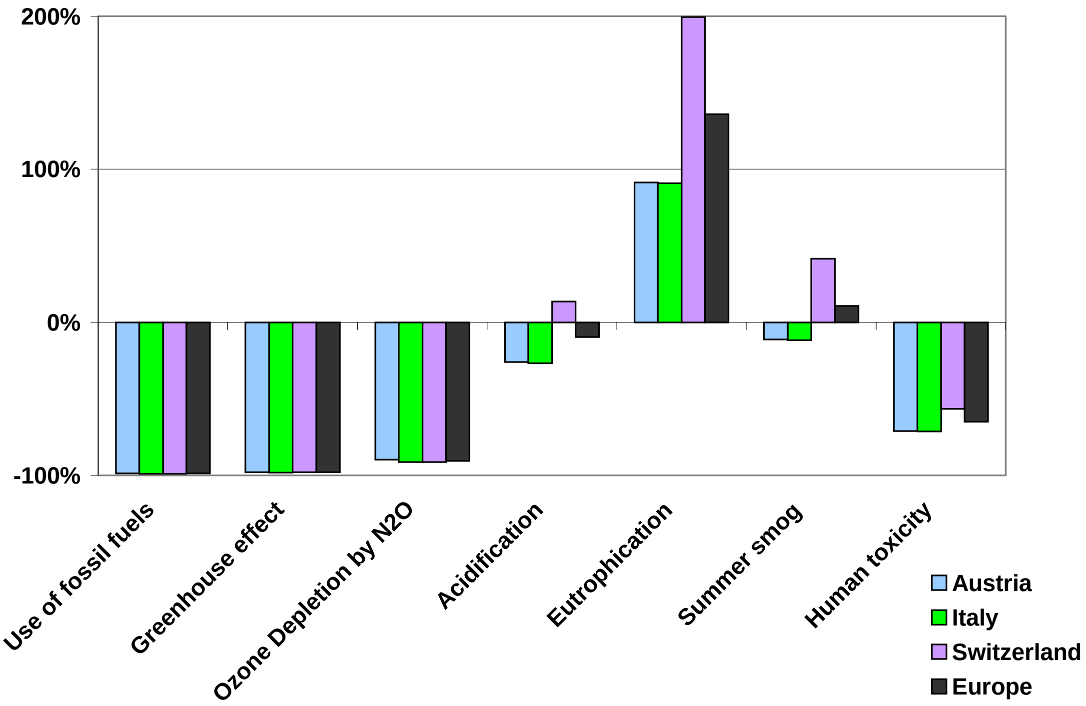
How to interpret the diagram

Environmental advantages and disadvantages of ETBE compared to MTBE for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuels. Therefore negative values indicate advantages for ETBE and positive ones represent advantages for MTBE. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

For the categories use of fossil fuels and greenhouse effect all country results are very close. Especially regarding eutrophication there are much greater differences. For eutrophication Germany stands out with an exceptionally high impact by using the defaults from the data collection guideline for nitrate emissions to water; for the Netherlands a more complex model was used which gave higher nitrate emissions from fallow than from the crop. Most of the other differences are rather small and to be regarded as less significant.

