BIOENERGY FOR EUROPE: WHICH ONES FIT BEST?

– A COMPARATIVE ANALYSIS FOR THE COMMUNITY –

Contract CT 98 3832

Executive Summary

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)
FAL	Eidgenössische Forschungsanstalt für Agrarökologie und Landbau (Switzerland)
FAT	Eidgenössische Forschungsanstalt für Agrarwirtschaft und Landtechnik (Switzerland)
IFEU	Institut für Energie- und Umweltforschung Heidelberg (Germany); Project Co-ordinator
INRA	Institut National de la Recherche Agronomique (France)
TUD	Technical University of Denmark (Denmark)

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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 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.

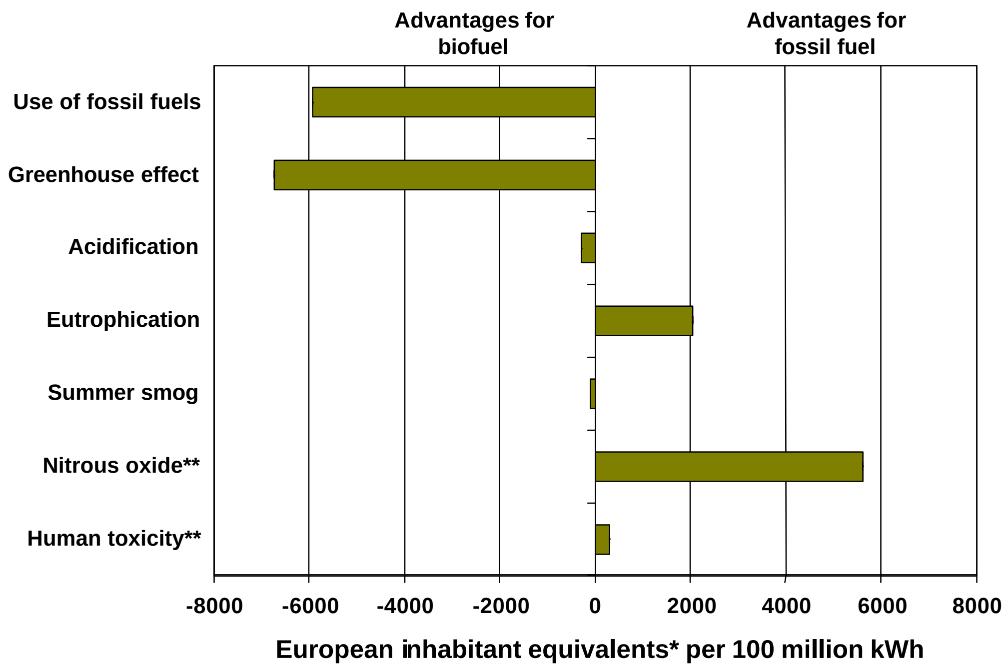
Table 2 Results of the European comparisons between biofuels and fossil fuels

Biofuel	Use of fossil fuels	Green-house effect	Acidi-fication	Eutro-phication	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.

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 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.