ifeu -
Institute for Energy
and Environmental
Research Heidelberg

Screening Life Cycle Assessment of Hydrotreated Jatropha Oil

Final Report

By order of
Daimler AG, Stuttgart

Heidelberg, 12 December, 2008

Screening Life Cycle Assessment of Hydrotreated Jatropha Oil

By order of
Daimler AG, Stuttgart

Dipl.-Geoökol. Nils Rettenmaier

Dipl.-Landschaftsökol. Susanne Köppen

Dipl.-Phys. Ing. Sven Gärtner

Dr. Guido Reinhardt

ifeu – Institute for Energy and Environmental Research Heidelberg GmbH
Wilckensstraße 3, D-69120 Heidelberg
Tel.: +49 / (0)6221 / 4767-0; Fax: -19
E-mail: nils.rettenmaier@ifeu.de, Website: www.ifeu.de

Heidelberg, 12 December, 2008

Table of Contents

1 Introduction

Background

Great hopes are pinned on *Jatropha curcas*, also called physic nut: it is a plant producing oleiferous seeds, the oil of which can be used as a source of bioenergy. The fact that Jatropha can even be grown on degraded land in sub-humid to semi-arid climates makes it a very attractive crop in the context of current discussions on food and fuel competition.

In order to evaluate the environmental implications associated with the production and utilisation of Jatropha biodiesel, Daimler AG commissioned the ifeu - Institute for Energy and Environmental Research Heidelberg GmbH, Germany, to conduct a screening life cycle assessment (LCA) of Jatropha biodiesel in 2007. In the study, two utilisations of Jatropha oil have been assessed (see Fig. 1-1, middle and left side): the direct use as straight vegetable oil (SVO) and the use as transesterified vegetable oil, commonly referred to as biodiesel (JME, Jatropha oil methyl ester). In the transesterification process, the alcohol group of the triglyceride (vegetable oil) – being an ester compound itself – is exchanged with another alcohol, most commonly with methanol, thus forming methyl esters and glycerine.

In the last years, an alternative vegetable oil processing technique has been developed: catalytic hydrotreating (see Fig. 1-1, right side). Here, oxygen containing groups in the triglycerides – being the main constituents of vegetable oil – are reacted with hydrogen and removed as water and carbon dioxide. Each triglyceride is converted into three separate branched chain paraffins, also referred to as hydrotreated vegetable oil (HVO).

Although both products – JME and HVO (hydrotreated vegetable oil) – can replace conventional diesel fuel, the production processes and fuel qualities are substantially different. As HVO is expected to play an important role in the future expansion of biofuels, Daimler AG commissioned the IFEU-Institute to conduct a screening life cycle assessment for Jatropha HVO as a supplement to the existing screening life cycle assessment of Jatropha biodiesel. Results of this study will be compared to results concerning Jatropha biodiesel (JME).

Goal and scope

The goal of this screening life cycle assessment is to evaluate the environmental advantages and disadvantages of Jatropha HVO compared to conventional diesel fuel. Only a centralised Jatropha HVO production concept is analysed due to the fact that hydrotreatment can only be realised in large-scale plants, i. e. decentralised production – as implemented for Jatropha biodiesel (JME) production – will not be regarded.

The subgoals of this study are as follows:

- Analysis of different production and use systems of Jatropha HVO including different cultivation scenarios, different centralised conversion technologies, different use options for by-products and different geographical scopes
- Quantitative assessment of the environmental impact categories ‘energy resources’, ‘greenhouse effect’, ‘acidification’, ‘eutrophication’, ‘summer smog’ and ‘nitrous oxide’ of all systems investigated

- Identification of significant influences on the results along the whole production and use system, amongst others by assessing the influence of land use changes
- Comparison of selected quantitative results with the results from the Jatropha biodiesel study /Reinhardt et al. 2007/
- A summary of main conclusions and recommendations for optimisation possibilities as well as for future research needs

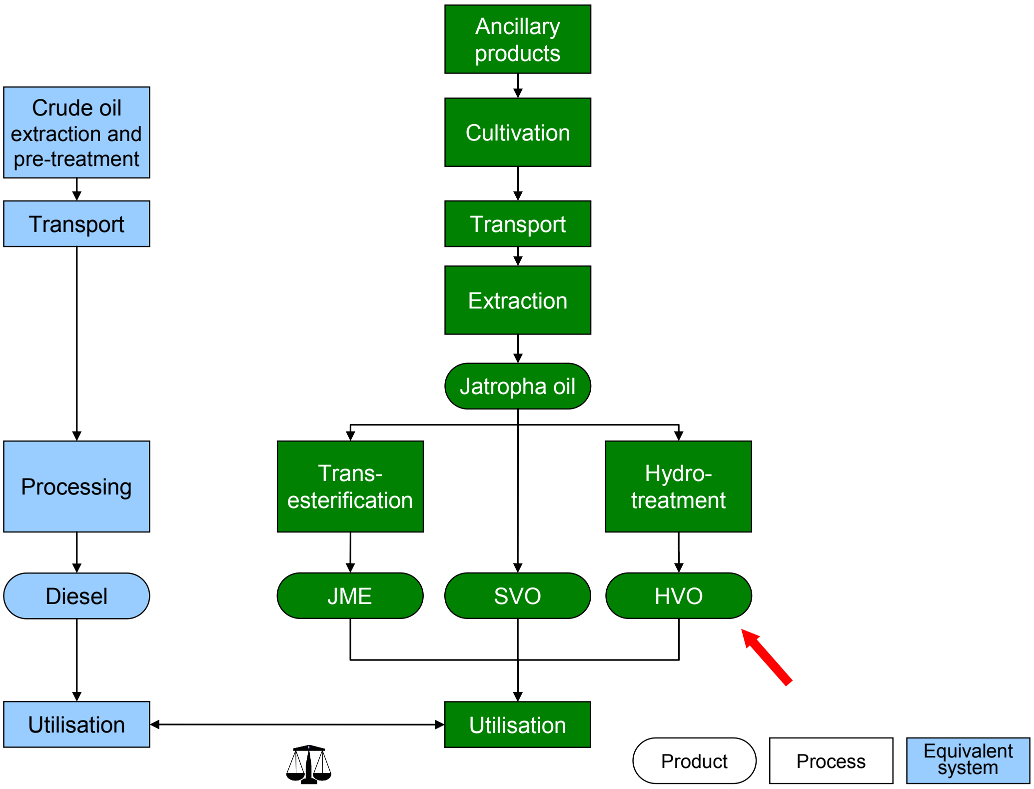


Fig. 1-1 Basic life cycle comparison between Jatropha biodiesel (JME), straight Jatropha oil (SVO), hydrotreated Jatropha oil (HVO) and conventional diesel fuel; arrow indicates life cycle regarded in this study

General approach

The goal of this study, an evaluation of environmental advantages and disadvantages of Jatropha HVO compared to conventional diesel fuel, is best achieved by means of a life cycle assessment (LCA). Therefore, this analysis is carried out according to LCA methodology, i. e. regarding the complete life cycle of Jatropha HVO – from Jatropha cultivation through biofuel production to its utilisation in a passenger car – compared to that of conventional diesel fuel.

Based upon this methodology, a number of variations and sensitivity analyses are calculated for all life cycle stages and unit processes, respectively, such as Jatropha cultivation or by-product utilisation. This serves the purpose of identifying those parameters which have the greatest influence on the overall outcome and of analysing their specific impacts on the results under different boundary conditions.

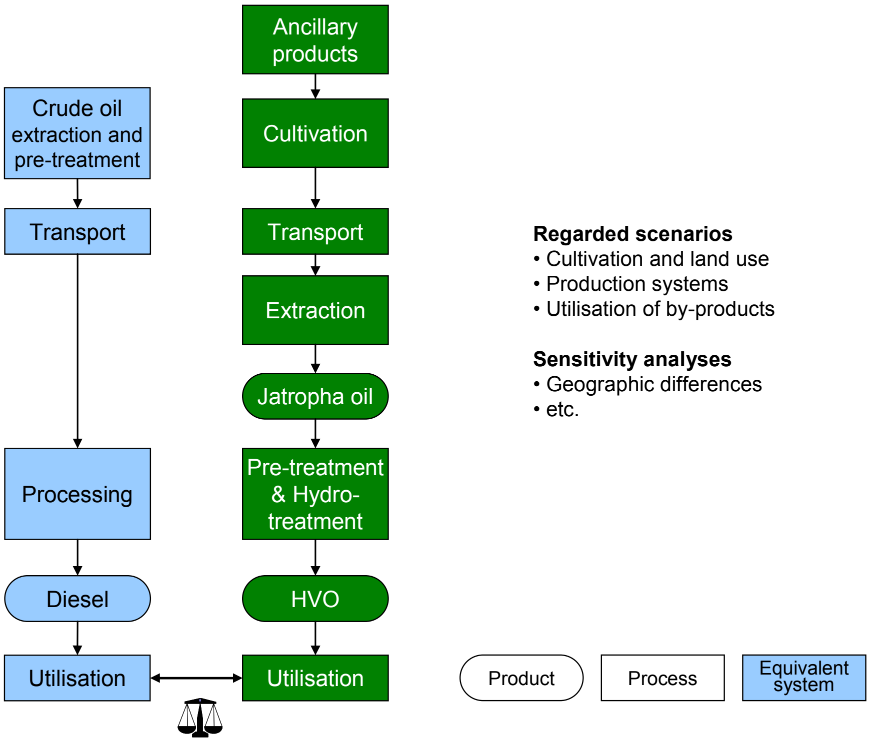
2 Methodology and specifications

This chapter describes the methodological framework as well as specifications which are applied in this study. Subsequently, the origin of the basic data used for the analyses is documented.

2.1 Methodology

The quantitative evaluation of environmental impacts of Jatropha HVO (hydrotreated vegetable oil) production systems is based on the methodology of a life cycle assessment (LCA). The principles of life cycle assessments of products are regulated by international standards /ISO 14040&14044/. The following aspects are covered in this study:

- All inputs and outputs along the product's entire life cycle from raw material acquisition through production to the utilisation of the product, i. e. a 'well-to-wheel' approach (see Fig. 2-1)
- Potential environmental impacts (e. g. greenhouse effect, acidification)



Regarded scenarios
- Cultivation and land use
- Production systems
- Utilisation of by-products

Sensitivity analyses
- Geographic differences
- etc.

Fig. 2-1 Basic principle of the life cycle comparison between Jatropha HVO and conventional diesel fuel featuring the production steps from 'well to wheel'

In order to quantify the influence of single parameters, a number of sensitivity analyses are calculated. They provide a basis for analysing specific impacts of certain parameters on the results and help to identify optimisation potentials.

