Pros and cons of RME compared to conventional diesel fuel

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SUMMARY

Since the beginning of the nineties methodology and content of LCAs on "Rape Seed Biodiesel versus Ordinary Diesel Oil" have continuously been developed. This eventually led to a solid knowledge concerning a final evaluation of the ecological advantages and disadvantages of rape seed biodiesel (RME) as a substitute for diesel oil. However, two questions regarding rape seed cultivation and land use that have been much discussed are being investigated here for the first time in sufficient depth: firstly, how the results of an environmental assessment of RME would change if rape seed would not be cultivated on set-aside land but on areas otherwise used for food crops, and secondly, usually argued by environmental organisations, would it not be more sensical to use the available land for more environmetally friendly farming methods rather than rape seed for energy?

The results show that different agricultural reference systems can lead to differences in the quantitative results but not to a reversal of signs. This means that generally the results obtained so far may still be regarded as reliable. However, with respect to the different land use options organic wheat production is superior to rape seed cultivation for bioenergy in all environmental categories investigated here, with the exception of the saving of fossil resources. As with the assessment methods already mentioned – e. g. on the basis of specific contributions and ecological importance – it will be necessary, and possible, to reach a final conclusion in this matter.

1. INTRODUCTION

In the eighties the first energy balances on RME including the comparison with ordinary diesel oil were completed (1). Yet they did not consider the whole life cycles of the fuels. In the beginning of the nineties the first overall energy and CO_2 balances on "RME versus Ordinary Diesel Oil" were presented (2). In the following years the LCAs were updated and further ecological parameters covering parts of the life cycles were added (3 to 6). In 1997 the most comprehensive project in Germany on this topic was completed. It examined numerous ecological parameters and quantified them for the whole life cycles (7). All parameters were examined to the same degree of differentiation like the parameters energy and CO_2 before. Based on this approach the range of results was determined by sensitivity analyses (8). In another project the emphasized problems in (7) and (8) like the integration of the coupled product glycerine in the balance were solved and the results updated (9). By then, the different ecological advantages and disadvantages were unambiguously determined and quantified. Recent advances allowed for the first time to tackle a final ecological assessment of RME based on the quantified results of the preceding studies (10, 11).

In the course of the discussion surrounding RME, two questions were raised regarding rape seed cultivation and land use: firstly, how the results of an environmental assessment of RME would change if rape seed would not be cultivated on set-aside land but instead of food crops, and secondly – usually argued by environmental organisations – would it not be more sensical to use the available land for more environmentally friendly farming methods rather than rape seed for energy? Both of these aspects were dealt with in detail in a study supported by the German ministry for agriculture and are discussed in chapters 4 and 5. In chapters 2 and 3 an overview of the current quantitative and qualitative results as well as their assessment methods is given.

