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Environmental assessment of SUPRABIO biorefineries

Main results of the SUPRABIO project from an environmental perspective

Heidelberg, June 30th 2014
(Updated version of October 31st 2014)

Acknowledgements

The authors would like to thank all SUPRABIO partners for the fruitful collaboration and discussions throughout the project lifetime as well as for the provision of primary data on their processes. Special thanks go to Per Nygård, Esther Ochoa-Fernández and Astrid Lervik Mejdell from Statoil ASA as well as Mattias Ljunggren from Biogasol ApS and Son Le from United Utilities Water PLC for their invaluable effort regarding process data collection and compilation of comprehensive technical models, which form the basis of this report. We also acknowledge the great support provided by Costa Komodromos from Brunel University, who facilitated countless telephone conferences and followed up on data delivery by the partners.

Last but not least, we are deeply thankful to our colleague Mathias Lederle from IFEU who produced most figures and polished the format of this report.

This work was supported by the European Commission through the FP7 project "Sustainable products from economic processing of biomass in highly integrated biorefineries" ("SUPRABIO", GA no. 241640).

Environmental assessment of SUPRABIO biorefineries

Main results of the SUPRABIO project from an environmental perspective

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Suggested citation:

Keller, H. *et al.*, Environmental assessment of SUPRABIO biorefineries, IFEU and IUS, Heidelberg, 2014

Heidelberg, June 30th, 2014 (Updated version of October 31st 2014)

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1 Publishable summary

The SUPRABIO project researches, develops and demonstrates a toolkit of novel generic processes that can be applied to a range of biorefinery concepts. In the last couple of years, a controversial discussion on the net benefit of biofuels, bioenergy and biomaterials has been going on, showing that the use of biomass is not environmentally friendly per se, simply because biomass is renewable. Furthermore, competition for agricultural land and biomass residues between various use options is increasing.

In this context, the environmental assessment as one part of the overall sustainability assessment validates the benefits and risks of the SUPRABIO biorefinery processes to provide a basis for decision making processes such as the development of policy incentives. The assessment of the proposed biorefinery concepts is performed on the basis of scenarios, which reflect potential implementations of mature, industrial-scale biorefineries in 2025 and of current technology on smaller scale in 2015. The scenarios were finalised in late 2013 on the basis of experts' expectations and data available at that time. More recent advancements within SUPRABIO such as results of the Piteå gasifier test in May 2014 (which would lead to more optimistic expectations) could not be taken into account any more. The main scenarios comprise a thermochemical route for the production of Fischer-Tropsch fuels (FT fuels) or dimethyl ether (DME) from forest residues and a biochemical route for the production of 2nd generation (lignocellulosic) ethanol from straw (see Table 1-1 and Table 1-2 and chapter 3.1 for details). Several sensitivity scenarios and alternative use options are analysed and compared to the main scenarios. Furthermore, a number of so-called ‘other routes’ or ‘add-ons’ for enhancement of overall performance were considered. The entire life cycles of the biorefinery products are compared with those of equivalent conventional (reference) products and competing use options for biomass and agricultural land. To comprehensively cover all impacts, the environmental assessment uses a combination of established life cycle assessment (LCA) to analyse global / regional impacts and novel life cycle environmental impact assessment (LC-EIA) to qualitatively evaluate local impacts. LC-EIA uses elements of environmental impact assessment (EIA) and applies them to whole life cycles. It supplements LCA to assess those impacts, which cannot be reliably quantified yet.

The assessed products show a wide range of results compared to their conventional (mostly fossil) equivalents. Local environmental impacts (assessed by LC-EIA) are dominated by biomass provision. Due to the large size of affected areas, land use impacts of SUPRABIO systems on soil, water and biodiversity are more extensive than impacts caused by conventional crude oil extraction although the former ones are largely reversible. Regarding core biorefinery processes, water use especially by biochemical biorefineries and concentrated biomass demand by large biorefineries pose risks for local environmental burdens. From an LC-EIA point of view it therefore makes sense to reduce plant capacities and to implement a configuration with distributed pre-treatment units. Compared to other bio-based processes, residue extraction from already cultivated land and cultivation of perennial (lignocellulosic) biomass generally cause lower local impacts than the cultivation of annual crops. In this regard, 2nd generation biofuels show advantages over 1st generation biofuels.

Regarding global and regional effects (assessed by LCA), impacts are mainly dominated by core biorefinery processes with important contributions of use phase, end of life and other life cycle stages depending on the scenario. The investigated biofuels (ethanol, FT fuels and

DME) typically lead to advantages in terms of non-renewable energy use and global warming potential compared to fossil fuels. At the same time, disadvantages are incurred regarding eutrophication and ozone depletion and other impact categories show indifferent results. Only products from forest residues show equal or lower eutrophication than conventional products, mainly because no compensation fertilisation of forest systems was assumed. This means that from an LCA point of view, the investigated biofuels do not show a clear advantage over conventional fuels. The investigated mixed organic acids lead to clear additional environmental burdens in all environmental impact categories.