2.2 General specifications for this study

This screening LCA closely follows the international standards /ISO 14040&14044/. The scope definition required by these guidelines includes the following main items:

- Functional unit: Depending on the questions to be answered, different functional units might be necessary. As most questions relate to land use efficiency, the potential use of Jatropha fruits from 1 ha of land is assessed. Therefore, most results are referred to this unit.
- Geographic and time-related coverage: The production and use of Jatropha biofuels is related to current Indian conditions except for some sensitivity analyses, in which the transferability to other regions is investigated. For processes taking place in other parts of the world or in other countries, the geographic scope is enlarged accordingly.
- System boundaries: Generally, allocation is avoided by expanding the system boundaries (see /Borken et al. 1999/ for details). In accordance with LCA methodology alternative land use issues are included as described in /Jungk & Reinhardt 2000/.
- Depth of balances: All system inputs and outputs are taken into account, except for the manufacturing of processing equipment, vehicles and infrastructure.

2.3 Data sources

The data used in the life cycle assessment can be divided into several categories:

- Data on the upstream process of ancillary products such as fertilisers, transport fuels as well as on conventional energy carriers (natural gas, power mixes etc.)
- Data on the cultivation of *Jatropha curcas* and the conversion of its fruits to Jatropha oil
- Hydrotreatment of Jatropha oil to HVO and its use as transport fuel

The first data are taken from IFEU's internal database /IFEU 2008/ (continuously updated). Where necessary, they were adapted to Indian state-of-the-art conditions.

Data on inputs and outputs at each life cycle stage from cultivation to conversion to Jatropha oil have been compiled and published in a joint report /Reinhardt et al. 2008/. Additional aspects and specification can be found in /Reinhardt et al. 2007/.

Data on the hydrotreatment of Jatropha oil are taken from the IFEU internal database /IFEU 2008/ and conformed to Indian state-of-the-art conditions.

Data on the use of Jatropha HVO as transport fuel are based on /Degen 2008/.

2.4 Environmental impact categories

In this study, seven environmental impact categories will be analysed (Table 2-1). This selection follows the environmental impacts usually regarded in LCA practice. Further details such as indicators, life cycle inventory parameters and characterisation factors are listed in Table 2-2. Note that the characterisation factor of NMHC and CH_4 for the environmental impact category 'summer smog' (POCP) has been changed compared to /Reinhardt et al. 2007/ due to better scientific evidence /CML 2004/.

Table 2-1 Environmental impact categories evaluated in this study

Environmental impact category	**Description**
Quantitative assessment	
Energy resources	Use of non-renewable primary energy sources, i. e. fossil fuels such as crude oil, natural gas and different types of coal as well as uranium ore.
Greenhouse effect	Global warming as a consequence of the anthropogenic release of greenhouse gases. Besides carbon dioxide (CO_2) originating from the combustion of fossil energy carriers, a number of other trace gases – among them methane (CH_4) and nitrous oxide (N_2O) – are included.
Acidification	Shift of the acid/base equilibrium in soils and water bodies by acid forming gases (keyword 'acid rain'). Emissions of sulphur dioxide, nitrogen oxides, ammonia, and hydrogen chloride are recorded.
Eutrophication	Input of nutrients into soils and water bodies (keyword 'algal bloom'). Nitrogen oxides and ammonia are recorded.
Summer smog	Formation of specific reactive substances, e. g. ozone, in presence of solar radiation in the lower atmosphere (keyword 'ozone alert'). Two category indicators are available: POCP (Photochemical Ozone Creation Potential) and NcPOCP (Nitrogen-corrected POCP). Hydrocarbons are recorded for both POCP and NcPOCP, whereas nitrogen oxides are only recorded for NcPOCP. For discussion of both parameters see /Reinhardt et al. 2007/.
Nitrous oxide (Ozone depletion)	Loss of the protective ozone layer in the stratosphere through certain gases such as chlorofluorocarbons (CFCs) or nitrous oxide (keyword 'ozone hole'). As only nitrous oxide is recorded in this study, this impact category is termed 'nitrous oxide' instead of 'ozone depletion'.
Semi-quantitative to qualitative assessment	
Land use	Change of an area's quality, e. g. in terms of biodiversity or soil ecological functions (biological, physical and / or chemical properties) as a consequence of its use (keywords 'land use change' and 'land cover change'). As the LCA methodology regarding this environmental impact category still is under development, only changes in carbon stock – which in turn have an impact on greenhouse effect (see above) – are recorded in this study.

/IFEU 2008/

Table 2-2 Indicators, life cycle inventory parameters and characterisation factors for the regarded environmental impact categories

Environmental impact category	Category indicator	Life cycle inventory parameter	Formula	Character. factor
Energy resources	Cumulative energy demand from non-renewable sources	Crude oil	—	—
		Natural gas		
		Hard coal		
		Lignite		
		Uranium ore		
Greenhouse effect	CO_2 equivalent (carbon dioxide equivalent)	Carbon dioxide fossil	CO_2	1
		Nitrous oxide	N_2O	298
		Methane fossil *	CH_4	27.74
		Methane biogenous	CH_4	25
Acidification	SO_2 equivalents (sulphur dioxide equivalent)	Sulphur dioxide	SO_2	1
		Nitrogen oxides	NO_X	0.7
		Ammonia	NH_3	1.88
		Hydrochloric acid	HCl	0.88
Eutrophication	PO_4 equivalents (phosphate equivalent)	Nitrogen oxides	NO_X	0.13
		Ammonia	NH_3	0.346
Summer smog (POCP)	C_2H_4 equivalents (ethylene equivalents)	Non-methane hydrocarbons	NMHC	1
		Methane	CH_4	0.006
Summer smog (NcPOCP)	Nitrogen-corrected C_2H_4 equivalents (ethylene equivalents)	Non-methane hydrocarbons	NMHC	—
		Methane	CH_4	—
		Nitrogen oxides	NO_X	—
Ozone depletion	—	Nitrous oxide (Dinitrogen oxide)	N_2O	—

* including CO_2 effect after CH_4 oxidation in the atmosphere /IFEU 2008/

Land use change, carbon stocks and greenhouse gas emissions

Land use changes occur either if an area is transformed from one land use category to another, e. g. from forest land to cropland, or if the type of cultivated crop changes, e. g. from perennial to annual crops. Two types of land use changes (LUC) are distinguished: direct LUC and indirect LUC. The first one refers to a situation in which the establishment of a plantation involves the clearing of natural vegetation, e. g. a shrubland. The second one occurs if a plantation displaces an existing agricultural use of the area to another area which then could be subject to direct land use change. In this study, only the production on degraded land not used for agriculture will be regarded. Therefore, indirect LUC is excluded.

Land use changes mostly induce changes in the area’s quality, e. g. in terms of carbon stored in both vegetation (above- and below-ground) an in soil. If this carbon is released to the atmosphere through forest clearing and/or cultivation practices, the greenhouse gas balance of the cultivated crop is influenced negatively. If on the other hand carbon-poor sites are planted with Jatropha and a net carbon sequestration is taking place, the greenhouse gas balance is improving.

3 Basic scenarios and sensitivity analyses

As stated in chapter 2, the environmental advantages and disadvantages of Jatropha HVO compared to conventional diesel fuel are evaluated by means of so-called 'life cycle comparisons'. Hereby, all Jatropha products and by-products are offset against the conventional products they substitute for. In the following subchapters, the detailed setup of the life cycle comparisons conducted in this study is described. The basic life cycle comparison and several variants regarding most relevant life cycle stages are presented in chapter 3.1. After, chapter 3.2 gives an overview of all sensitivity analyses conducted.

All steps from cultivation to Jatropha oil extraction are similar to the production of Jatropha biodiesel (JME). As this use option already has been described in detail in /Reinhardt et al. 2007/, in the following, only processes and specifications differing from the Jatropha biodiesel production will be described.

3.1 Basic scenarios and variations

In the following chapter (chapter 3.1.1), the basic life cycle comparison of Jatropha HVO is presented. Due to a large number of possible scenarios, options and variants, the main life cycle stages cultivation (chapter 3.1.2), land use change (chapter 3.1.3), conversion (chapter 3.1.4) and utilisation of by-products (chapter 3.1.5) are described separately before being merged in a synthesis (chapter 3.1.6).

3.1.1 Basic life cycle comparison

For the evaluation of the environmental advantages and disadvantages of Jatropha HVO compared to conventional diesel fuel, a schematic life cycle comparison has already been established in chapter 2 (Fig. 2-1). For simplification, the various by-products which emerge along the life cycle were not depicted. Fig. 3-1 illustrates the detailed basic life cycle comparison of Jatropha HVO and shows possible conventional products substituted by the by-products.

The scheme only represents one possible configuration of cultivation and conversion. More scenarios, options and variations are presented in the following subchapters (3.1.2 to 3.1.5).

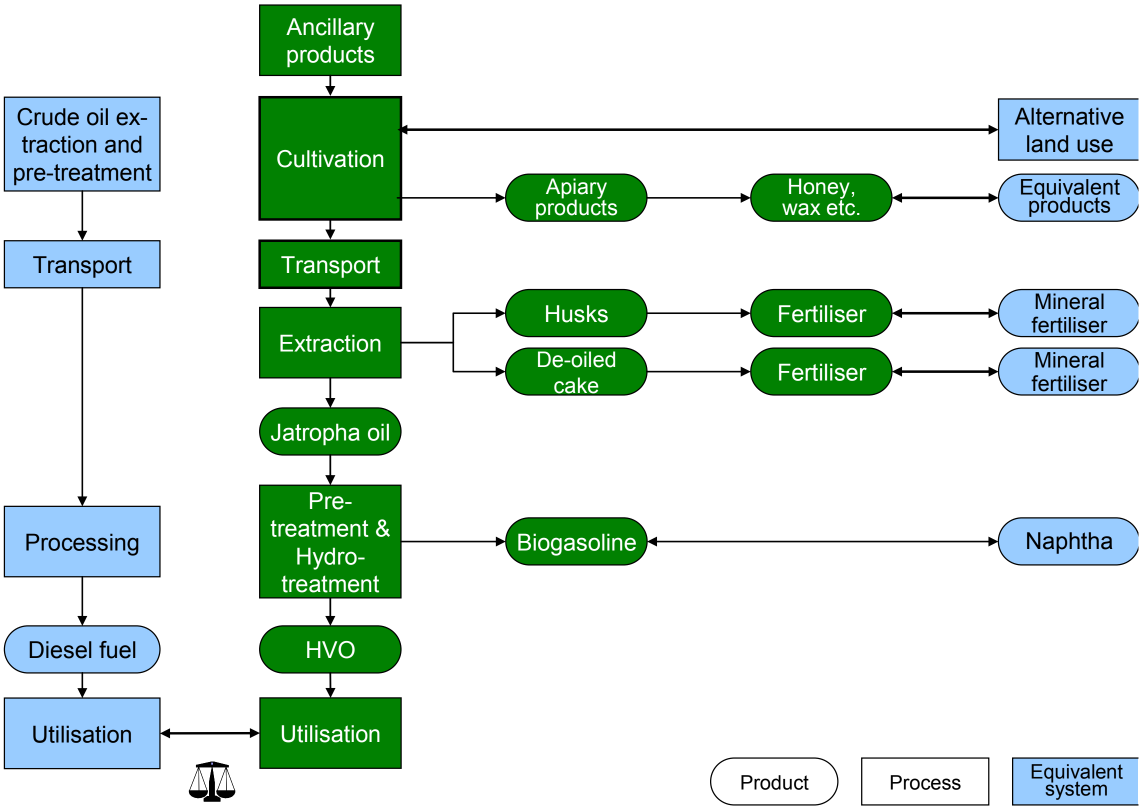


Fig. 3-1 Basic comparison between the life cycles of conventional diesel fuel and Jatropha HVO