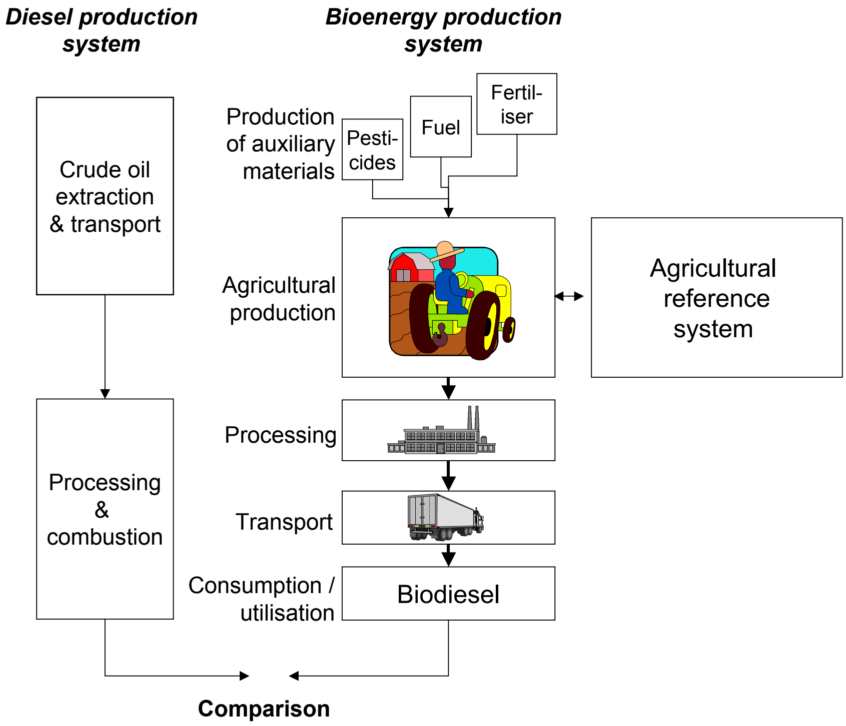


Figure 1: Comparative assessment of liquid biofuels versus fossil fuels

2. ENVIRONMENTAL IMPACT OF RME IN COMPARISON TO DIESEL OIL

This section gives an overview on the comparison of the environmental impacts of RME and those of diesel oil. For this purpose the complete life cycles of both fuels are compared against each other (see Fig. 1). For all fundamental methodological procedures, basic assumptions, parameters and environmental criteria under concern as well as data used we refer to the literature, especially /9/.

The detailed inventory of the life cycle assessment of RME is illustrated in Table 1 for finite energy, CO_2 equivalents, NO_x emissions and SO_2 equivalents. Basically all other balances are calculated in the same way. Firstly, the individual results for RME and diesel oil are calculated, then the ecological impact is assessed on balance. Negative values signalize results in favour of RME, positive values indicate results in favour of diesel oil. E.g. the energy balance shows the potential to reduce finite energy consumption by the substitution of diesel oil with RME. Note that the energy consumed is balanced with respect to savings in finite resources. Therefore in this assessment the energy bound as biomass is not considered. The same applies to CO_2 fixed in the energy plant because only that carbon is released that has been stored during the plant's growth. The comparison is based on the same amount of useful energy in both life cycles.

The results obtained can be categorised into the following groups:

Certain quantities

- can be precisely determined like the consumption of energy and mineral resources, the greenhouse effect (via CO_2 equivalents), the stratospheric ozone depletion (via N_2O – as there occur no relevant amounts of (H)CFCs in the life cycle) or the potential acidification,

- can be partly determined like the human and eco toxicity that can only be evaluated for some parameters, e.g. for SO_2 and NO_x,

- can be qualitatively analysed – mainly by risk analysis –, or,

- cannot be calculated – like noise or land use – because of lack of an accepted balancing method.

The results for all precisely determinable parameters are given in Table 2. The values are given for the standard assessment "Rape Seed Biodiesel versus Ordinary Diesel Oil" for a modern diesel car (EURO 4 norm). However, apart from quantitative parameters there are numerous others that can only be determined qualitatively. In particular you have to decide whether risks of accident or ecological damage by mishandling should also to be accepted in the balance. For a few cases there is no clear distinction possible even if the balancing criteria and the system's borders are precisely defined.

Life cycle step	Finite energy MJ/kg*	CO_2 equivalents g/kg*	NO_X g/kg*	SO_2 equivalents g/kg*
Plant production				
Harrowing	0,86	66	0,638	0,488
Ploughing	0,66	50	0,486	0,372
Sowing	0,33	25	0,263	0,200
Harvest	0,67	51	0,482	0,369
Seeds	0,01	2	0,004	0,017
N-fertilizer	7,19	1.124	2,303	4,216
P-fertilizer	0,95	64	0,235	0,598
K-fertilizer	0,31	20	0,034	0,032
Ca-fertilizer	0,04	6	0,010	0,009
Biocides	0,33	15	0,019	0,059
Field emissions	0,00	896	0,000	11,079
Sub-total	11,36	2.319	4,474	17,441
Provision				
Storage	1,36	98	0,066	0,186
Transport	0,42	32	0,417	0,313
Oil extraction	3,05	181	0,261	0,410
Hexane	0,16	2	0,003	0,007
Refinement	0,54	31	0,043	0,064
Fuller´s earth	0,02	1	0,008	0,011
Phosphoric acid	0,01	1	0,003	0,013
Esterification	2,44	143	0,191	0,303
Methanol	4,81	352	0,136	0,347
Soda lye	0,12	8	0,009	0,027
Glycerine synthesis	0,24	14	0,019	0,026
Sub-total	13,17	864	1,155	1,709
Energetic use				
Transport	0,22	17	0,158	0,12
Use	0,00	216	10,190	7,316
Sub-total	0,22	233	10,348	7,437
Credits RME				
Reference system	-0,83	-67	-0,616	-0,485
Soy bean meal (agric.)	-4,46	-318	-1,305	-1,485
Soy bean meal (transp.)	-2,03	-162	-1,263	-1,697
Glycerine energy	-10,30	-758	-1,015	-4,421
Chlorine	-4,01	-275	-0,293	-0,918
Soda lye	-2,68	-184	-0,197	-0,614
Propylene	-7,03	-188	-0,247	-0,751
Sub-total	-31,34	-1.952	-4,936	-10,371
Diesel oil				
Provision	4,82	374	0,649	1,825
Use	42,96	3.392	10,190	8,101
Sub-total	47,78	3.766	10,839	9,925
RME minus diesel oil	**-54,37**	**-2.303**	**0,200**	**6,291**