Several optimisation options for all assessed scenarios were deduced from an in-depth analysis of all life cycle steps. From an LCA point of view, thermochemical biorefineries should for example not have separate pre-treatment units to increase energy efficiency. Thus, it depends on local biomass availability if risks of local environmental damages due to concentrated biomass demand are low enough to allow for an integrated plant. Furthermore, several proposed integration schemes of biorefinery elements, such as algae production as a form of wastewater treatment for a biochemical biorefinery, were studied. They did not yield outstanding improvements in environmental sustainability over simpler implementations given the increase in complexity and contradicting directions for optimisation. Nevertheless, important lessons were learned from these scenarios.

Compared to other land use options, 2nd generation technology does not show the potential to significantly improve the land use efficiency of 1st generation ethanol, i.e. it doesn't live up to the high expectations connected to it in terms of environmental benefits. Based on the scenarios assessed here, the thermochemical route towards FT fuels is more environmentally friendly than bioethanol production: FT fuels can be optimised to be similarly advantageous regarding climate change mitigation and savings of non-renewable energy but cause less disadvantages in terms of e.g. eutrophication. Furthermore, FT fuels might display advantages over lignocellulosic ethanol in terms of greater biomass flexibility. Compared to other use options of lignocellulosic residues, combined heat and power production usually outperforms the biofuel use of biomass by far – at least as long as coal has a significant share in electricity production. 2nd generation biofuels will become more attractive from an environmental viewpoint in the future.

Table 1-1 SUPRABIO main scenarios for the biochemical route
Odt BM: oven dry tonnes biomass, SHF: separate hydrolysis and co-fermentation, SSF: simultaneous saccharification and co-fermentation.

	Straw to Ethanol (2015)	**Straw to Ethanol (2025)**	**Poplar to Ethanol (2025)**	**Straw to Mixed Acids (2025)**
Feedstock	Straw	Straw	Poplar	Straw
Capacity	40,000 odt BM/a	400,000 odt BM/a	400,000 odt BM/a	400,000 odt BM/a
Pre-treatment	Steam explosion	Steam explosion	Steam explosion	Steam explosion
Main process	SHcF	SScF	SScF	Hydrolysis & an-aerobic ferment.
Main product(s)	Ethanol (310 kg/odt BM)	Ethanol (340 kg/odt BM)	Ethanol (250 kg/odt BM)	Propionic and butyric acid (up to 520 kg/odt BM)
Co-product	Electricity (250 kWh/odt BM)	Electricity (350 kWh/odt BM)	Electricity (650 kWh/odt BM)	-
Assessed variants	-	Different processes for energy recovery from processing residues	-	Different product ratios and amounts

Table 1-2 SUPRABIO main scenarios for the thermochemical route
Odt BM: oven dry tonnes biomass, FT: Fischer-Tropsch, DME: dimethyl ether.

	Forest residues to FT fuels (2015)	**Forest residues to FT fuels (2025)**	**Forest residues to DME (2025)**	**Straw residues to FT fuels (2025)**	**Poplar residues to FT fuels (2025)**
Feedstock	Forest residues	Forest residues	Forest residues	Straw	Poplar
Capacity	5 x 8,000 odt BM/a	5 x 80,000 odt BM/a	5 x 80,000 odt BM/a	5 x 80,000 odt BM/a	5 x 80,000 odt BM/a
Pre-treatment	Pyrolysis	Pyrolysis	Pyrolysis	Pyrolysis	Pyrolysis
Main process	Gasification (fed by 5 pyrolysers)	Gasification (fed by 5 pyrolysers)	Gasification (fed by 5 pyrolysers)	Gasification (fed by 5 pyrolysers)	Gasification (fed by 5 pyrolysers)
Main product(s)	FT diesel, FT gasoline (34 / 37 kg/odt BM)	FT diesel, FT gasoline (52 / 42 kg/odt BM)	DME (186 kg/odt BM)	FT diesel, FT gasoline (41 / 33 kg/odt BM)	FT diesel, FT gasoline (43 / 35 kg/odt BM)
Co-product	Electricity (110 kWh/odt BM)	Electricity (100 kWh/odt BM)	Electricity (30 kWh/odt BM)	Electricity (70 kWh/odt BM)	Electricity (80 kWh/odt BM)
Assessed variants	-	Deviating steam provision, centralised pyrolysis and different gasification conditions	-	-	-

2 Introduction

2.1 Background and objective

2.1.1 The SUPRABIO project

The SUPRABIO project researches, develops and demonstrates a toolkit of novel generic processes that can be applied to a range of biorefinery concepts based on sustainable types of biomass feedstock.

In the last couple of years, a controversial discussion on the net benefit of biofuels, bioenergy and biomaterials has been going on, showing that the use of biomass is not environmentally friendly per se, simply because biomass is renewable. The discussion gained momentum in the light of increasing competition for agricultural land between the production of food, feed, fibre and fuel which might even aggravate in the decades to come and jeopardise food security.

In this context, a strict and overarching sustainability assessment is needed to validate the benefits and risks of any given biorefinery concept and, ultimately, to provide a basis for the development of policy incentives. In SUPRABIO, the sustainability of the biorefinery concepts under investigation is assessed in an integrated manner and by taking into account the entire life cycle (value chain).