Jatropha cultivation and extraction of Jatropha oil for HVO production are the same as for the production of Jatropha biodiesel. For a detailed description of these steps, see /Reinhardt et al. 2007/. For the production of HVO, the extracted Jatropha oil is not transesterified but hydrotreated after a pre-treatment. Hydrotreatment involves that oxygen containing groups in the triglycerides – being the main constituents of vegetable oil – are reacted with hydrogen and removed as water and carbon dioxide. Each triglyceride is converted into three separate branched chain paraffins, also referred to as hydrotreated vegetable oil (HVO). During the process, sludge, propane and biogasoline are obtained as by-products. Sludge and propane are used internally for process steam production whereas biogasoline replaces fossil naphtha. In contrast, in the transesterification process, the alcohol groups of the triglycerides are exchanged with another alcohol, most commonly with methanol, thus forming methyl esters and glycerine.

The fuel resulting from hydrotreatment is a synthetic hydrocarbon fuel which can replace conventional diesel fuel. It has a superior emission profile when compared to either conventional diesel fuel or JME. As no oxygen is left, NO_X emissions are reduced. In contrast, Jatropha biodiesel shows higher levels of NO_X compared to conventional diesel fuel. This is due the fact that the transesterified Jatropha oil still contains oxygen. The influence of these differences in emission profiles on the outcome of the life cycle assessment is analysed with a sensitivity analysis (see chapter 3.2.2 and 4.3).

3.1.2 Variation: Cultivation

Despite considerable breeding efforts in the past, the yield of *Jatropha curcas* is still quite variable. Moreover, the full potential of Jatropha is believed to be much higher than current yields suggest; improved agronomic practices and better plant breeds could possibly lead to increased yields.

In order to capture the current status as well as possible future developments, three yield classes are regarded in this study (see Table 3-1). The first scenario, named ‘Today’, reflects the current yields of Jatropha. The second scenario (‘Optimised’) assumes higher yields due to future optimisations of agronomic practice. The ‘Best’ scenario is even more optimistic: it assumes a yet increased yield based on further agronomic improvements and especially breeds with a higher seed-to-husk ratio. Please note that the yields refer to the cultivation of Jatropha under marginal growing conditions on degraded land. In order to avoid competition with food production, in this study, only the cultivation on degraded land will be regarded.

In this study, the current yield (‘Today’) is taken as a basis.

Table 3-1 Average yields of Jatropha fruits, seeds and oil

Cultivation scenario	Yield fruits [kg / (ha*yr)]	Yield seeds [kg / (ha*yr)]	Yield oil [kg / (ha*yr)]
Today	2,270	1,418	402
Optimised	3,811	2,382	676
Best	6,572	4,436	1381

/Reinhardt et al. 2007/

More detailed information such as data on cultivation inputs in the different scenarios can be found in /Reinhardt et al. 2007/ and /Reinhardt et al. 2008/.

3.1.3 Variation: Alternative land use

When a comparison is being made between bioenergy and a fossil energy carrier, it is always necessary to define an alternative way in which the required land might be used if not for the production of bioenergy or – in case natural vegetation is converted – what kind of alternative land cover would exist. Any environmental assessment of a bioenergy production system must take into account such alternative land uses, which are also referred to as the (agricultural) reference systems /Jungk & Reinhardt 2000/. The Jatropha plant is well adapted to the marginal growing conditions on degraded land which makes it an ideal crop to avoid both further land degradation and competition with food production. In order to capture this advantage, in this study the reference systems defined exclude all agricultural land uses. Only the production on degraded land not used for agriculture as well as the production in plantations replacing natural ecosystems will be regarded.

Nevertheless, any land use change, even from degraded land to Jatropha cultivation, influences an area’s quality (see Table 2-1). Land use change can be either direct or indirect. The latter occurs on arable land if the cultivation of a (bioenergy) crop displaces existing crop productions to other areas causing land use changes at that very area. In this study, Jatropha cultivation on arable land is excluded, therefore, no indirect land use change can occur.

Land use change influences the carbon stock of an area and therefore the greenhouse gas balance of the cultivated crop. In this study, three possible developments are regarded for Jatropha cultivation: a net carbon loss, no change in the carbon stock or, presumably, a net carbon gain. Table 3-2 gives an overview on the respective carbon stock changes. The derivation of carbon stocks in the replaced vegetation and in Jatropha plantations can be found in /Reinhardt et al. 2008/. For this study, a depreciation period of 20 years was selected which corresponds to a Jatropha plantation's productive life span.

In the basic scenarios, scarce vegetation and therefore no carbon stock change is assumed. In this way, carbon changes do not influence the greenhouse gas balances and changes due to other parameters become visible.

Table 3-2 Carbon stock changes for different land use scenarios

Alternative land use	Carbon stock of natural vegetation [t C / ha]	Carbon stock of Jatropha plantation [t C / ha]	Carbon stock change [t C / ha]
No vegetation	0	5	+ 5
Scarce vegetation	5	5	± 0
Medium vegetation	25	5	- 20

/Reinhardt et al. 2008/

3.1.4 Variation: Production systems

In contrast to the screening life cycle assessment of Jatropha biodiesel, in this study only a centralised Jatropha extraction and processing is assessed. As hydrotreatment can only be realised in large-scale plants, a decentralised processing of Jatropha oil would not be realistic. For the centralised processing, two variants are regarded. Either the Jatropha seeds can be extracted directly after dehusking or they can be decorticated prior to pressing. In the latter case, kernel and shells are obtained from the Jatropha seeds. In contrast to the de-oiled cake, the protein-rich meal could – after detoxification – be used as animal feed replacing soy meal. Fig. 3-2 shows both centralised variants depicting one possible use of the by-products. For further details on the use options of the by-products see chapter 3.1.5.

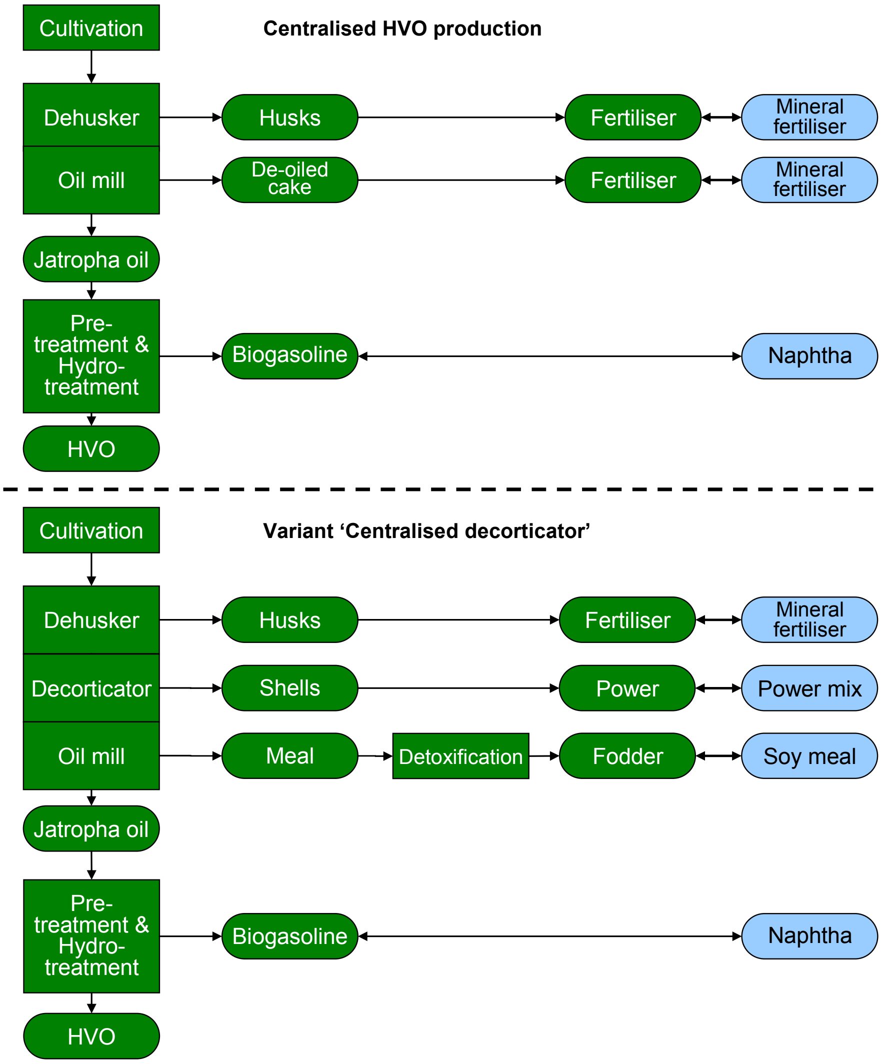
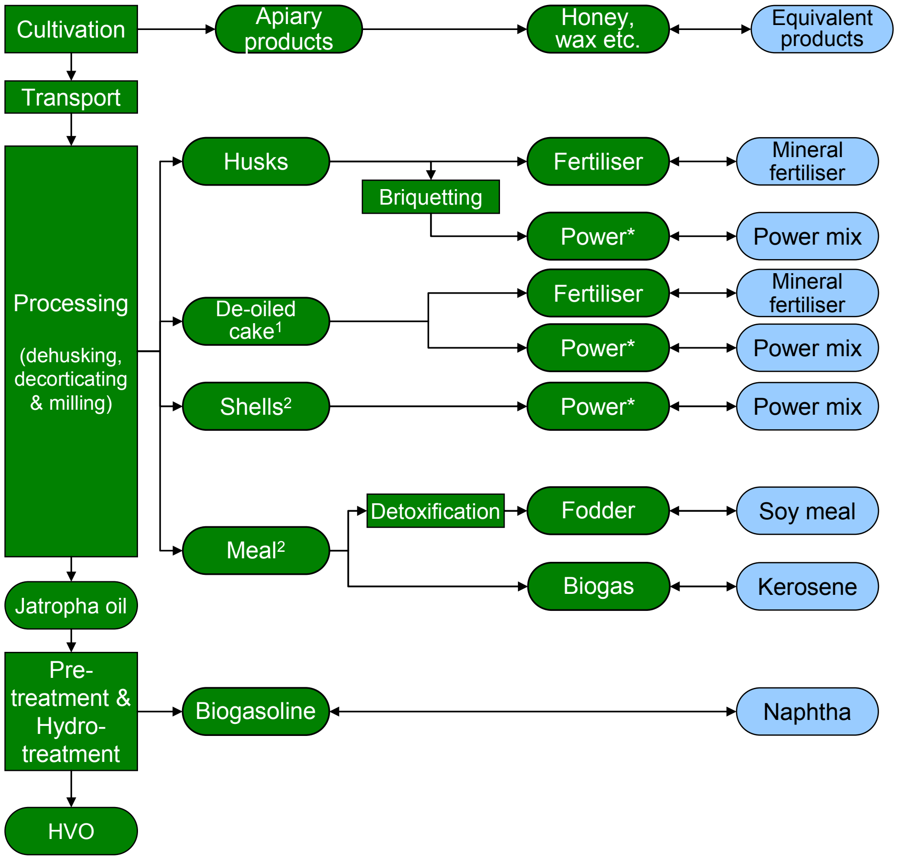