7.2.8 Traditional firewood versus light oil for residential heating: relative impact differences related to fossil fuels



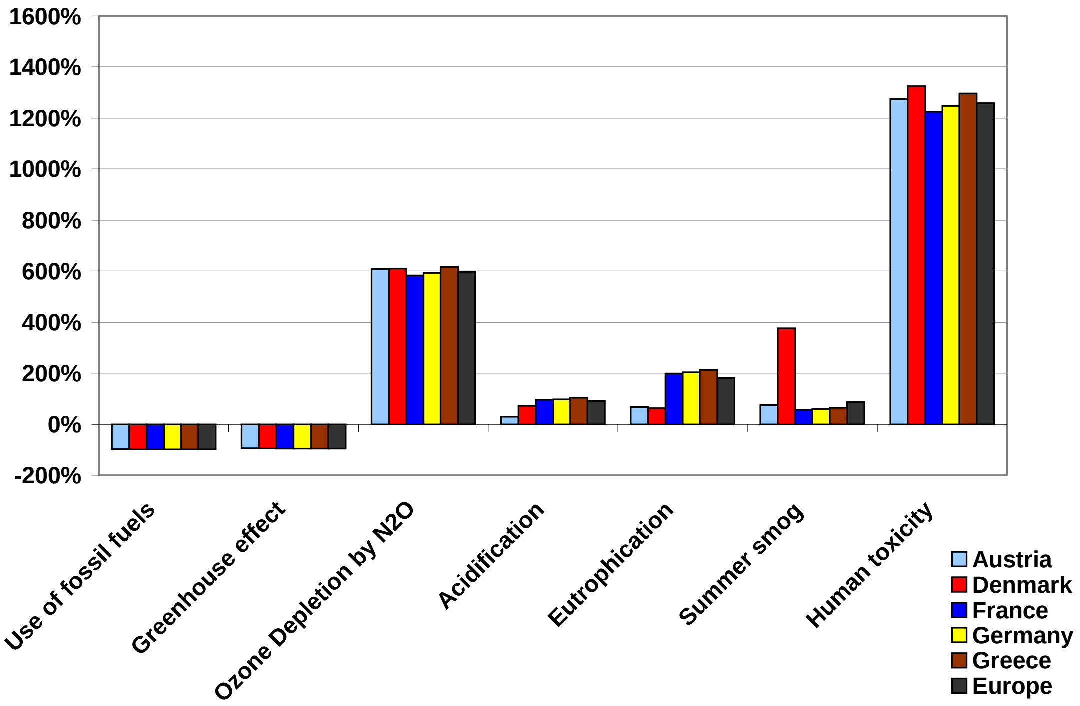
How to interpret the diagram

Environmental advantages and disadvantages of firewood compared to light oil for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuels. Therefore negative values indicate advantages for firewood and positive ones represent advantages for light oil. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

Regarding the parameters use of fossil fuels, greenhouse effect and ozone depletion, the results are similar for all three countries. Regarding eutrophication, Switzerland shows a very high value, which is caused by an very high NO_X emissions of the combustion. The differences for acidification and summer smog among the countries and among the biofuel and fossil fuels are rather small and to be regarded as less significant.

7.2.9 Wheat straw versus light oil for district heat production: relative impact differences between biofuels and fossil fuels