2.1.2 Environmental assessment as part of the sustainability assessment

In SUPRABIO, the sustainability assessment in consists of a series of individual assessments that separately assess the major aspects determining the sustainability of biorefinery systems. Among these is the environmental assessment, which is subject of this report. It assesses scenarios on industrial scale implementations of processes investigated in SUPRABIO, which were commonly defined for all parallel assessments of individual sustainability aspects. This allows for the later integration of all results into an overall integrated sustainability assessment.

2.1.3 Objective

The description of work /DoW 2011/, which is the contractual basis of this project, specifies the objectives of the sustainability assessment to “provide a multi-criteria evaluation of the sustainability of the entire value chain by taking into account technological, environmental, economic, social, political and legal aspects”. Based on this comprehensive main goal, the following key questions have been specified in the “Interim report on definitions and settings” /Rettenmaier et al. 2011/.

General questions:

- What are the implications of the SUPRABIO biorefinery systems on sustainability?
- Which processes determine the results significantly and what are the optimization potentials?
- What main products/product systems perform best regarding the replacement of fossil fuels?
- What system performs best regarding CO_2 savings per tonne of biomass input?
- What is the performance of SUPRABIO systems compared to other uses of the raw material?

Within each route (biochemical, thermochemical), the following questions will be discussed:

- Which product portfolio performs best?
- Which co-product treatment performs best?
- How do the different add-ons and advanced technology options affect sustainability?
- What are the implications of plant capacity, e.g. on rural development?
- How does the time frame influence the results?

These questions are answered within this report. For clarity, these questions are not addressed one by one but the answers are part of the overall discussion of results.

2.2 Environmental assessment: General scientific approach

Environmental impacts can be assessed with a wide variety of techniques (Fig. 2-1). The choice of the appropriate method depends on the goal and scope of the environmental assessment.

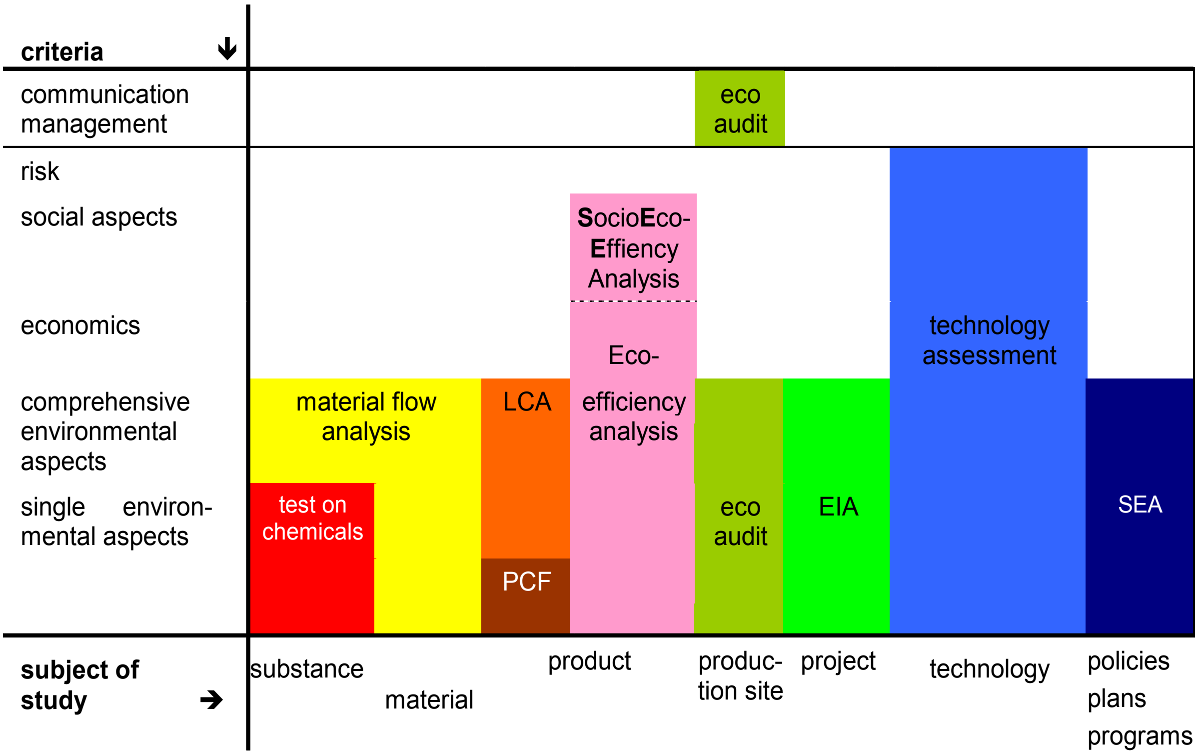


Fig. 2-1 Available techniques for environmental assessment (IFEU, own compilation)

In this case, life cycle assessment (LCA) is the technique that is most suitable to answer many of the questions raised above (chapter 4). It provides a comprehensive quantitative analysis of the potential environmental impacts of a product system. In this project, a screening LCA largely following the international standards for product LCAs (see chapter 4.1 for details) is applied to assess the whole biorefinery concept and its products from cradle to grave and to compare it to alternative products providing the same utility (Fig. 2-2). The used methodology has been harmonised between the projects SUPRABIO, BIOCORE and EUROBIOREF, which are financed within the same call. Among others, a minimum set of midpoint impact categories and associated LCIA methods were defined (see chapter 4.1.5 for details)

However, the assessment of several important environmental aspects, especially those regarding local and site-specific impacts, is still under methodological development. At the time the SUPRABIO project was set up, the methodological developments regarding land use and water use were considered to be too immature to be covered in the life cycle assessment (LCA). Even today, balanced quantitative results regarding these aspects, which are certain enough for decision support, cannot be provided.