*: All values refer to 1 kg diesel oil respectively 1 kg diesel oil equivalents of RME, referred to the same amount of useful energy.

Table 1: Energetic expenditures (finite energy) and selected emissions (CO_2 equivalents, NO_x, SO_2 equivalents) for RME and diesel oil (9)

Environmental impact category	Parameters	Results	Further interpretation	Ecological relevance
Resource demand	Finite primary energy	-54,37 GJ/ha	+	high
	Limestone	113 kg/ha		
	Phosphate ore	201 kg/ha		
	Sulphur total	13,7 kg/ha		
	Potash ore	207 kg/ha		
	Sodium chloride	– 312 kg/ha		
	Clay	8,7 kg/ha		
Greenhouse effect	CO_2 equivalents	– 2,30 t/ha	+	very high
Ozone depletion	N_2O	4,91 kg/ha	+	high / very high
Acidification	SO_2 equivalents	6,29 kg/ha	+	medium
Eutrophication	N total	5,58 kg/ha	+	medium
Human and eco toxicity	NO_X	0,20 kg/ha	+	medium
	SO_2	– 6,49 kg/ha		
	CO	– 0,68 kg/ha		
	NMHC	0,19 kg/ha		
	Diesel particulates	-440 g/ha	+	high
	Dust	0,25 kg/ha		
	HCl	– 18 g/ha		
	NH_3	6,7 kg/ha		
	Formaldehyde	1,6 g/ha		
	Benzene	– 1,46 g/ha		
	Benzo(a)pyrene	– 144*10(-6) g/ha		
	Dioxines	-12,7*10(-9) g/ha		

Table 2**:** Quantitative results for the LCA "RME versus Ordinary Diesel Oil" including first assessment step and ecological relevance (9, 10)

Environmental impact category	Advantages for RME	Disadvantages for RME
Resource demand	Savings of finite energy carriers	Consumption of mineral resources
Greenhouse effect	lower emissions of greenhouse gases	
Stratospheric ozone depletion		more N_2O emissions
Acidification		higher acidification
Photo smog		higher ozone production potential
Eutrophication		higher NO_X emissions
		Risk: eutrophierung of surface waters
Human and eco toxicity	lower diesel particle emissions in urban areas	
	lower SO_2 emissions	
	less pollution of oceans due to exploration and transport of crude oil	Risk: pollution of surface waters by pesticides
	Risk: less pollution by oil spillage after an accident	Risk: pollution of ground water by nitrate
	Risk: less toxicity / better eco degradability	

Table 3: Ecological advantages and disadvantages of the substitution of diesel oil by RME (12)

For example, if the remnants of a pesticide are washed into the sewage this is clearly a mishandling of the pesticide. But what if after its application the weather unforeseeably changes and heavy rain starts?

Therefore it is at least to some extent justified to consider such risks in a life cycle assessment. A list of all quantitative and qualitative environmental impacts of the substitution of diesel by RME based on the topical knowledge is given in Table 3.

3. EVALUATION

How can the ecologically relevant parameters be evaluated once they are determined? The ecological advantages and disadvantages of RME compared to diesel fuel (see Tables 2 and 3) show the difficulties of an assessment of the two types of fuel. RME has a significantly better energy efficiency and less SO_2 emissions while diesel oil has a better NO_x and N_2O balance. Which do you prefer? There have been several suggestions for handling this problem so far, but meanwhile national and international committees for the standardisation of LCAs prefer models that integrate diverse quantifiable ecological parameters and a verbal, non-quantitative discussion of advantages and disadvantages into their final assessment. Such an evaluation method is discussed here for the comparative LCA "RME versus Ordinary Diesel Oil". In the first assessment step all parameters are selected that do **not** qualify for further consideration. The second step covers the final assessment of the remaining parameters.