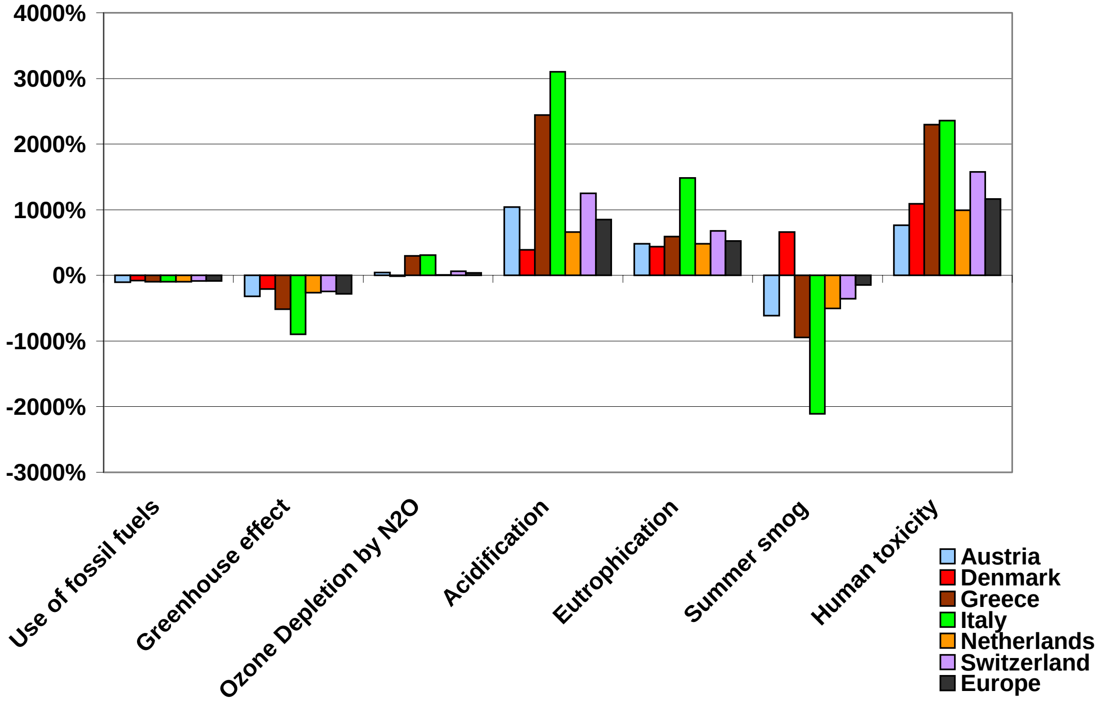
How to interpret the diagram

Environmental advantages and disadvantages of wheat straw compared to light oil for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuels. Therefore negative values indicate advantages for wheat straw and positive ones represent advantages for light oil. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

Regarding the parameters use of fossil fuels, greenhouse effect, and ozone depletion the results are very uniform between all countries. Regarding acidification and eutrophication Austria and Denmark show very low results caused by very low NO_X emissions from combustion. Regarding summer smog Denmark stands out with a high value due to very high methane and NMHC emissions from combustion. Most of the other differences are rather small and to be regarded as less significant.

7.2.10 Biogas from swine excrements versus natural gas for combined heat and power production: relative impact differences between biofuels and fossil fuels



How to interpret the diagram

Environmental advantages and disadvantages of biogas compared to natural gas for each country involved as well as for Europe are shown by *relative differences* between the biofuels and the fossil fuel: *(biofuel – fossil fuel) / fossil fuel*. The zero line indicates the level for fossil fuel. Therefore negative values indicate advantages for biogas and positive ones represent advantages for natural gas. For example, assuming the production and combustion of fossil fuel causes an emission of 1 kg of N_2O (Ozone depletion), then a value of -100 % means no net N_2O emissions in the case of the biofuel, 0 % means 1 kg N_2O (i.e. the same as the fossil fuel), 100 % means 2 kg N_2O and so on.

Remarks and conclusions

Regarding the parameter use of fossil fuels the results are very uniform for all countries, whereas the values for the other impacts are extremely different. Regarding greenhouse effect and summer smog Italy shows the greatest benefits, but it also has the highest impacts regarding acidification and eutrophication.

7.3 Abbreviations and symbols

a	year
BaP	benzo(a)pyrene
BAT	best available technology
CF	characterisation factor
CFC11-equivalents	common unit for ozone depletion potential
CH_4	methane
CO_2	carbon dioxide
eq.	equivalent(s)
ETBE	ethyl tertiary butyl ether
EU15	The 15 states of the European Community
EURO-4	European emission standards for motor vehicles from 2005 onwards
fNPP	free net primary biomass productivity
g	gram
GAP	good agricultural practice
GJ	gigajoule (10^9 Joule)
GWP500	global warming potential, time horizon 500 years
ha	hectare (10,000 m^2)
HCl	hydrochloride
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardisation Organisation
kg	kilogram
km	kilometre
kWh	kilowatt hour
LCA	life cycle analysis
LCI	life cycle inventory
LCIA	life cycle impact analysis
m^2	square meter
m^3	cubic meter
Mg	megagram (10^6 g)
Mio	million
MJ	megajoule (10^6 Joule)
MTBE	methyl tertiary butyl ether
N_2O	nitrous oxide (laughing gas)
NH_3	ammonia
NMHC	non-methane hydrocarbons
NMVOC	non-methane volatile organic compounds
NO_2	nitrogen dioxide
NO_3^--equivalents	common unit for all eutrophying substances
NO_x	nitrogen dioxide (NO_2) and nitrogen monoxide (NO)
NPP	net primary biomass productivity
ODP	ozone depletion potential
PJ	petajoule (10^{15} Joule)
POCP	photochemical ozone creation potential
RME	rape seed oil methyl ester
SME	sunflower oil methyl ester
SO_2	sulphur dioxide
SO_2-equivalents	common unit for all acidifying substances
SPOLD	Society for the Promotion of Life Cycle Assessment Development
SRC	short rotation coppice
t	ton (10^3 kg)
TJ	terajoule (10^{12} Joule)
USLE	Universal Soil Loss Equation
vs.	versus
yr	year

7.4 List of authors and addresses

BLT – Federal Institute for Agricultural Engineering (Austria)

Marion Lechner: Born in 1968, studied biochemistry at the University of Vienna with a PhD in chemistry. She has work on research projects dealing with the perspectives of vegetable oils as raw materials for the oleochemical industry, the utilisation of biofuels and participated in the BIOFIT project. Since 1999 she is working as a formulation chemist in a private company. Marion Lechner prepared the detailed life cycle graphs and the inventory lists and started with the data collection.