In SUPRABIO, the screening LCA is therefore supplemented by an assessment of local and site-specific impacts using methods originating from other techniques, e.g. environmental impact assessment (see chapter 5.1 for details). These methods are applied to whole life cycles as it is done in LCA instead of only to single sites. In this report, they are thus termed life cycle environmental impact assessment (LC-EIA). In contrast to a classical LCA, LC-EIA methods yield qualitative results.

In conclusion, the environmental assessment applied in SUPRABIO consists of a combination of screening LCA and LC-EIA. A comprehensive list of environmental impact categories is addressed; some of which are covered by screening LCA, others by LC-EIA (see Table 2-1).

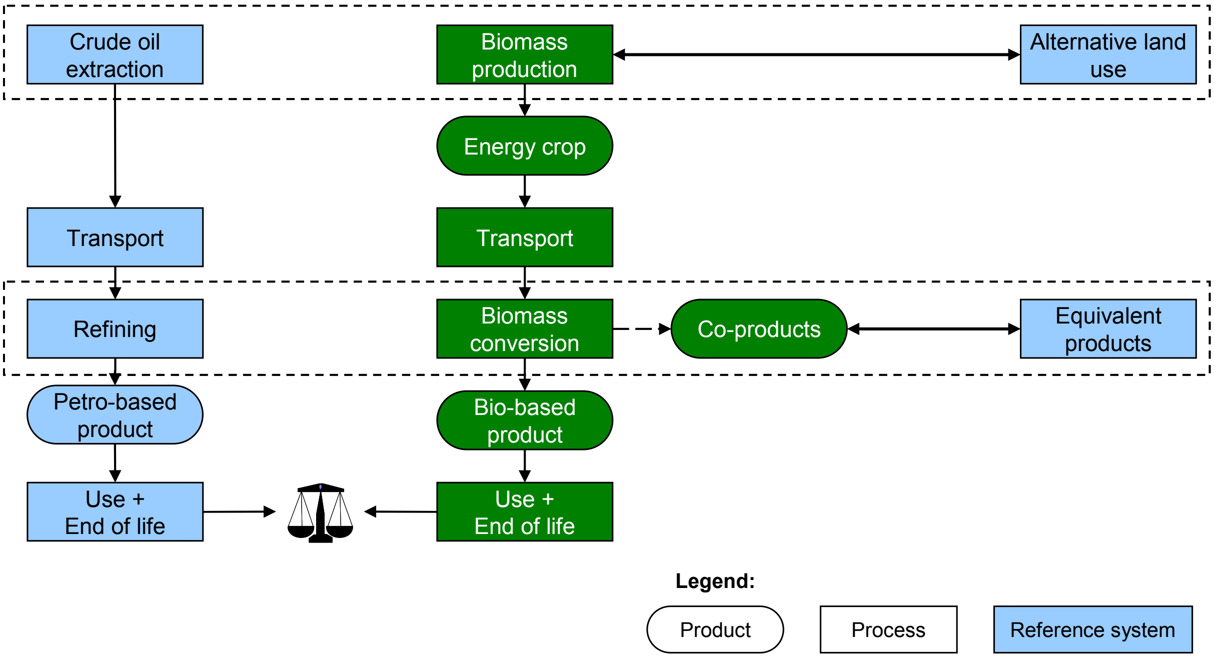


Fig. 2-2 General approach of the environmental assessment in SUPRABIO: life cycle-oriented, comparative assessment

Table 2-1 Environmental impact categories covered in SUPRABIO

Environmental impact category	Covered by LCA	Covered by LC-EIA
Climate change	✓	–
Ozone depletion	✓	–
Human toxicity	–	–
Particulate matter formation	✓	–
Ionising radiation	–	–
Photochemical ozone formation	✓	–
Acidification	✓	–
Aquatic eutrophication	✓	–
Ecotoxicity	–	(✓)
Land use	–	✓
Resource depletion: water	–	✓
Resource depletion: energy	✓	–

3 System description

The SUPRABIO biorefining system can be implemented in many different variants and ways. For the purpose of the sustainability assessment, scenarios are defined to reflect the most important of all possible implementations. Chapter 3.1 describes the scenarios that are assessed and introduces general aspects of the SUPRABIO biorefining system, which are relevant for the environmental assessment. These scenarios include the whole life cycles of product provision and use 'from cradle to grave'. Additionally, the whole life cycles of conventional products that are replaced by SUPRABIO products are included in these scenarios as a reference.

Furthermore, any implementation of a SUPRABIO biorefinery replaces existing ways of using (or not using) land and / or biomass. These alternatives are described in chapter 3.2.

3.1 The SUPRABIO biorefining concept

This chapter describes scenarios depicting how bio-based products can be provided by a biorefinery according to the SUPRABIO biorefining concept (see Fig. 3-1 for an overview), how these products are used, and which conventional products are replaced.