Fig. 3-2 Basic steps of centralised Jatropha HVO production and a variant – possible uses of the by-products and their equivalents (rightmost column) are exemplified for one option

3.1.5 Variation: Utilisation of by-products

Along the life cycle of Jatropha HVO, about 80% (by weight) of the Jatropha fruits emerge as by-products which can be used in multiple ways. Fig. 3-3 gives an overview of the by-products and their respective uses regarded in this study.

In total, six different combinations of by-product utilisations will be assessed. Compared to the screening life cycle assessment of Jatropha biodiesel, fewer scenarios are regarded. In this study, only most important use options will be analysed in order to show the most relevant results and correlations. For further use options, see /Reinhardt et al 2007/.



* surplus power; [1,2] production-specific by-products: [1] Centralised, [2] Centralised decorticator

Fig. 3-3 Utilisation of by-products from Jatropha cultivation and processing regarded in this study and their conventional equivalents (rightmost column)

Table 3-3 summarises all by-product use combinations assessed in this study. The basic scenario is marked with italic text and an asterisk.

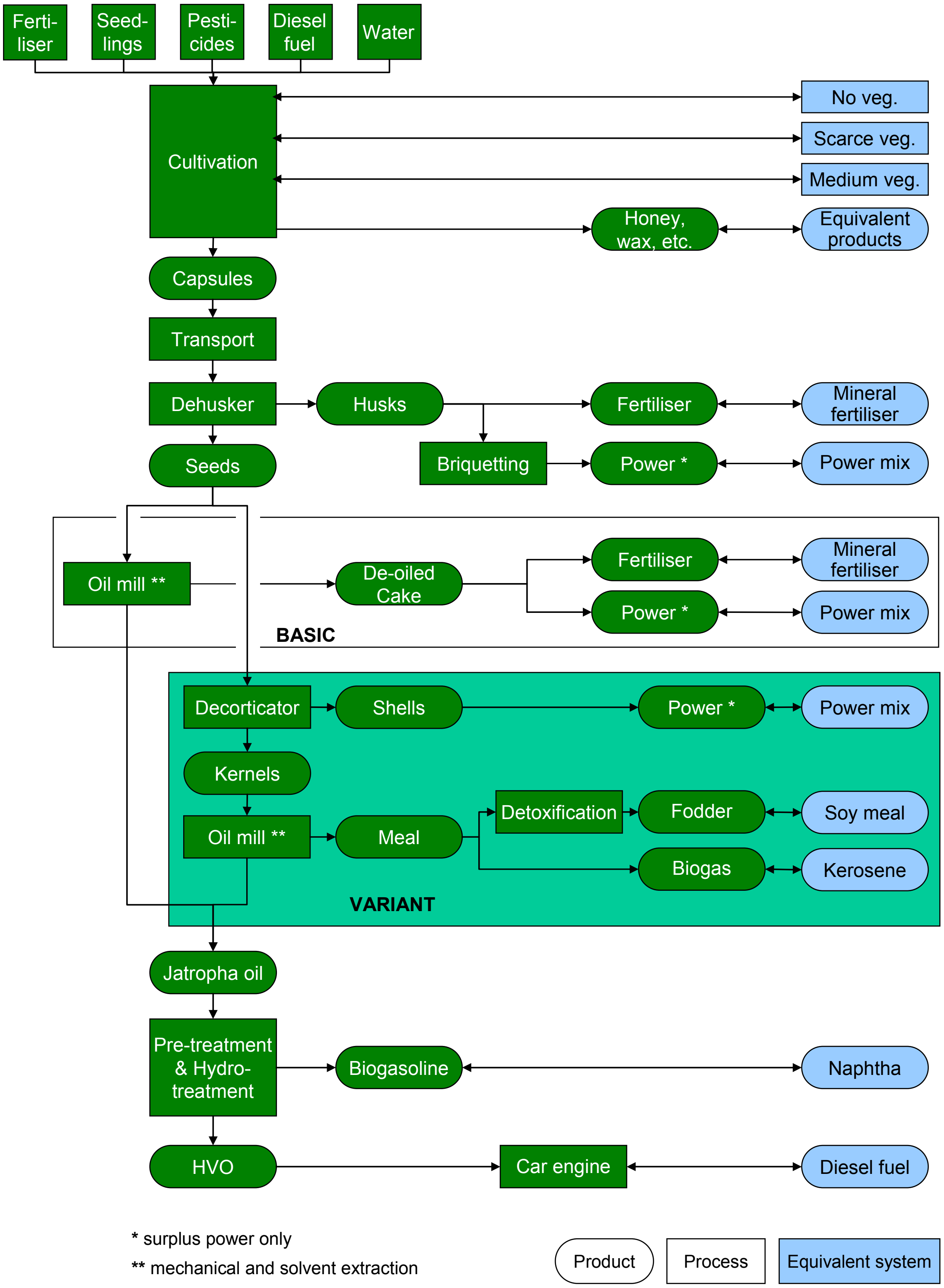
Table 3-3 Overview on the different by-product use combinations regarded in this study

	Scenario	**Husks**	**De-oiled cake**	
Without decorti-cating	*Fertiliser / fertiliser**	*Fertiliser*	*Fertiliser*	
	Fertiliser / power	Fertiliser	Power	
	Power / fertiliser	Power	Fertiliser	
	Power / power	Power	Power	
	Scenario	**Husks**	**Meal**	**Shells**
With decorti-cating	Fertiliser / fodder + power	Fertiliser	Fodder	Power
	Power / biogas + power	Power	Biogas	Power

* basic scenario /IFEU 2008/

3.1.6 Synthesis of all main scenarios

Fig. 3-4 shows all scenarios and variants regarded in this study. It depicts the complete life cycle comparison including all Jatropha HVO life cycle stages 'from well to wheel'. Accordingly, the life cycle includes the by-products generated from these production paths which can be used in different ways and represent added values.



* surplus power only

** mechanical and solvent extraction

Fig. 3-4 Schematic life cycle comparison of Jatropha HVO from centralised production, including different reference systems, cultivation and production scenarios as well as a number of alternative utilisations of by-products

3.2 Sensitivity analyses

In addition to the topics discussed so far, other factors may influence the environmental performance of Jatropha HVO. These factors are discussed in the following. The results regarding their relevance for the balances are presented in the result chapter (chapter 4.2).

3.2.1 Jatropha HVO production and use in Europe

Besides producing and using Jatropha HVO in India, the extracted Jatropha oil could also be transported to Europe and processed and used under European conditions. With doing so, several parameters would change. First of all, expenditures for the transport to Europe would have to be added. Further changes compared to Indian conditions are the composition of the power mix used in the hydrotreatment process and the sulphur content of conventional diesel fuel replaced. Table 3-4 shows the relevant changes assumed in this study.

Table 3-4 Differences between Jatropha HVO production and use in India and in Europe

	Energy input		**Energy output**	
Country	**Ocean transport**	**Power mix**	**Power mix**	**Sulphur content of substit. diesel fuel**
India	n.a.	Indian mix	Marginal mix: 80 % hard coal, 20 % natural gas	500 ppm
Europe	7000 nautical miles	UCTE mix	n.a.	10 ppm

/IFEU 2008/

3.2.2 Emissions due to Jatropha HVO use

The use of Jatropha HVO as transport fuel leads to emissions which usually differ from those related to the use of conventional diesel fuel. Default emission reductions due to the use of Jatropha HVO are displayed in Table 3-5. In the sensitivity analysis, emissions are set equal to conventional diesel fuel.

Table 3-5 Overview on Jatropha HVO related emissions compared to conventional diesel fuel

	Emissions due to Jatropha HVO use (compared to conventional diesel fuel)			
Scenario	**CO**	**HC**	**NO_X**	**PM**
Default	- 50 %	- 50 %	-10 %	- 10 %
Sensitivity analysis	± 0 %	± 0 %	± 0 %	± 0 %

/IFEU 2008/ based on /Degen 2008/

4 Results

In the following, the results of the life cycle comparison between Jatropha HVO and conventional diesel fuel are presented. The most decisive aspects along the life cycle are highlighted for different scenarios and further investigated by means of sensitivity analyses. Selected results will finally be compared to results of Jatropha biodiesel (JME).

4.1 Basic scenarios and variations

4.1.1 Basic life cycle comparison

The life cycle comparison between Jatropha HVO and conventional diesel fuel is exemplified for the basic scenario – the centralised processing of Jatropha oil with by-products used as fertiliser (see chapter 3.1 for details). Fig. 4-1 illustrates the results of the life cycle comparison between Jatropha HVO and conventional diesel fuel for different environmental impact categories.