Renate Neumayr: Born in 1974 in Vienna/Austria, studied at the University of Agriculture, Forestry and Renewable Natural Resources in Vienna and made her master degree in the studies of "Landscape Architecture and Planning" on “Life Cycle Assessment of Sewage Sludge Treatment”. Fields of experience: technical and environmental consultation; scientific research at the Austrian Association for Agricultural Research in the fields of cultural landscape, renewable energy, sewage sludge, biogas and environmental impact assessment. Renate Neumayr collected most of the Austrian data and prepared the data for the calculation tool.

Josef Rathbauer: Born in 1964 in Schrick, a small village in the north-east of Austria. He studied at the Agricultural University in Vienna, specialising in agriculture and plant production. He made his master thesis in the field of biology and biodiversity of weeds. After one year as consultant in the field of biomass fuelled district heating plants he changed in 1991 to the Federal Institute of Agricultural Engineering. He is the head of the unit renewable raw materials and of the laboratory of the research department. Fields of expertise: Production, standardisation and analysis of liquid and solid biofuels; production chain of plant fibres; manure treatment and biogas production. Josef Rathbauer contributed to the project frame, co-ordinated the life cycle description and the data collection and prepared the Austrian data for the evaluation.

Manfred Wörgetter: Born in 1948 at Kufstein, Tirol (Austria). Study at the TU Graz, Faculty for Mechanical Engineering, graduated with a mechanical engineering diploma. Since 1975 at the Federal Institute for Agricultural Engineering; 25 years experience in biomass for energy and industry; head of the department of agricultural engineering research and vice director of the institute. Responsible for the Biomass Framework Programme of the Federal Ministry for Agriculture, leader of the working group “Renewable Raw Materials” of the Ministry. Research work: (a) wood gasifier for farm tractors; (b) vegetable oil as Diesel fuel (studies, bench and endurance tests); (c) Biodiesel (production, analysis, bench, fleet and emission tests, standardisation, non-technical barriers); (d) solid biofuels from agriculture and forestry (studies, research in combustion); (e) boiler tests (test methods, state of the art); (f) participant in international research projects and networks: FAIR (96-1877, 97-3832, 98-3952); IEA Bioenergy (Liquid Biofuels Task), ALTENER (AFB-net, NTB-net, NF-AIRID). Member of national and European standardisation activities, member of conference committees (e.g. "International Conference on Standardisation and Analysis of Biodiesel, "2nd European Motor Biofuels Forum, "Crops for a GREEN Industry"). Manfred Wörgetter co-ordinated all the activities of BLT, contributed to the project frame, prepared the selection methodology of the biofuels under study and the Austrian conclusions in chapter 7.

CLM – Centre for Agriculture and Environment (Netherlands)

Anton Kool: Born in 1972 in Zevenhoven, The Netherlands on a mixed dairy and arable land farm. After graduating high school in 1991 he started at the Agricultural University in Wageningen studying Animal Sciences. During his study he was particularly interested in the relation animal husbandry and environment. Because of that he did a thesis concerning nitrate leaching and a thesis concerning ammonia volatilisation out of cattle stables. After graduating at the university in 1996 he started working as a nutritionist. In 1998 he changed jobs and since then he works for CLM (Centre for Agriculture and Environment) as a researcher. His work within this project concentrated on the environmental assessment and the results of the environmental analysis for The Netherlands. He was involved in the project from September 1999 till August 2000.

Ir. Henk van Zeijts: Senior Scientist, born in 1966. Diplom in Agronomy at Wageningen Agricultural University, with CLM since 1992. Fields of expertise: farm management strategies, nutrients, agri-environmental policies, life cycle assessment (LCA), bio-energy. Henk van Zeijts shared the responsibility of co-ordinating the work of CLM with Marjoleine Haanegraf. His work within the project comprised the issues of biodiversity and soil quality as well as the development of the methodology for the socio-economic and policy analysis.