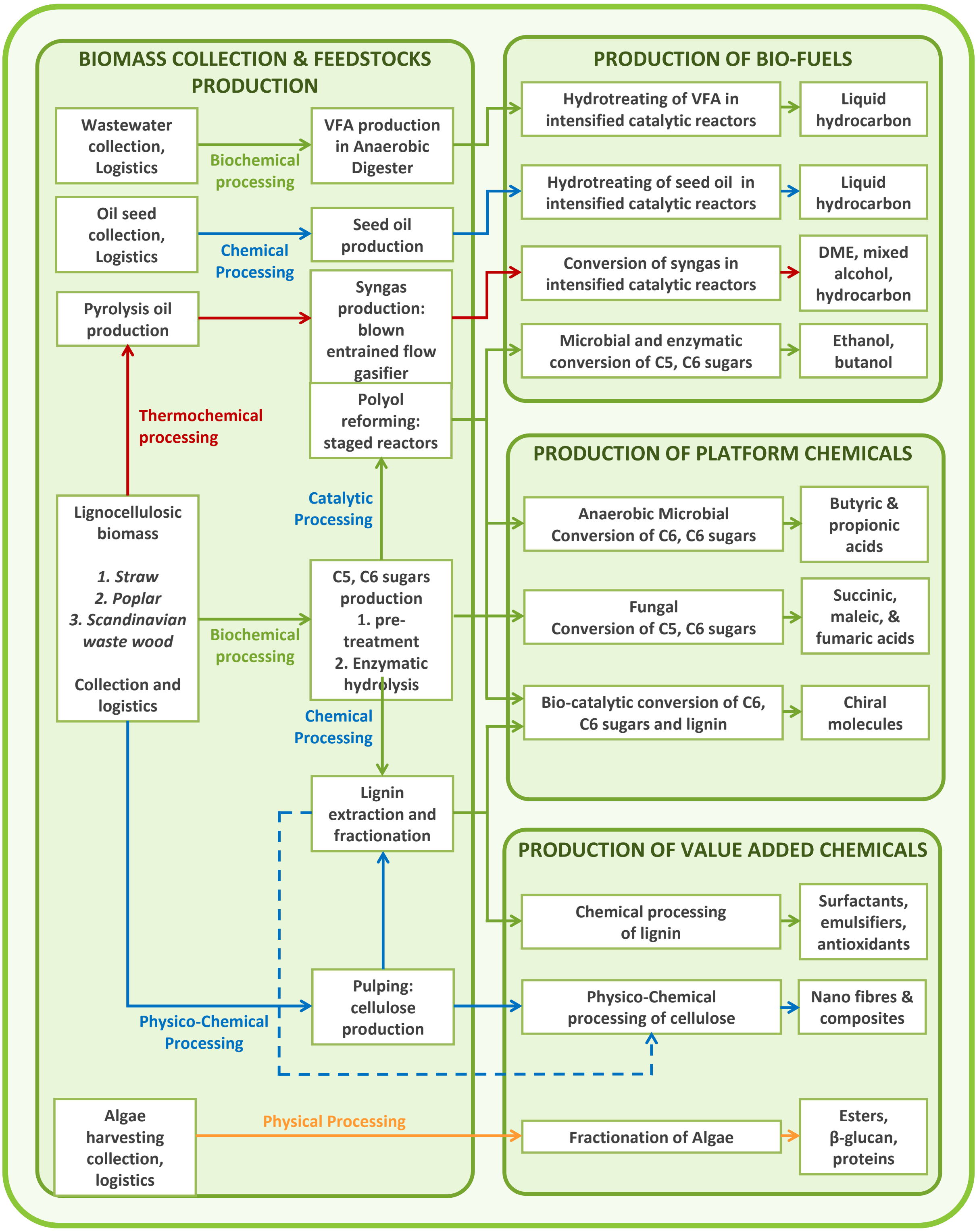


Fig. 3-1 Overview of routes within the SUPRABIO biorefining concept

3.1.1 Raw material production / extraction

Biorefineries according to the SUPRABIO concept use a wide range of biogenic feedstocks depending on the conversion routes and products. The provision of these feedstocks is part of the SUPRABIO scenarios. In a first step, these scenarios are assessed based on the precondition that biomass and land is available. Thus, they are compared to the reference systems of (non-wooded) idle land or not extracting residues (chapter 3.1.5.1). In a second step, these scenarios are compared to alternative use options of the same land or biomass, which are described in chapter 3.2, thus taking into account competition about land and biomass. For residues that are used as feedstocks, only those expenditures are allocated to the biorefinery, which occur additionally compared to the reference system (no extraction of residues) such as the collection of the biomass.

The following feedstocks are assessed:

- Poplar short rotation coppice: This feedstock represents an example of a dedicated crop used to produce lignocellulosic biomass on agricultural land.
- Oil crops (rapeseed, oil palm, soy, Jatropha): These crops are used to produce vegetable oils for certain biorefinery routes on agricultural land (see chapter 3.1.3.3).
- Residual wood from forestry: This residue is extracted from forests during thinning or harvest operations as a co-product of stem wood extraction.
- Cereal straw (wheat): This residue is extracted from wheat fields after the harvest.