First assessment step:

Parameters are excluded from the assessment for the following reasons:

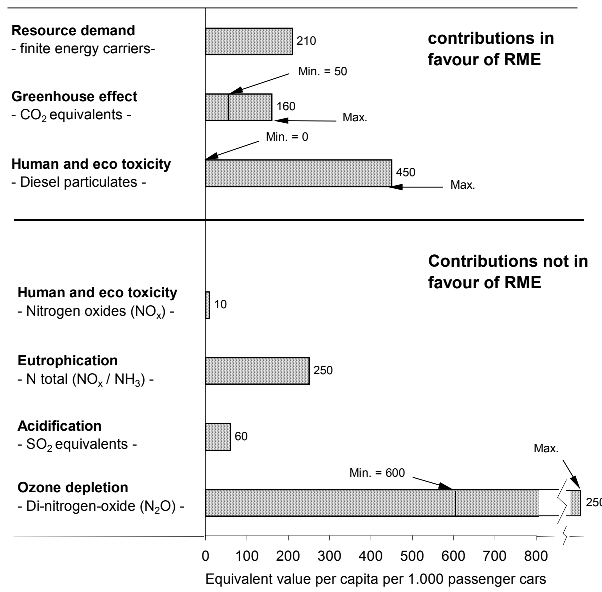
- The results are neutral, i.e. they show neither significant advantages nor disadvantages (as for formaldehyde).
- There is no significant ecological relevance of the respective parameter. E.g. neither CO nor SO_2 particularly affect the human health (however, SO_2 is assessed for its acidification potential).
- The results are not reliable due to an uncertain data basis or change sign due to the underlying uncertainties. This concerns TCDD equivalents and benzo(a)pyrene.

Parameters qualifying for the next assessment step are marked with "+" in the column "Further interpretation" in Table 2**.**

Final assessment step

The final assessment is made on a verbal, non-quantitative level and is based on the evaluation of the so-called "specific contributions" and the "ecological relevance" of the selected environmental impact categories. The procedure was proposed by the Umweltbundesamt (UBA), Berlin, and applied for the first time in 1995 to the "LCA on beverage containers" (13). Since then this assessment procedure has been applied – partly modified and partly updated – to other LCAs. It plays also an important role in the current discussion on international standardisation of LCAs.

Evaluation method: specific contributions



Examples how to read:

- 1.000 cars save as much energy as 210 inhabitants of Germany consume on average when RME is used instead of diesel oil.

- 1.000 cars emit as much additional SO_2 equivalents as 60 inhabitants of Germany on average when RME is used instead of diesel oil.

Figure 2: Specific contributions of the selected environmental impact categories (10)

The determination of the specific contributions is a means to measure the importance of the individual ecological advantages and disadvantages relative to the overall situation in Germany. The method is here applied directly to the values of the qualifying parameters in Table 2. For better graphical presentation the specific contributions in Fig. 2 refer to the so-called equivalent value per capita and to the average mileage of 1.000 passenger cars in Germany. However this shall not mask that the specific contributions listed here are just a normative means. The figures are rounded in order to avoid the pretence of too high accuracy. Nevertheless it can be stated that under the assumed system boundaries the results are reliable because non-reliable results have already been excluded in the first assessment step. Uncertainties which result from uncertain basis data and occur for agricultural N_2O emissions, CO_2 equivalents or diesel particulates are indicated in Fig. 2 by a minimum-maximum-assessment.

In the subsequent phase of the assessment the various ecological advantages and disadvantages are compared among each other. The verbal, non-quantitative discussion draws on the weightings of the different impact categories by the specific contributions and on their ecological relevance. The ecological relevance of the different impact categories is based on a list drawn up by the Umweltbundesamt (UBA) in 1995 and is extensively documented in (13). Only the category "ozone depletion" was not included. Given the public interest we consider the ecological importance of this impact category high to very high. Table 2 contains the respective evaluations of their significance for the parameters to be assessed. It is important to note that the listed evaluations cannot be scientifically objective by nature but are subject to change. Evaluations may vary within time, space or individual approach of the user. Yet at least for the time being they roughly represent the situation in Germany.