Marjoleine Hanegraaf: Born in 1960, studied tropical agriculture at the Rijks Hogere Landbouwschool in Deventer and obtained a MSc-degree in soil science at the University of London. She has worked as a researcher on a number of projects related to the effects of nutrients, pesticides and heavy metals on soil fertility. At the Centre for Agriculture and Environment which she joined in 1993, she works on energy consumption and production in agriculture. Marjoleine Haanegraf shared the responsibility of co-ordinating the work of CLM with Henk van Zeijts. Her work within the project comprised the issues of biodiversity and soil quality as well as the socio-economic and policy analysis.

CRES – Centre for Renewable Energy Sources (Greece)

Calliope Panoutsou: Her activities cover agricultural engineering and agricultural economics. She is the head of Biomass Department of CRES, with eight years of RTD experience in biomass for energy. She has been involved as a partner and project manager, in several European projects. She participated in the second year of the project as the scientific responsible for CRES and she collaborated with the other partners in the determination of the methodology applied and the interpretation of the results for Greece.

Anastasia Nikolaou: Her activities cover agricultural engineering and agricultural biology. From 1997 until today she has been a staff member in the Biomass department of CRES specialised on energy crops and environmental aspects of biomass energy systems. At her position in CRES she has participated in the carrying of many European projects. In the framework of this project she was involved in the determination of the bioenergy chains under study, data collection and interpretation of the results for Greece.

Dr. Nicholas Dercas: His activities cover both agricultural and hydraulic engineering. From 1993 until 1999 he was a staff member in the Biomass Department of the Center for Renewable Energy Sources (CRES). At his position in CRES he has participated in the carrying of many European projects. He participated to the first year of the project as the scientific responsible for CRES and he collaborated with the other partners in the determination of the methodology applied and of the bioenergy chains under study. Since 1999, he is a Lecturer in the Agricultural University of Athens.

CTI – Italian Technical Committee (Italy)

Prof. Ing. Giovanni Riva: Born in 1952. Mechanical engineer. Since 1976 he works in the field of energy and has a remarkable expertise in process analysis/design with special reference to thermal/electric plants. Full professor at the University of Ancona (mechanics), he worked for different international organisations (UN, UE). More than 250 technical papers. Since 1993 general secretary of CTI and of ATI (Italian Thermotechnical Association; around 1500 members). Due to these activities he has also developed an expertise in congresses and working groups organisation. In this project he was the co-ordinator of the Italian staff.

Dr. Elio Smedile: Born in 1938. Biologist and Environmentalist. From 1988 to 1994 head of Environmental Dept. of the Italian Electricity Board (ENEL); since 1996 responsible of R&D activities of CTI. Member of the Board of Directors of ITABIA (Italian Biomass Association) and co-chairman of the committee "Energy & Environment aspects" of ESNA (European Society for New methods in Agricultural research). In this project he was involved as scientific co-ordinator and as expert in political and economical matters.

Dr. Antonio Panvini: Born in 1966. Graduate in Agronomic Sciences. He works as CTI's responsible for data banks and databases since 1996. He is involved in different projects and works concerning biomass and biofuels. Between these works: a report on biodiesel application in Italy and the development of standards in the field of renewable sources. He maintains two yearly data-books on Italian energy laws and standards. In this project he developed and applied the tools for LCIA calculation for all chains studied in the different participating countries; he was responsible for environmental and economic data relevant to the Italian chains.

Dr. Julio Calzoni: Born in 1964. Graduate in Agronomic Sciences. He works as CTI's responsible for different researches. Among the different works: a technical-economic study on heat-pump application, a report on the future developments of standards on renewable sources, an intensive experimentation on biomass drying and storage. He works also on the organisation of different national and European working groups committed to the energy use and the installation of the relevant combustion plants for biomass and wastes. In this project he was involved in the Italian data collection.