Besides main feedstocks, the provision of several inputs like phosphorous fertiliser requires land for mining etc. These land uses are taken into account as well in the sustainability assessment.

3.1.2 Transport and logistics

Transport and logistics of biogenic feedstocks face particular challenges because their energy densities are lower than those of fossil feedstocks. This leads to a higher transportation volume. One approach for a solution is to convert biomass in several distributed units into a high energy density intermediate, which saves transport costs. This strategy is followed in the thermochemical route (chapter 3.1.3.2), which is based on five distributed pyrolysis units supplying pyrolysis oil to one central biorefinery for gasification and subsequent Fischer-Tropsch synthesis. In the biochemical route (chapter 3.1.3.1), however, primary biomass is transported to central biorefineries.

Additionally, biomass requires extensive storage capacity because of its energy density and (in most cases) seasonal harvesting. SUPRABIO scenarios are mainly based on distributed storage of biomass close to the field / forest.

3.1.3 Raw material conversion (SUPRABIO biorefinery)

The SUPRABIO biorefining concept includes three classes of conversion routes:

- **Biochemical routes** based on a pre-treatment of lignocellulosic biomass via steam explosion and followed by enzymatic and / or microbial conversion (chapter 3.1.3.1)

- **Thermochemical routes** based on pyrolysis and subsequent thermochemical (catalytic) conversion of lignocellulosic biomass (chapter 3.1.3.2)
- **Other routes / add-ons**, which aim at using co-products of the core biorefinery (biochemical or thermochemical) but may also use a variety of other feedstocks via specific conversion technologies (chapter 3.1.3.3)

Technical reference, time frame and geographical coverage

The technical reference describes the technology to be assessed in terms of plant capacity and development status / maturity. The time frame of the assessment determines e.g. the development status of biorefinery technology. Likewise, the environmental impact associated with conventional products changes over time (hopefully decreasing), e.g. greenhouse gas emissions associated with electricity generation. In this assessment, scenarios distinguish between an early implementation and a later implementation with the following differences:

Early implementation:

- 2015
- Current technology
- 40,000 tonnes / year of dry matter input to central biorefinery or 8,000 tonnes / year of dry matter input to five distributed pyrolysis units (depending on scenario)

Later implementation (all main scenarios):

- 2025
- Mature technology
- 400,000 tonnes / year of dry matter input to central biorefinery or 80,000 tonnes / year of dry matter input to five distributed pyrolysis units (depending on scenario)

Geography plays a crucial role in many sustainability assessments, determining e.g. agricultural productivity, transport systems and electricity generation. The SUPRABIO project focuses Europe and thus all parameters and reference processes are chosen based on this region (mostly EU 27). Deviating from this specification, some of the other routes / add-ons are also assessed based on imported biomass because this represents a large fraction of the production and use in Europe, e.g. in the case of hydrogenated vegetable oils (HVO).

3.1.3.1 Biochemical route

The fermentative conversion of lignocellulosic biomass pre-treated by means of steam explosion can yield a variety of products. Furthermore, a variety of feedstocks can be used and several plant configurations are possible. Out of all these options, five combinations were chosen to be modelled in detail and to be depicted in scenarios for sustainability assessment. These are:

Early implementation scenario:

I. Straw to Ethanol (2015)

Main scenarios (mature technology):

II. Straw to Ethanol (2025)

III. Poplar to Ethanol (2025)

IV. Straw to Mixed Acids (2025)
IVa: Butyric acid
IVb: Propionic acid

Simplified schemes of the respective life cycles of these processes, their products and the respective conventional reference processes and products can be found in Fig. 3-2 to Fig. 3-4 for scenarios I to IV.

All biochemical processes use lignocellulosic biomass (wheat straw or poplar short rotation coppice) and share the pre-treatment process. They mainly differ in the fermentation sections, which produce various products from hydrolysed cellulose and hemicellulose. The utilisation of co-products again follows a similar strategy in all processes: Anaerobic digestion and staged gasification followed by combustion of the resulting biogas and syngas are used to produce process energy from process residues. These residues mainly consist of stillage, which is left over after product separation and also contains the lignin.

The early implementation scenario on ethanol production in 2015 differs from the corresponding mature technology scenario in the configuration of the hydrolysis and fermentation section. In 2015, simpler but already available separate hydrolysis and co-fermentation (SHcF) is used, whereas simultaneous saccharification and co-fermentation (SScF) in employed in the 2025 mature technology scenarios.