The specific contributions are combined with the ecological relevance of the environmental impact categories. Two of the three categories unequivocally in favour of RME are of high to very high ecological importance ("resource demand", "greenhouse effect"). Under certain circumstances this is also valid for the urban emissions of diesel particles as third category. On the contrary, two of the three categories clearly against RME – namely "eutrophication" and "acidification" – have a medium ecological relevance. Only for ozone depletion there is a high to very high ecological disadvantage for RME. Without this the overall assessment would clearly be in favour of RME.

There are a few uncertainties concerning the general assessment of the specific contribution of N_2O to the stratospheric ozone depletion. For in principle N_2O should be compared to the amounts as well as reactivities of CFCs, which also deplete ozone. Yet we do not know relevant data. Therefore we can only state qualitatively that the more CFCs are emitted, which is actually the case, the more the value of the specific contribution decreases – and in extreme cases comes close to zero. And with decreasing specific contribution the relative weight of this criterion to the overall assessment decreases also.

4. RME AND DIFFERENT AGRICULTURAL REFERENCE SYSTEMS

In the above assessment, the agricultural reference system that was used for the calculations was fallow set-aside land. The agricultural reference system defines what the land area on which the rape seed is be grown would be used for in the case of conventional diesel utilisation. This question is by no means trivial, but in the past it has received relatively little attention. The choice of the agricultural reference system can in certain circumstances have a significant impact on the result of a life cycle assessment. The reason for this is as follows: in an LCA that does not involve any – or little – land use, the manufacture of a certain product can be assessed directly and compared to an alternative scenario where the required resources (e. g. water or minerals) are saved. Where large areas of land are concerned though (as is the case in agriculture or forestry), this is not possible because the land area in question cannot be "saved" but is always occupied or utilised. It is necessary to define this alternative use, because for example there will most certainly be a difference in the environmental performance of an agricultural product depending on whether it is compared to a land use of fallow, or another crop, or a nature reserve. Furthermore, any change in land use has repercussions on land use practices elsewhere, as is demonstrated in the following examples (see Figure 3).

Here again RME is compared to conventional diesel with regard to a number of environmental categories. In the first example, the reference system used is set-aside fallow land as before. In the second example however a different scenario has been chosen: rape seed is grown instead of wheat in Germany. In order to ensure a fair and meaningful comparison between RME and diesel, it must then be defined where the "sacrificed" wheat would now come from. Otherwise the comparison would not be "RME vs. diesel" but "RME versus diesel plus wheat", which might distort the true result regarding the environmental impact of diesel substitution by RME. In example 2 it has therefore been assumed that the wheat is imported from the United States.

Following the same reasoning, it must now further be defined what the land there would be used for otherwise, and in this case, fallow land has been chosen. It is important to consider, however, that in this scenario the environmental impacts of the wheat transport from the USA to Europe would have to be included in the assessment. The last two examples follow the same principle, defining each "chain of land use changes" that must be followed to the end, where no economic commodity is produced anymore on the land in question. There may be an endless number of possible reference systems, which are all valid as long as they allow to compare "like with like", i. e. the same commodities. For a definition of the principles which the choice of a valid reference system has to consider see (14). In each of the above examples, the complete life cycle comparison between RME and diesel has been carried out, each time using a different agricultural reference system. The results indicate that indeed the reference system may have a significant influence on the quantitative outcome of the assessment (Figure 4). On the other hand the results show that in these examples no reversals of signs occur. Therefore the results can be regarded as fairly reliable with regard to the discussion in the previous chapter. This means that with respect to the actual comparison between RME and diesel the various possible reference systems only lead to quantitative differences.