FAL – Swiss Federal Research Station for Agroecology and Agriculture (Switzerland)
(Since 1.10.1999 after the transfer of the Swiss agricultural LCA research from FAT to FAL)

Dr. Gérard Gaillard: Group Leader Life Cycle Assessment at the FAL Research Station. He studied agricultural engineering at the Swiss Technical Institute of Technology of Lausanne (EPFL). Since 1993 active in the field of life cycle assessment in agriculture, first at the FAT, since 1999 at the FAL. He published several studies on life cycle assessment of crops and agricultural techniques, co-author of the Swiss Evaluation Report on Renewable Raw Materials, participated in the European concerted actions "Environmental Life Cycle Assessment for Agriculture" and "LCA network for the food chain", member of the Editiorial Board of the International Journal of Life Cycle Assessment. He co-ordinated the methodological contributions of all groups for the LCA part of the project.

FAT – Swiss Federal Research Station for Agricultural Economics and Engineering (Switzerland)

Lena Heinzer: Agricultural engineer from the Swiss Federal Institute of Technology Zurich. Employed at FAT from 1998 until 2000, involved in all tasks of the project.

Cornelia Stettler: Environmental engineer from the Swiss Federal Institute of Technology Zurich. Three months trainee at FAT with responsibility for the economic calculations.

IFEU – Institute for Energy and Environmental Research Heidelberg (Germany)

Nicolai Jungk MSc: Born in 1972, BSc Environmental Science, MSc Sustainable Agriculture, graduated from the Universities of Edinburgh and Aberdeen and has been working for the IFEU Institute since August 1999. He has specialised in the subjects of renewable resources and land use assessment within LCA. Within the "Bioenergy for Europe" project he was responsible for the composition of the final report.

Gitty Korsuize MSc: Trainee at the IFEU Institute from November 1999 to May 2000. She studied Environmental Science at the University of Utrecht and Stuttgart. Master thesis on “Urban flora and urban climate” in August 1999. In “Bioenergy for Europe” she has been involved in collection of life cycle input data related to Germany, the validation of the input data for all countries and the assessments on costs and employment for Germany.

Dr. Andreas Patyk: Co-ordinator (one of two), Senior Scientist at the IFEU Institute. He studied chemistry at the University of Heidelberg, PhD in Chemistry at Heidelberg University and PosDoc at the University of Gothenburg. Since 1992 at the IFEU Institute working in the fields of life cycle assessment (LCA), transport and environment, and ecological assessments of fossil and regenerative energy conversion systems and primary industry. Main author, co-author and project leader of numerous scientific studies. Retained as expert consultant by the UNECE work group preparing the convention on persistent organic pollutants. He has published two books and a number of contributions to journals, books, and scientific conferences. Beside co-ordinating the project he has been involved in collection of life cycle input data related to Germany, the compilation of the common base data bank and the calculation of the fossil life cycles for all chains and partners, the validation of the input data for all countries and the assessments on costs and employment for Germany.

Dr. Guido A. Reinhardt: Co-ordinator (one of two), Scientific Director of the IFEU Institute. He studied chemistry, math, and biology at the University of Heidelberg, PhD in Chemistry at Heidelberg University. Since 1991 at the IFEU Institute working in the fields of life cycle assessment (LCA), transport and environment, and ecological assessments of food, energy, and industrial crops. He has been involved in numerous research and consultancy activities including several European programs like AIR, FAIR, and ALTENER. He is a member of standardisation panels and advisory committees such as VDI. In the last 10 years he has published several books and has made more than hundred contributions to journals, books, scientific conferences and expert hearings. He is the main author, co-author and project leader of numerous scientific studies. Beside co-ordinating the project he has been involved in methodological issues, interpretation and most conceptual issues including the final report.

INRA – National Institute of Agronomic Research (France)

Dr. Ghislain Gosse: Head of the research unit "Environment and Arable Crops" of INRA (Grignon), is an agronomist specialised in atmospheric physics and crop modelling. He is also Scientific advisor of ADEME in the area of Agriculture and Environment. He has been engaged for 20 years in bio-energy production in France and at the EU level (co-ordination of Sorghum network especially) and was expert in France in the environmental evaluation of liquid biofuels (RME, ETBE) in the Levy Mission for example. Involved in this FAIR project since its beginning, he directed the data collection and verification of all chains studied in France and contributed to the redaction of the French results.