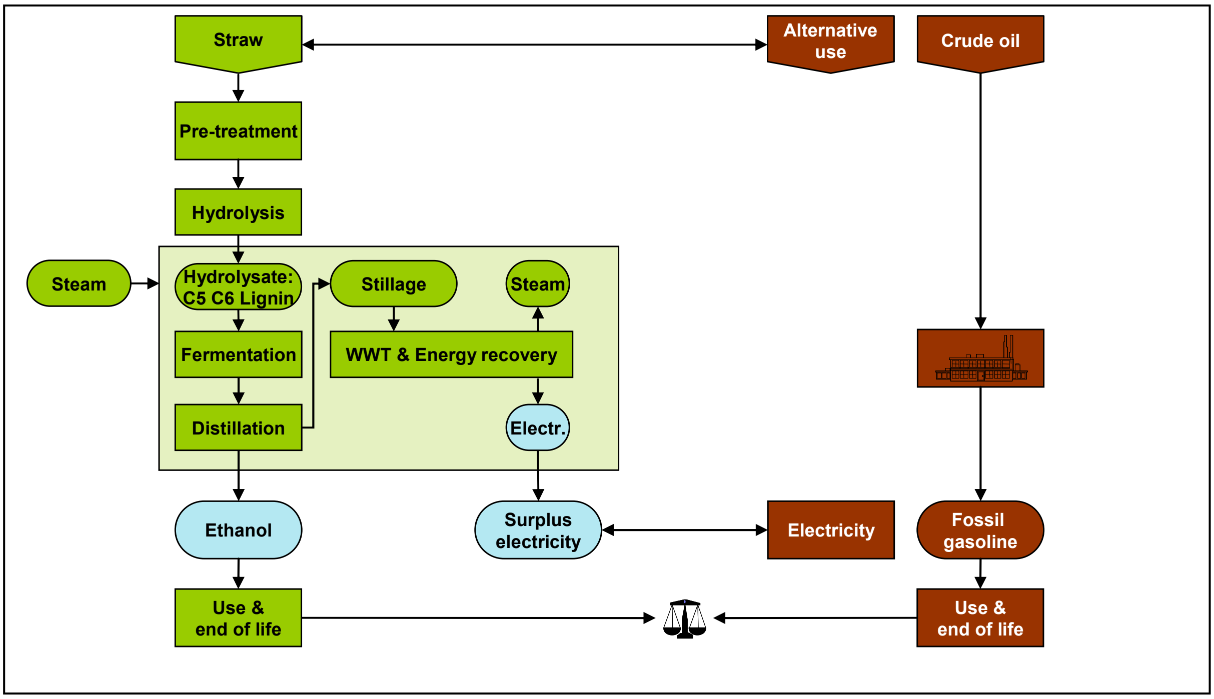


Fig. 3-2 Life cycle comparison between ethanol from straw (2015) and its reference products and processes (Scenario I). WWT: wastewater treatment.

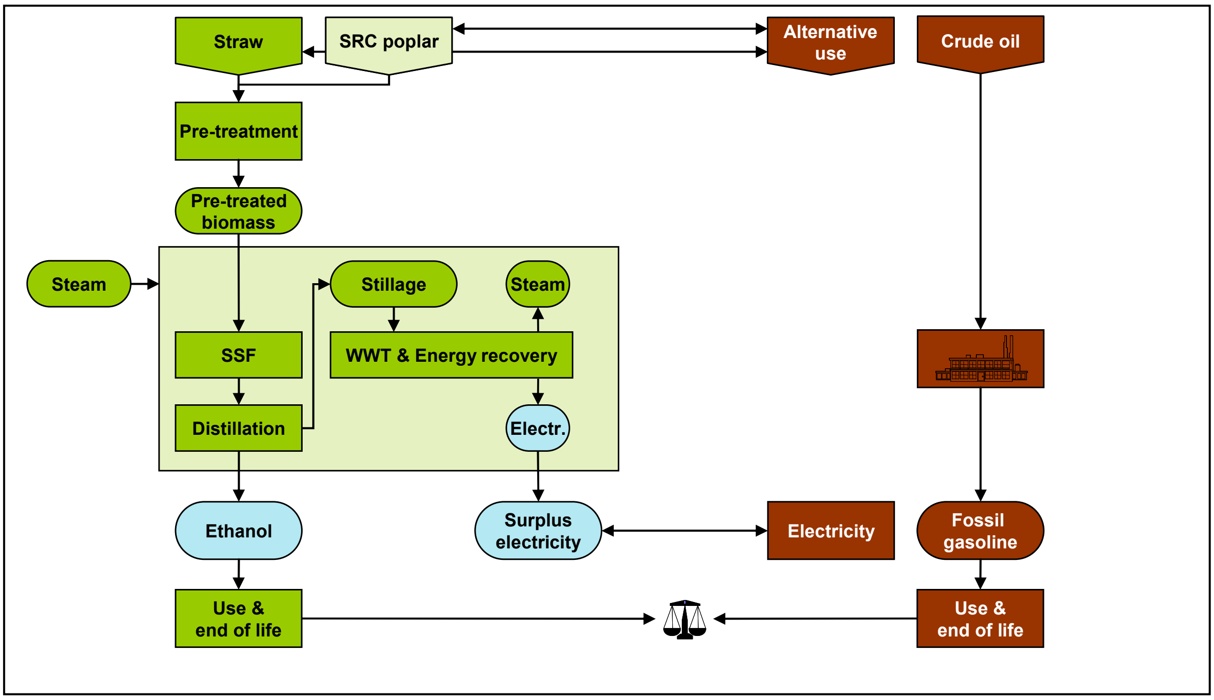


Fig. 3-3 Life cycle comparison between ethanol from straw (2025) or poplar (2025, light green) and their reference products and processes (Scenarios II and III, respectively). SSF: simultaneous saccharification and fermentation, WWT: wastewater treatment.