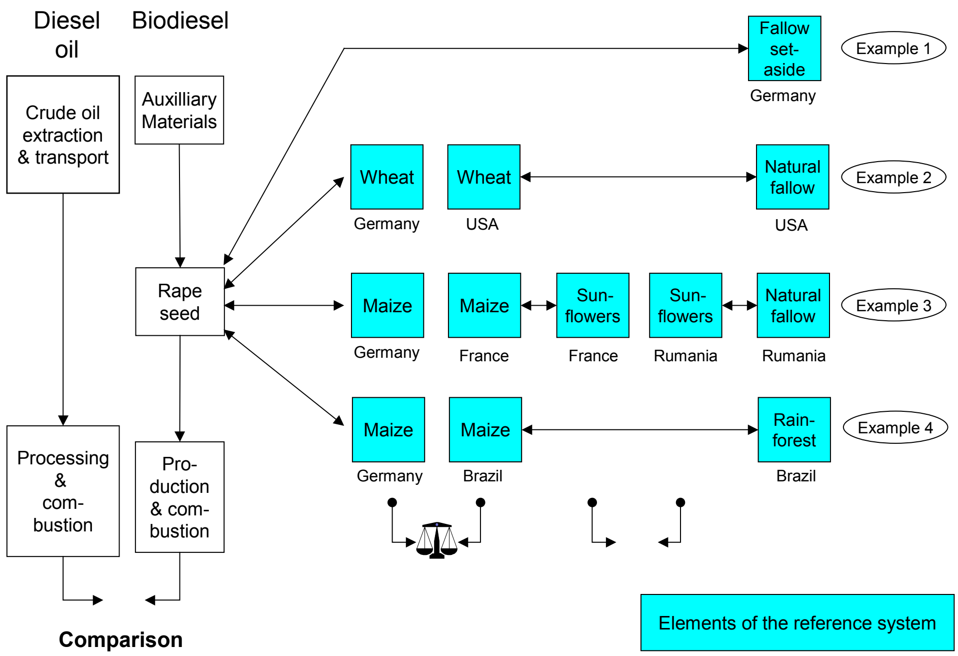


Figure 3: Four examples of different agricultural reference systems for the comparison RME vs. conventional diesel

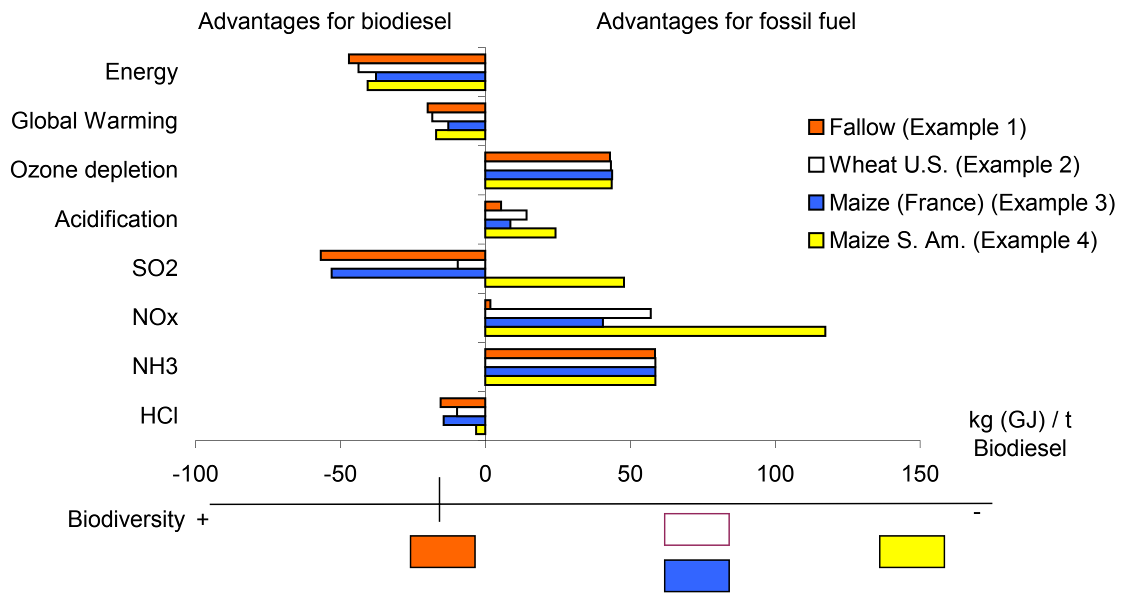


Figure 4: Results of the life cycle comparison RME vs. diesel taking into account four different agricultural reference systems (14)

It should be noted that these differences are almost entirely due to the transport of the respective goods, rather than the direct influences of agricultural production, since these are assumed to be proportional to the quantity of the products. An exception to this is the parameter biodiversity, which has here been assessed purely qualitatively, due to a current lack of standard assessment methodology. It is however self-evident that the relative environmental impact of rape seed production instead of cultivated fallow land is smaller than if rainforest has to be cleared as an indirect consequence for the same purpose. The impact of rape seed cultivation versus natural fallow land abroad has been considered to be somewhere in between these extremes.