Results

- Greenhouse gas and energy balances both show advantageous results, which means that the use of Jatropha HVO replacing conventional diesel fuel leads to savings in greenhouse gases and fossil energy resources.
- In contrast, the environmental categories ‘acidification’, ’eutrophication’ and ’nitrous oxide’ show disadvantageous results compared to the production and use of conventional diesel fuel. This is mainly due to emissions occurring during Jatropha cultivation (e. g. N_2O) and during the combustion of fossil energy carriers for process energy production required in the conversion steps (e. g. NO_X, SO_2).
- The ‘summer smog’ balances have been calculated with two different methods (see Table 2-1 and /Reinhardt et al. 2007/). Here, both parameters show advantageous results. With different combinations of by-product utilisation, however, the results for NcPOCP can show disadvantageous results while POCP shows advantageous results. Due to these significantly differing results – pointing at a major influence of NO_X – it is not possible to come to a final conclusion regarding this environmental impact category.
- The contribution of single production steps to the results differ between the environmental impact categories. For example, ammonia field emissions during cultivation strongly influence acidification but have no influence on the energy balance.

Conclusions

The outcomes of the comparison between Jatropha HVO and conventional diesel fuel show both advantages and disadvantages for the biofuel. Based on these findings, an objective overall valuation is impossible. Instead, this decision has to be based on subjective criteria.

If, for example, saving energy and greenhouse gases is given the highest environmental priority, then Jatropha HVO can be judged superior to conventional diesel fuel.

The results show the same pattern as many bioenergy systems: advantages regarding ‘energy resources’ and ‘greenhouse effect’, disadvantages regarding ‘acidification’, ‘eutrophication’ and ‘nitrous oxide’. Therefore, in the following chapters, results will primarily be exemplified for the greenhouse gas balances.

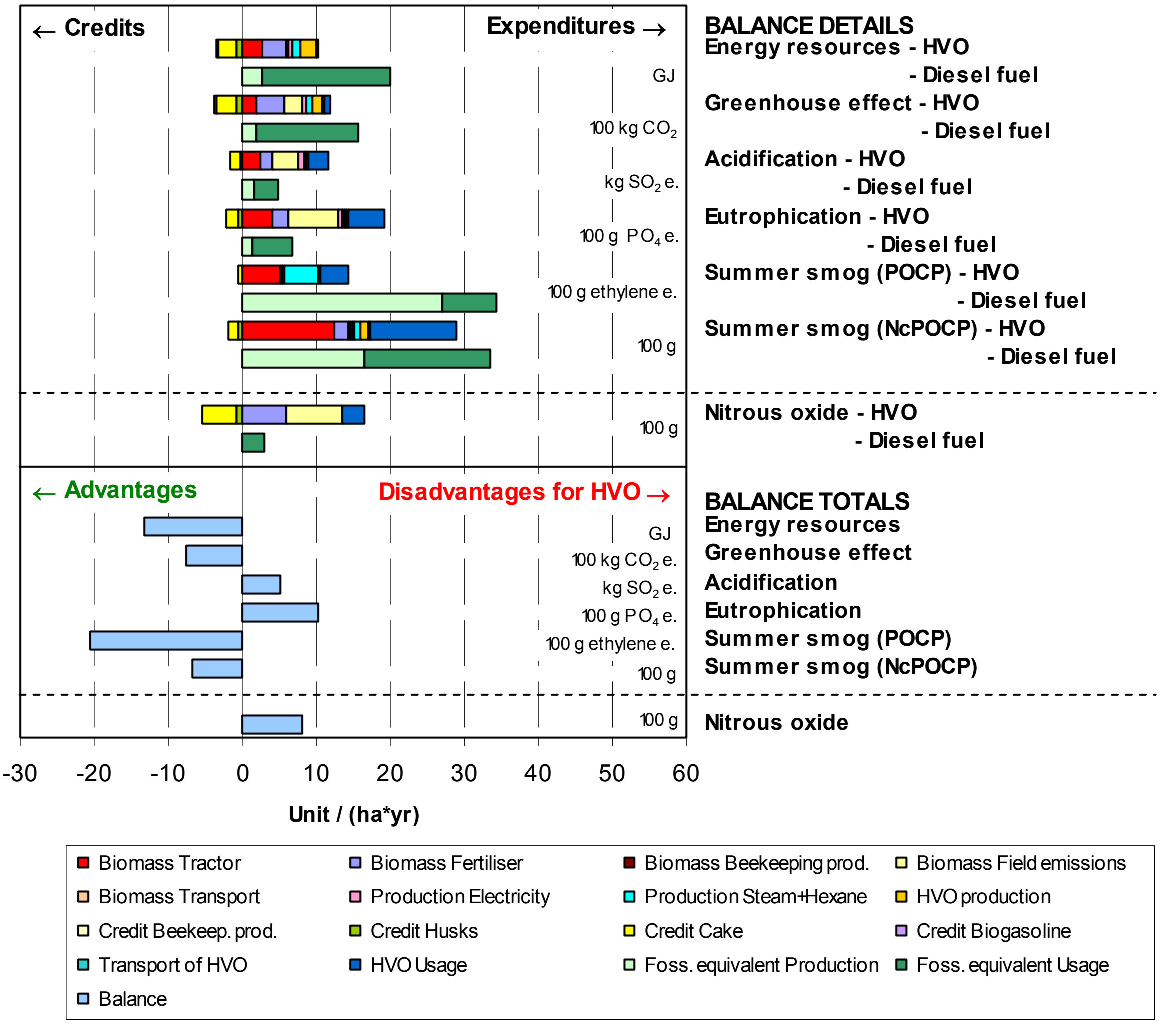


Fig. 4-1 Results of the life cycle comparison between Jatropha HVO produced in a centralised plant and conventional diesel fuel. Upper part: detailed expenditures and credits. Lower part: resulting advantages and disadvantages for Jatropha HVO

Reading the diagram (Exemplification)

The 1st bar shows expenditures of 10 GJ / (ha*yr) and credits of 3.4 GJ / (ha*yr) along the life cycle of Jatropha HVO. The 2nd bar shows the corresponding expenditures for the production of conventional diesel fuel, which amount to 20 GJ / (ha*yr). The 15th bar from the top depicts the energy balance total: By using HVO instead of conventional diesel fuel in an average passenger car, about 13.4 GJ of primary energy can be saved yearly per hectare.

4.1.2 Variation: Alternative land use

As indicated in chapter 3.1.3, the carbon stock (in biomass and soil) of the land used for the establishment of Jatropha plantations may change. For example, if a desert-like area is chosen, its carbon stock can increase. The so-called alternative land use can therefore greatly influence the outcome of the greenhouse gas balance.

Fig. 4-2 exemplifies the impact of three possible carbon stock changes on the centralised Jatropha HVO production scenario.

Results

- The transformation of an area for Jatropha cultivation has a strong influence on the above and below ground carbon stock of that area which in turn influences the greenhouse gas balance of Jatropha HVO. In case an area with no or scarce vegetation is used for Jatropha cultivation, advantageous results are obtained (0.8 - 1.7 t CO_2 equivalents). In contrast, if an area with medium vegetation is transformed for Jatropha cultivation, the balance becomes negative (2.9 t CO_2 equivalents) as the high expenditure for carbon loss cannot be compensated by credits for by-product and HVO use.

Conclusions

When land cover changes are involved, the quantitative outcomes of the greenhouse gas balances depend largely on the carbon stocks of the above- and below-ground biomass as well as the carbon stock in the soil. Any accumulative or depleting change due to the establishment of Jatropha plantations has an immediate and clear impact on the greenhouse gas balance; this impact is more disadvantageous the higher the carbon stock of the area transformed. Therefore, when a piece of land is developed for Jatropha cultivation, a reduction of the carbon stock of this area must be prevented. However, enormous potentials for saving greenhouse gases are offered if Jatropha is cultivated on carbon poor (e. g. desert-like or degraded) soils.

However, for the cases regarded here, only example values are known for this type of data; the carbon stocks must thus be explored in more depth within a system-analytical approach.

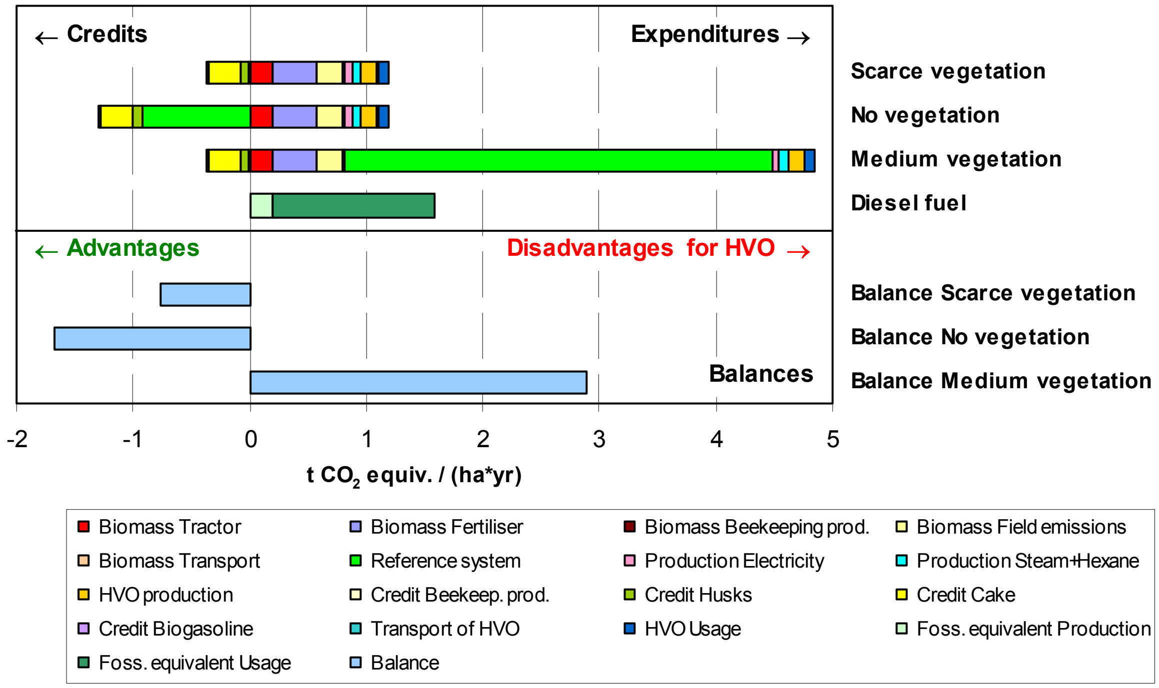


Fig. 4-2 Detailed greenhouse gas balance results for Jatropha HVO from the centralised production scenario under consideration of three different alternative land uses (‘No vegetation’, ‘Scarce vegetation’ and ‘Medium vegetation’)

Reading the diagram (Exemplification for 2nd bar in the “Balances” group)

Replacing conventional diesel fuel as a transport fuel with Jatropha HVO from the centralised production scenario can lead to yearly savings of 1.7 t of CO_2 equivalents per hectare cultivation area when the alternative land use is ‘No vegetation’, i. e. a desert situation.