Dr. Bruno Leviel: Engineer for INRA: He studied physics and chemistry for environment at the polytechnic institute of Toulouse (INPT). For 5 years, at Unit Environment and Arable Crops of INRA Versailles-Grignon, he has been involved in several projects concerning environmental balances, analyses of risks for environment of energy crops -especially sugar beet, wheat, rape seed and sweet sorghum- and life cycle assessments. Involved in this FAIR project since its beginning, he collected and checked the data of all chains studied in France and contributed to the redaction of the French results.

TUD – Technical University of Denmark (Denmark)

Dr. Nina Caspersen: MSc Chem. Eng, PhD, 6 years experience in life cycle assessment, especially materials and energy systems. Co-reviewer of a large Danish LCA-project on electricity and combined power systems. Involved in the large Danish LCA-project: EDIP (Environmental design of industrial products) and in the national methodology project on LCA in Denmark. Main tasks in the methodology project: allocation and future forecasting in LCA. Involved in simplification of LCA in connection to small and medium size enterprises and development of tools for quick environmental assessment in connection with product development.

Dr. Bo Pedersen Weidema: Born in 1956, 28 years of experience in environmental issues, since joining the emerging environmental grassroots movements in 1972. In 1984, with a M.Sc. in horticulture from the Royal Agricultural University of Copenhagen, he initiated an interdisciplinary, inter-university course on environment of which he became the first administrator and lecturer. As private consultant and member of international committees from 1985-1989 he was involved in developing standards and markets for ecological food products. In 1993 he obtained the Ph.D. degree from the Technical University of Denmark on a thesis on life cycle assessment. Since then he has been working as a consultant on life cycle assessment. He is an expert delegate to the ISO TC 207 / SC5 Working Group on life cycle inventory, general secretary to the Society for Promotion of Lifecycle assessment Development (SPOLD), member of the SETAC Steering Committee on Life Cycle Assessment, chairman of the CODATA (Committee on Data for Science and Technology of the International Council of Scientific Unions) Working Group on data for environmental life cycle inventories, board member of the EEE network for Environmental Engineering and Education, and member of the Editorial Board of the International Journal of Life Cycle Assessment.

Anne Merete Nielsen: Environmental Economist from the Royal Agricultural and Veterinarian University of Denmark (1998). Since then employed at the Technical University of Denmark.

Per H. Nielsen: He received his M.Sc. in Chemical Engineering from Technical University of Denmark in 1988 and his Ph.D. in Environmental Science and Engineering from Technical University of Denmark in 1994. After receiving his Ph. D. Per H. Nielsen has specialised in lifecycle assessment and served as researcher, course instructor and consultant in the field. Per H. Nielsen now holds a position as associate professor in Asian Institute of Technology, Bangkok, Thailand.

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7.5 Data availability

The following documents can be found on a CD-ROM available from the IFEU-Institute, Heidelberg, Germany (see address below), or from the following Internet site:

www.ifeu.de/nr_fair.htm

Data set	**Content**
life-cycle-charts.ppt	flow charts of the life cycles under study
external-annex.doc	external annex to the final report: Goals of the study Functions of the product systems Functional unit Allocation procedures System expansion for protein fodder by-products Choice of reference-systems and technologies Characterisation of resource uses and environmental impacts Methodology for ‘Land Use’ Data collection guidelines Flow for the data collection Results ‘Land Use and Biodiversity’ Methodology for ‘Socio-economic and political analyses’
lca-1-triticale.xls	life cycle assessment of triticale versus hard coal for power production
lca-2-rme.xls	life cycle assessment of RME versus diesel fuel for transportation
lca-3-sme.xls	life cycle assessment of SME versus diesel fuel for transportation
lca-4-etbe.xls	life cycle assessment of ETBE versus MTBE for transportation
lca-5-misc.xls	life cycle assessment of Miscanthus versus light oil and natural gas for district heat production
lca-6-willow.xls	life cycle assessment of willow versus light oil and natural gas for district heat production
lca-7-wood.xls	life cycle assessment of traditional fire wood versus light oil and natural gas for residential heat production
lca-8-biogas.xls	life cycle assessment of biogas versus natural gas for combined heat and power production
lca-9-straw.xls	life cycle assessment of wheat straw versus light oil and natural gas for district heat production
all-chains.xls	LCA results of all national and European chains

If problems should arise with the downloading of these files please consult:

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7.6 Literature

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