5. RME with respect of use of land

In the past, the agricultural reference system used in the assessment of bioenergy carriers has been fallow set-aside land. This is mainly due to the fact that it is most economic for the farmer to produce energy crops on set-aside land in order to receive the subsidies defined within the General Agricultural Policy (GAP) for the purpose of curbing surplus food production. Thus at present, fallow set-aside land is indeed the most realistic reference system for bioenergy production within the EU, as no energy crops are likely to be cultivated on areas which would otherwise be used for food production. However, more recently the question has been raised whether it would not be more appropriate to use reference systems other than fallow land, particularly in the case of a possible future reduction of set-aside subsidies. Such alternatives might include for example nature reserves, or else an extensification of food production, such as the use of organic production methods. Therefore in the following examples three scenarios have been chosen which lead to three different land use comparisons. In each case, the same amount of energy and food are produced on an equal share of agricultural land, but the production methods differ:

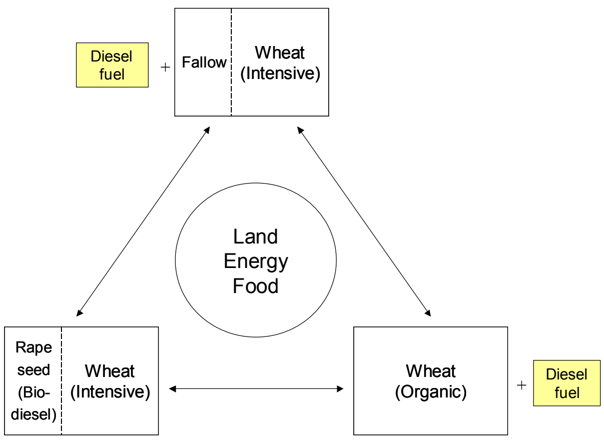


Figure 5: Three scenarios of food and energy production on the same amount of land, using different combinations of production methods

In the first case, the currently predominant situation in Europe is reflected, namely conventional food production with set-aside fallow land in order to reduce surplusses. The energy is obtained from fossil resources. In the second case (bottom left in Fig. 5) rape seed is produced on the set-aside area, rendering the use of fossil fuels unnecessary. In the third and final option, the whole land area is used for food production, but using organic production methods (achieving the same yields as the intensive production by using a larger amount of land). Again the energy is obtained from fossil resources as no surplus area is available for the production of energy crops. Thus here it is important to consider RME production within the larger context of land use questions. It may be added that it would also be possible to include the option of a nature reserve in such a comparison (e. g. instead of fallow land); however, as mentioned above, such a comparison is currently not possible using standardised quantitative assessment methods.

In Figure 6 the results of the various system comparisons are given, indicating that the context in which a certain production method is embedded may well inflence its relative environmental performance. In this case, each of the systems may be regarded as reference system to any of the other systems. The reasons for the differences in this case are slightly more complex than in the four examples given before. Thus for instance the system including organic production is superior to either of the others regarding most categories (except for energy and SO compared to the biofuel system) due to the saving of energy and emissions that result from industrial fertiliser use. The third comparison is incidentally the same as example 1 above, i. e. the "classical" RME assessment, since the intensive wheat production is cancelled out and what remains is the comparison RME vs. diesel with fallow land as agricultural reference system.