4.1.3 Variation: Cultivation

As described in chapter 3.1.2, three cultivation scenarios are regarded in this study: ‘Today’, ‘Optimised’ and ‘Best’. Fig. 4-3 shows the impact of these cultivation scenarios on the greenhouse gas balance of a centralised Jatropha HVO production.

Results

- Yield increases positively influence the greenhouse gas balance – granted the reference is the area under cultivation. The higher the yield, the higher is the amount of biofuel replacing conventional fuel and the higher are credits due to by-product use. In the ‘Best’ scenario, 2.2 t of additional CO_2 equivalents can be saved compared to current yields (‘Today’).
- However, if the results are regarded for tonnes of seeds, agronomic optimisation has nearly no effect in terms of greenhouse gas savings while improved crop breeds have a positive effect – albeit only to a small extent.

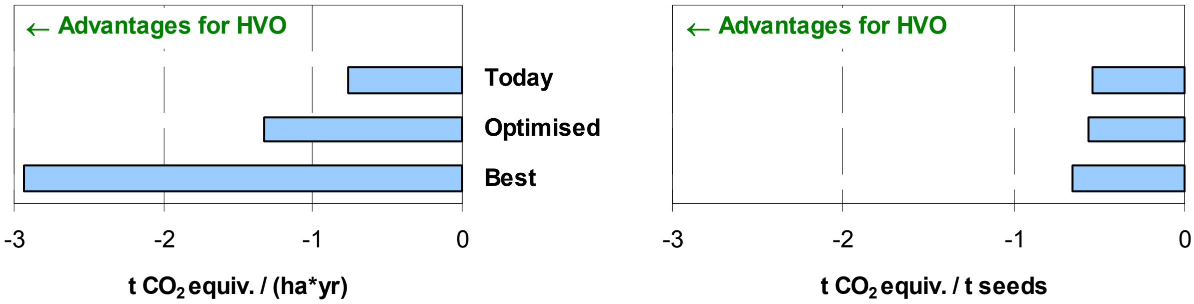


Fig. 4-3 Results of greenhouse gas balances for Jatropha HVO from the centralised production scenario under consideration of three different cultivation scenarios, i. e. biomass yield levels (‘Today’, ‘Optimised’ and ‘Best’)

Reading the diagram (Exemplification for 3rd bar in the left figure)

By fuelling a passenger car with Jatropha HVO from centralised production instead of conventional diesel fuel, 2.9 t of CO_2 equivalents can be saved yearly per hectare cultivation area if improved plant breeds are grown under optimised cultivation conditions.

Conclusions

The influence of optimised agronomic methods and improved crop varieties on the greenhouse gas balance strongly depends on the reference chosen. A production increase per hectare cultivated area does not necessarily lead to more advantageous results. On the background of increased land competition, land use efficiency is becoming more and more relevant and therefore it is appropriate to regard one hectare of cultivated land. Although the cultivation of Jatropha on arable land is excluded in this study, yield increases still are desirable as they reduce competition with other bioenergy crops that could be cultivated on degraded land (e. g. castor oil plant or Pongamia) and result in a decreased pressure on natural ecosystems.

4.1.4 Variation: Production systems

As stated in chapter 3.1.4, two variants of centralised production are analysed. Fig. 4-4 depicts the respective results of a centralised production and a variant involving the additional step of decorticating the seeds prior to extraction. Hereby, meal used for animal feeding can be obtained after detoxification (see chapter 3.1.4).

Results

- The greenhouse gas balance is more advantageous in the ‘Centralised decorticator’ variant. Here, 1.3 t of CO_2 equivalents can be saved compared to 0.8 t in the centralised plant without decorticating. High credits are obtained for the by-products meal and shells. These credits are dominated by the shells which are used for power generation.

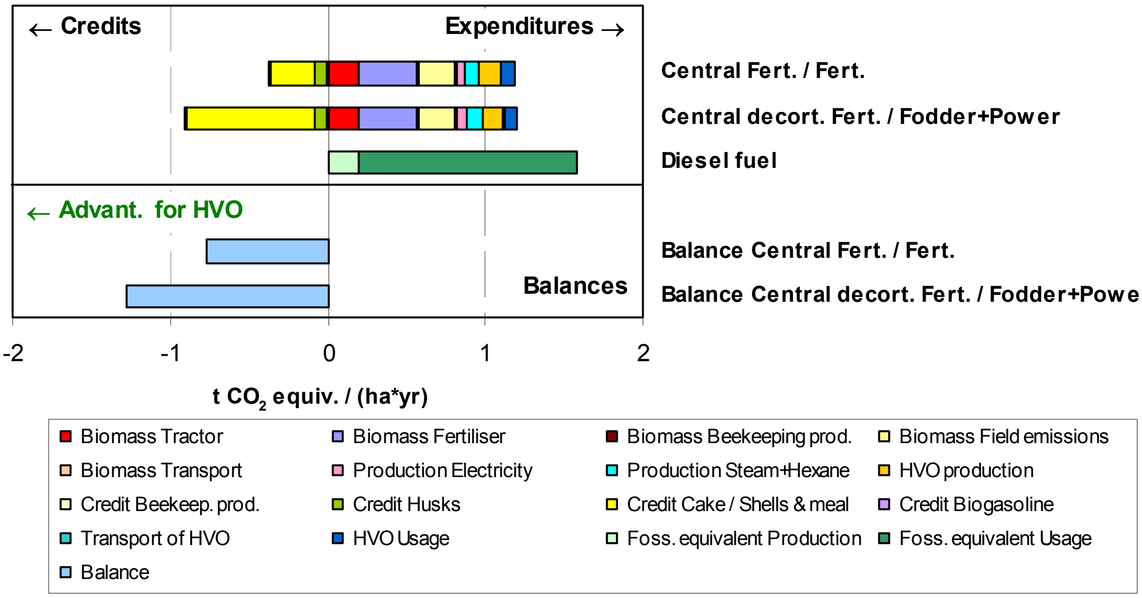


Fig. 4-4 Detailed greenhouse gas balance results for Jatropha HVO from different centralised production scenarios

Reading the diagram (Exemplification for 1st bar in the “Balances” group)

If Jatropha HVO from centralised production is used instead of conventional diesel as transport fuel, 0.8 t of CO_2 equivalents can be saved yearly per hectare cultivation area.

Conclusions

From a climate protection point of view, the ‘Centralised decorticator’ variant should be given priority. It shows more advantageous results due to the shells which can be used for power generation leading to high credits for replaced conventional power.

However, detoxification of the second by-product – meal – as a precondition for its use as animal feed currently is only possible at laboratory scale. It therefore remains to be seen whether this centralised variant can be realised in future Jatropha biofuel concepts.

4.1.5 Variation: Utilisation of by-products

As mentioned in chapter 3.1.5, the by-products obtained during the processing of Jatropha fruits to biofuel account for the greatest part of the credits and expenditures which are weighed against each other in the balances. Fig. 4-5 highlights the results of the greenhouse gas balances for different by-product use combinations and production scenarios.

Results

- In both production scenarios, the use of by-products strongly influences the outcome of the greenhouse gas balances. If energy is produced, more advantageous results are obtained compared to the use as fertiliser or animal feed. For example, if husks and cake in the centralised production system without decortication are used for power generation, higher credits are gained compared to their use as fertiliser. In the former case, 1.8 t of CO_2 equivalents can be saved compared to only 0.8 t in the latter case.
- The credits assigned to the use of the by-products have a strong influence on the greenhouse gas balance. Using the by-products for power generation leads to even greater savings of greenhouse gases than the use of the main product – Jatropha HVO – itself. That means that with the right choice of a certain use option negative environmental impacts such as greenhouse gas emissions of Jatropha HVO can be reduced significantly.

Conclusions

In order to tap the advantages of Jatropha HVO to a full extent, big efforts should be put on an optimised use of the by-products. Wherever technically and logistically possible, husks and cake or – in the case of the ‘Centralised decorticator’ variant – husks, shells and meal should be used for power generation replacing conventionally produced energy as this positively influences the greenhouse gas balance. This option is to be preferred over an utilisation as biomaterials such as fertiliser or animal feed, both of which produce less advantageous results. However, although the latter use option should be avoided from a climate protection point of view, there might be social and / or economic factors supporting this use option.

Therefore, apart from using Jatropha HVO, great efforts should be made to push the development of concepts for facilitating the use of the by-products for energy-producing purpose. However, concerning the cake which might be difficult to handle in combustion facilities, it remains to be seen if and to what extent its use for generating power is technically possible.