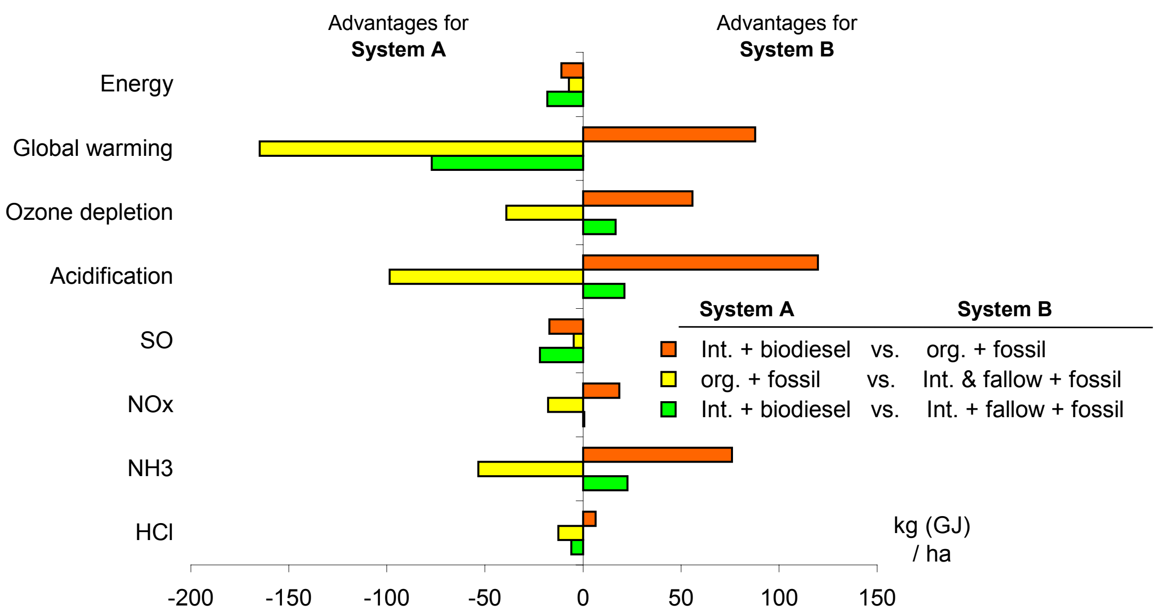


Figure 6: Results on different system comparisons

The interpretation of the results is somewhat more difficult than it initially appears, because none of the investigated systems is highly superior to the others. This means that either only one system comparison may be looked at (indicated by the double arrow in Figure 5) or else two system comparisons may in turn be compared to each other. This way one can for example clearly deduce from the results that the environmental performance of RME in comparison to conventional diesel is significantly more favourable in the context of intensive wheat production plus fallow land than in the case of organic farming.

If on the other hand these systems are considered in the light of the question whether agricultural land that is available at a given time should be used for biodiesel production or for organic wheat cultivation, the results show that with regard to all parameters apart from "resource demand" organic wheat production plus conventional diesel production is superior to biodiesel plus conventional wheat cultivation. Thus in this case there is a phenomenon which is rather atypical for LCA, namely that one option is better suited for the saving of energy resources and the other for the reduction of greenhouse gas emissions. So whether one form of land use is given preference over the other in this case depends strongly on the priorities of the decision maker. If for example one takes the position of the German Federal Agency of the Environment, which regards the reduction of the greenhouse effect as ecologically much more important than the saving of fossil resources, then in this case the decision would clearly be made in favour of organic wheat production, particularly since the results for all other parameters are also in its favour.

A further comparison, which however is not connected to RME, shows that organic wheat production is superior to conventional wheat production in all investigated environmental parameters.

6. CONCLUSION

The previously obtained results of comparative LCA regarding RME versus diesel are in essence still valid today. In particular, the different agricultural reference systems have merely quantitative influences on the results, i. e. there are no reversals of signs: the results suggest an overall final assessment in favour of RME. "Resource demand" and "greenhouse effect" – two environmental impact categories of high to very high ecological importance – are unequivocally in favour of RME. On the contrary, diesel oil obtains better results only in several categories of medium and in one category of high to very high "ecological relevance", that is in the category "ozone depletion". But problems to interprete the available data lead to uncertainties concerning the general assessment of the "specific contribution" of N_2O to the stratospheric ozone depletion. An overall final assessment in favour of RME can be justified. However this assessment is not inescapable. In particular when a precautionary environmental aproach is preferred the above argumentation can be reversed as long as there is interpretational ambiguity concerning N_2O.

The comparison RME versus diesel with regard to the question whether available land should rather be used for RME production or organic farming shows essentially similar features, but a detailled look reveals differences as well: here all investigated parameters show advantages for organic farming apart from "resource demand". Thus here again the choice of priorities of the decision maker is crucial. In the light of the currently prevailing political priorities though (Kyoto protocol etc.), the decision will in most cases be in favour of organic farming.

Finally, it is still necessary to mention that all evaluation models – including the present – cannot *a priori* be completely scientifically objective. The modells may produce different results if used at other times and/or by other users. This fact stringently requires the documentation of the complete evaluation process in order to allow a comprehensible review. The results cannot be generalized unrestrictedly. In the present case study different processes of rape seed production, provision and energetic use, or the development of optimized motor engines for the use of RME can lead to different assessments. Therefore any final assessment has to define explicitely the system boundaries. Additionally, assessments of individual ecological objectives are possible, e.g. if a water protection area is to be protected by the use of RME instead of diesel oil.

7. ACKNOWLEDGEMENT

The financial support of the Bundesministerium für Landwirtschaft, Ernährung und Forsten for the project on which the section regarding reference systems is based, is gratefully acknowledged.

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