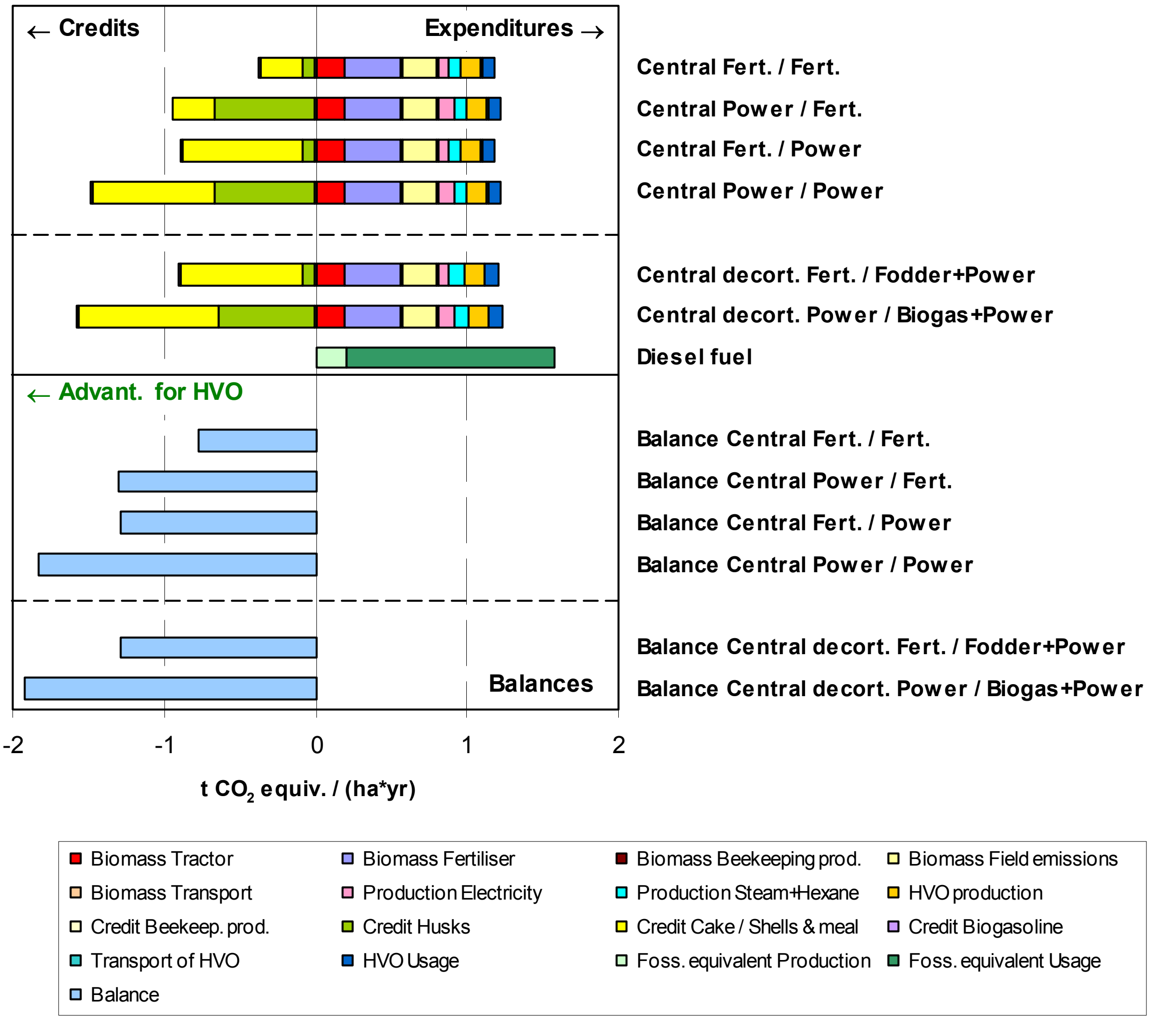


Fig. 4-5 Detailed greenhouse gas balance results for Jatropha HVO originating from two centralised production variants and different uses of the by-products

Reading the diagram (Exemplification for 4th bar in the “Balances” group)

By replacing conventional diesel fuel as a transport fuel with Jatropha HVO from centralised production and by using the by-products husks and cake entirely to generate power, 1.8 t of CO_2 equivalents can be saved yearly per hectare cultivation area.

4.2 Sensitivity analyses

Several parameters influence the LCA results of Jatropha HVO. In the following, sensitivity analyses are presented in order to quantify the influence of specific parameters and to help interpret their meaning for the environmental effects of the use of Jatropha as a biofuel.

4.2.1 Emissions due to Jatropha HVO use

This sensitivity analysis investigates the variation of biofuel-related emissions which usually differ from those related to the use of conventional diesel fuel (see chapter 3.2.2 for details). Fig. 4-6 shows the respective balances for ‘acidification’ and ‘eutrophication’.

Results

- If reduced emissions are assumed for Jatropha HVO compared to conventional diesel, slightly reduced disadvantages regarding acidification and eutrophication are obtained.

Conclusions

The level of emissions from Jatropha HVO use has a slight impact on ‘acidification’ and ‘eutrophication’ – they are reduced if conventional diesel fuel is replaced by Jatropha HVO.

However, underlying figures regarding HVO emissions are still quite uncertain. Therefore, more research is needed for exactly quantifying possible emission reductions due to the use of Jatropha HVO.

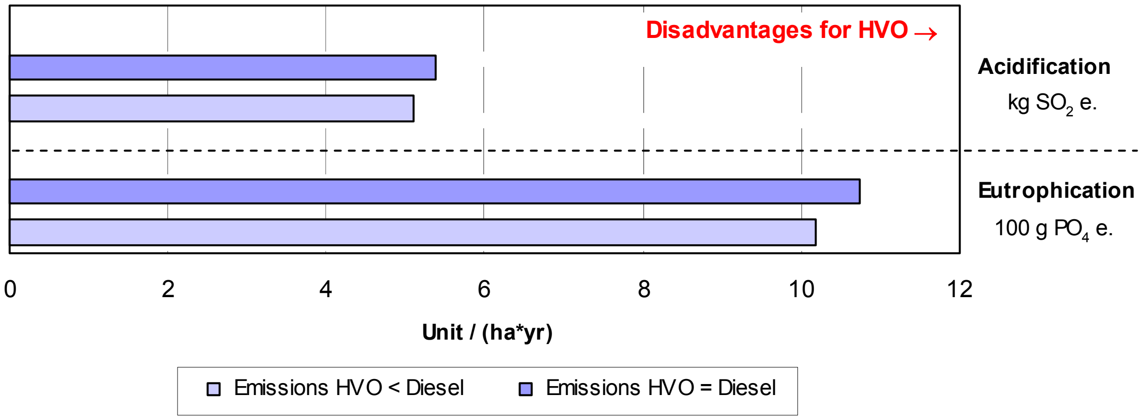


Fig. 4-6 Results of acidification and eutrophication balances for different emission levels resulting from Jatropha HVO use

Reading the diagram (Exemplification for 1st bar)

If Jatropha HVO from the centralised production scenario is used instead of conventional diesel as transport fuel, acidification is increased by 5.4 kg per hectare and year if HVO emissions are equal to those from conventional diesel fuel.

4.2.2 Jatropha HVO production and use in Europe

Jatropha HVO could be produced and used in Europe instead of in India (see chapter 3.2.1). Fig. 4-7 depicts the results for several environmental impact categories.

Results

- The production and use of Jatropha HVO in India instead of in Europe leads to more advantages regarding ‘energy resources’ and ‘greenhouse gases’ and to less disadvantages regarding ‘eutrophication’ and ‘acidification’. The Jatropha oil transportation to Europe would lead to high expenditures. Additionally, by replacing conventional diesel fuel in India which requires high amounts of fossil energy resource inputs more energy and greenhouse gases could be saved. Regarding acidification, the sulphur content in the replaced conventional diesel fuel plays the major role – this content is higher in India than in Europe. Thus fewer disadvantages occur if Indian fossil fuel is replaced.

Conclusions

From an environmental point of view, Jatropha oil should rather be processed and used in India than being transported to Europe. Advantages would be twofold: conventional diesel fuel with rather energy-intensive upstream processes and with high sulphur content could be substituted and expenditures for the transport to Europe could be avoided.

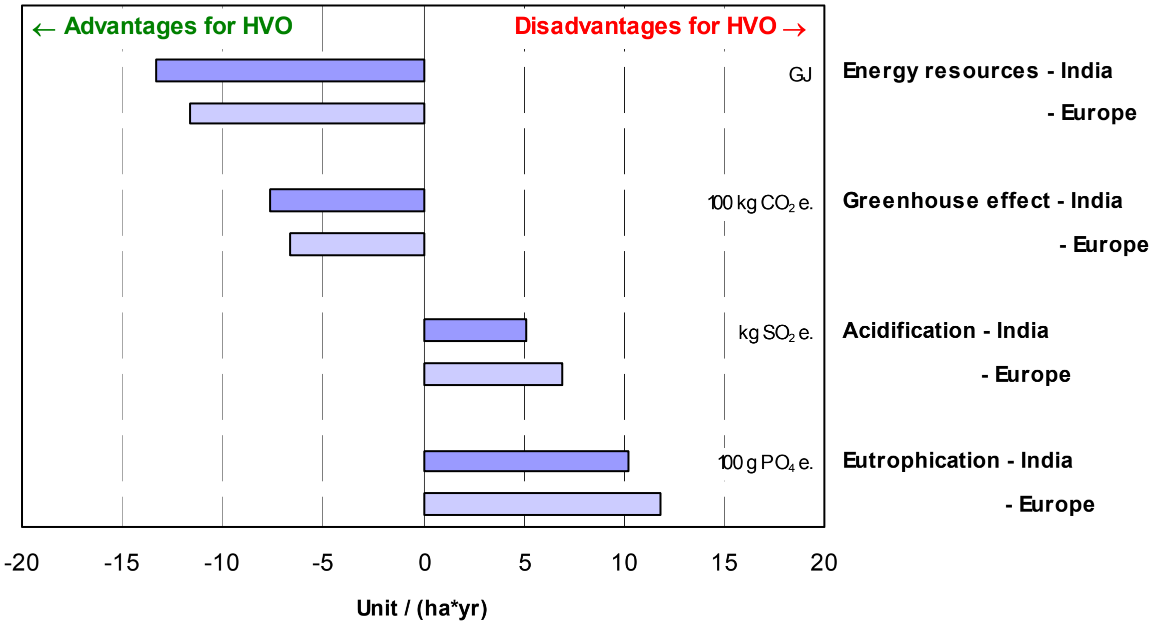


Fig. 4-7 Results of different life cycle balances for the production and use of Jatropha HVO in India and Europe

Reading the diagram (Exemplification for 5th and 6th bar)

Replacing conventional diesel fuel with Jatropha HVO produced in Europe increases acidification by 1.8 kg per hectare and year compared to a production and use in India.

4.3 Comparison of Jatropha biofuels: HVO versus JME

In this chapter, the results of the screening life cycle assessment of Jatropha HVO are compared to the results for JME (see /Reinhardt et al. 2007/). Although both products can replace conventional diesel fuel, the production processes and fuel qualities are substantially different. For the comparison, the centralised production of Jatropha biofuel is taken as a base with husks and cake used as fertiliser. For both biofuels, the life cycles are the same until Jatropha oil. If Jatropha HVO is produced, the oil is hydrotreated with biogasoline as a further by-product (replacing fossil naphtha), if JME is produced, the oil is transesterified with glycerine as by-product (replacing crude-oil based chemicals).

In Fig. 4-8 the results of the life cycle comparison between Jatropha HVO, JME and conventional diesel fuel are displayed for the environmental impact categories ‘energy resources’, ‘greenhouse effect’, ‘acidification’, ‘eutrophication’, ‘summer smog’ and ‘nitrous oxide’.

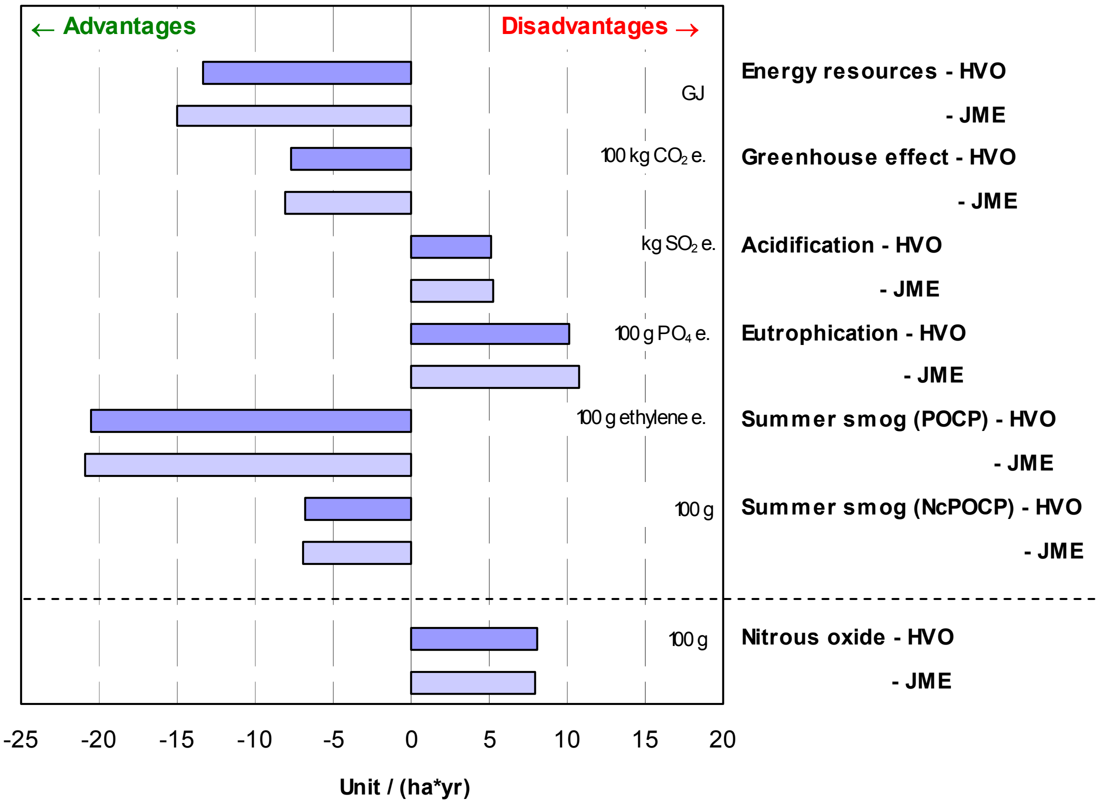


Fig. 4-8 Results of life cycle comparisons of Jatropha HVO and JME with conventional diesel fuel for a centralised production system

Reading the diagram (Exemplification for 5th bar)

Replacing conventional diesel fuel with Jatropha HVO from the centralised production scenario as transport fuel leads to an increase of acidification by 5 kg per hectare and year.

Results

- Regarding ‘energy resources’, JME shows clearly better results than Jatropha HVO. In all other environmental impact categories, both biofuels perform quite similar. Mostly, JME shows (very) slight advantages, however, regarding ‘eutrophication’ and ‘acidification’ HVO is a little less disadvantageous.
- In the single environmental impact categories, different life cycle steps are decisive for the results. In nearly all categories, JME earns high credits for the by-product glycerine. For ‘greenhouse gases’ and ‘summer smog (POCP & NcPOCP)’, these credits lead to slightly better results for JME compared to HVO although partly, they are outweighed by the fact that with HVO, more conventional diesel can be replaced. For ‘energy resources’, the advantage for JME is increased as expenditures for fuel production are higher for HVO – here the difference is clearly visible. For ‘eutrophication’ and ‘acidification’ the high glycerine credits are outweighed by higher expenditures for the use of JME as transport fuel and in total, HVO shows slightly less disadvantageous results. For ‘nitrous oxide’ all life cycle steps are almost equal for both biofuels.

Conclusions

If Jatropha HVO and JME are compared, the only significant difference occurs regarding the savings of fossil energy resources – here JME is to be favoured. In all other environmental impact categories, differences between the two biofuels can be neglected.

The use of JME not only shows advantages from an energy saving point of view but also offers more flexibility regarding its production design (decentralised or centralised) or its range of use (mobile or stationary). HVO, on the other hand, is a high quality fuel which should exclusively be used as transport fuel and which can only be produced in centralised large scale plants.

It has to be noted, however, that the production of JME in decentralised facilities would lead to less advantageous results compared to the (centralised) production of HVO. But usually, in the decision for or against a decentralised production, savings of energy resources and greenhouse gases are not the only criteria but also other social and / or economic factors are taken into consideration such as rural development.

5 Summary and conclusions

Replacing conventional diesel fuel by Jatropha HVO can help save non-renewable energy resources and reduce the greenhouse gas emissions these fuels account for. These benefits, however, are associated with increased negative environmental impacts such as acidification, eutrophication and ozone depletion through nitrous oxide. Therefore, advantages and disadvantages have to be weighted against each other. If saving non-renewable energy resources and the reduction of greenhouse gas emissions are given the highest environmental priority, for example, then the production and utilisation of Jatropha HVO is desirable.

The life cycle comparison of Jatropha HVO with conventional diesel fuels leads to numerous results. Please note, that all results in this study refer to the cultivation of Jatropha on degraded or desert-like land – the use of arable land is excluded.

Most important results have been:

- Along the life cycle of Jatropha HVO, certain life cycle stages have proved to be especially important for the outcome of the environmental performance. Decisive life cycle steps are land use change, the use of by-products, the production plant design as well as – to a lesser extent – the cultivation of Jatropha.
- On the other hand, expenditures for the provision of pesticides as well as for specific ancillary products used in Jatropha oil production, its hydrotreatment and during some sub-steps of by-product processing have a relatively small impact on the balance results. Transport expenditures, however, only influence the results in case Jatropha oil is exported to Europe for hydrotreatment and use.
- Jatropha HVO rather should be produced and used in India than in Europe as by doing so transport expenditures could be saved and conventional diesel fuel with high sulphur contents could be replaced which reduces acidifying effects.
- If Jatropha HVO and JME are compared, from an energy resource saving point of view, the use of JME is to be preferred. Other criteria such as higher flexibility in production and use options might support this decision – but could lead to less advantageous results.

All in all, Jatropha HVO has a great environmental potential, especially if optimisation potentials derived in this study are tapped. The fact that Jatropha can be cultivated on degraded or desert-like soil not only poses a great advantage in the current discussion on food and fuel competition but also leads to considerable increases in greenhouse gas savings. In contrast, the establishment on areas with high carbon stocks should be avoided as the corresponding greenhouse gas balance can turn out to be unfavourable.

Several needs for further research have been identified. There is a lack of scientific data regarding carbon storage in Jatropha plantations as well as in the vegetation replaced. Furthermore, emission data of HVO compared to conventional diesel fuel should be evaluated more precisely.

6 Literature and glossary

Literature

/Borken et al. 1999/ Borken, J., Patyk, A. & Reinhardt, G.A.: Basisdaten für ökologische Bilanzierungen (Basic data for ecological balances). Verlag Vieweg, Braunschweig / Wiesbaden, 1999.

/CML 2004/ Institute of Environmental Sciences (CML): CML's impact assessment methods and characterisation factors. Leiden University, Institute of Environmental Sciences (CML), Department of Industrial Ecology. Leiden, 2004.

/Degen 2008/ Degen, W. (Daimler AG): Personal communication, September 2008.

/IFEU 2008/ Continuously updated internal IFEU Database. Heidelberg, 2008.

/ISO 14040&14044/ Deutsches Institut für Normung e.V. (German Institute for Standardization): ISO 14040:2006(E) & ISO 14044:2006(E). Environmental management – Life cycle assessment – Requirements and guidelines. Beuth Verlag, Berlin, 2006.

/Jungk & Reinhardt 2000/ Jungk, N.C. & Reinhardt, G.A.: Landwirtschaftliche Referenzsysteme in ökologischen Bilanzierungen (Agricultural reference systems in ecological balances). By order of the Federal Ministry for Agriculture, Food and Forestry, FKZ 99 NR 009, Bonn, 2000.

/Reinhardt et al. 2007/ Reinhardt, G. A.; Gärtner, S.O.; Rettenmaier, N.; Münch, J.; von Falkenstein, E.: Screening Life Cycle Assessment of Jatropha Biodiesel. By order of Daimler AG, Stuttgart, 2007.

/Reinhardt et al. 2008/ Reinhardt, G.A., Ghosh, P.K., Becker, K., Chaudhary, D.R., Chickara, J., von Falkenstein, E., Francis, G., Gärtner, S.O., Gandhi, M.R., Ghosh, A., Makkar, H.P.S., Münch, J., Patolia, J.S., Reddy, M.P., Rettenmaier, N. & Upadhyay, S.C.: Basic Data for Jatropha Production and Use. Institute for Environmental Research Heidelberg (IFEU), Central Salt & Marine Chemicals Research Institute (CSMCRI), University of Hohenheim. Heidelberg, Bhavnagar and Hohenheim, 2008.

Glossary

Abbreviation / Expression	Explanation / Description
Parts of the Jatropha fruit and processed states	
Capsule	Husk + seeds; entire fruit
Husk	Outer core of fruit, surrounding seeds; green and 'fleshy' in fresh state, later brown and dry
Seed	Shell + kernel; compact unit inside fruit, consists of shell and kernel, usually 2-3 per capsule
Shell	Brown or black shell surrounding the kernel
Kernel	White compact nucleus of seed, actual oil-containing part of the fruit
De-oiled cake	Seeds (processed); leftovers from mechanical and solvent-aided oil extraction from seeds
Meal	Kernels (processed); leftovers from mechanical and solvent-aided oil extraction from kernels
Others	
C	Carbon
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
GJ	Gigajoule; 1.000.000.000 Joule
ha	Hectare
HC	Hydrocarbons
HVO	Hydrotreated Vegetable Oil; synthetic, diesel-like biofuel made by hydrotreatment of vegetable oil
JME	Jatropha oil Methyl Ester; biodiesel made by transesterification of Jatropha oil
LCA	Life Cycle Assessment
N_2O	Nitrous oxide (Dinitrogen oxide)
NcPOCP	Nitrogen-corrected Photochemical Ozone Creation Potential
NO_X	Generic term for nitrogen oxides
PM	Particulate matter; tiny particles of solid or liquid; increased levels of fine particles in the air are linked to health hazards
POCP	Photochemical Ozone Creation Potential
ppm	Parts-per-million; one part per 1,000,000 parts; 10^{-6}
SO_2	Sulphur dioxide
SVO	Straight Vegetable Oil; can be used as biofuel in technically modified diesel engines
yr	Year