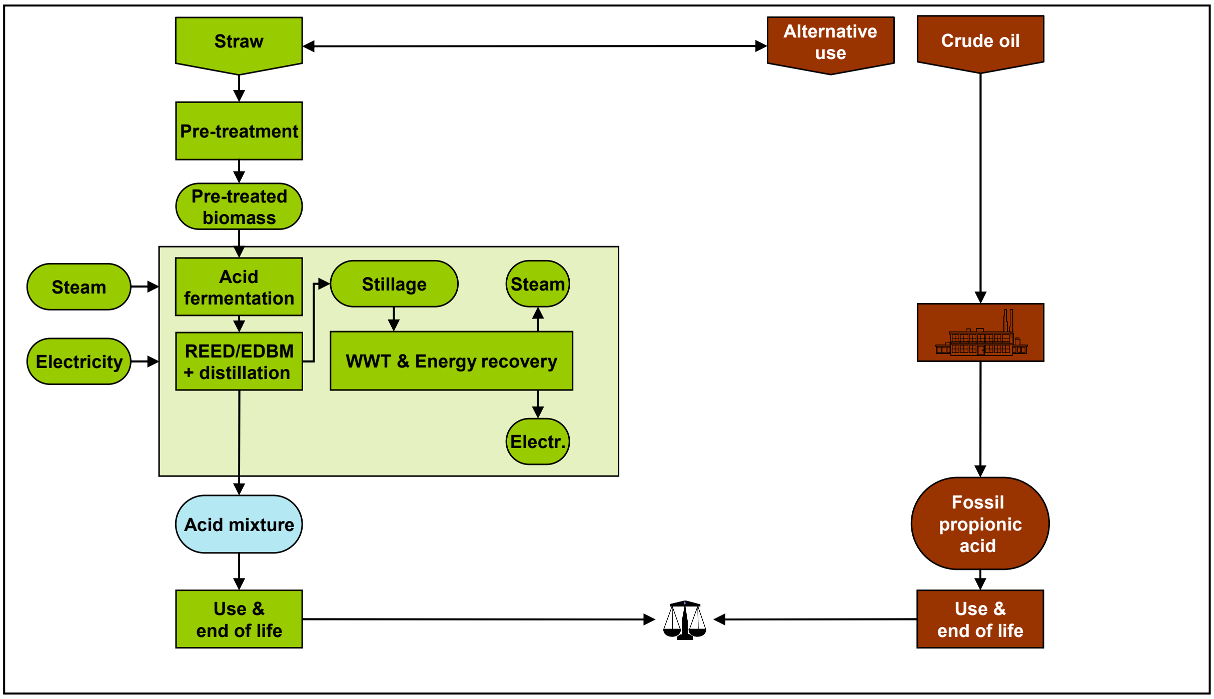


Fig. 3-4 Life cycle comparison between mixed acids from straw (2025) and their reference products and processes (Scenario IV). REED: reversed electro-enhanced dialysis, EDBM: electrodialysis using bipolar membranes.

For details on the processes including process flow sheets and mass and energy balances please refer to /Ljunggren et al. 2013/ and /Nygård et al. 2013/. A summary of the most important quantitative input data for the environmental assessment can be found in the annex in chapter 9.2.

Sensitivity analysis scenarios:

The efficiency of process energy generation is a very important parameter for the overall performance of the biorefinery because it determines whether additional energy input from fossil resources is required or if excess electricity can be fed into the power grid. Therefore, this section is studied in a separate sensitivity analysis as a variation of scenario II (Fig. 3-5).

Based on scenario II: Straw to Ethanol (2025)

II-1-A. Straw to Ethanol (2025) – Gas turbine (identical to main scenario)

II-1-B. Straw to Ethanol (2025) – Gas engine

II-2-A. Straw to Ethanol (2025) – Gas turbine and early solids separation

II-2-B. Straw to Ethanol (2025) – Gas engine and early solids separation

II-2-C. Straw to Ethanol (2025) – Circulating fluidized bed boiler and early solids separation

One varied parameter concerns the order of process steps: Solids can be separated from the stillage stream after anaerobic digestion (sub-scenarios 1-A and 1-B) or before anaerobic digestion (sub-scenarios 2-A, 2-B and 2-C). The other difference between the scenarios in the sensitivity analysis is the kind of CHP technology used for the co-production of steam and power. This can either be a gas turbine, a gas engine (both for the co-combustion of syngas and biogas) or a steam turbine, the latter being coupled to the boiler which co-combusts solids and biogas.

The standard biorefinery scenarios are based on a wastewater treatment (WWT) consisting of an activated sludge process (ASP) followed by reverse osmosis (RO), yielding recycled water (back to the biorefinery) and brine. The latter, however, still contains substantial amounts of N and P and needs further external sewage treatment before being released to a receiving water body. For details on the processes including process flow sheets and mass and energy balances please refer to /Ljunggren et al. 2013/ and /Nygård et al. 2013/. A summary of the most important quantitative input data for the environmental assessment can be found in the annex in chapter 9.2.

In SUPRABIO, an alternative WWT including algae production was investigated, too. The idea was to make use of the nutrients (N and P) still contained in the biorefinery wastewater. In this scenario, pre-treated wastewater (by means of ASP) is subjected to an ultrafiltration unit (UF) before entering the algae production process in open ponds (raceway configuration) under a greenhouse. Furthermore, it was assumed that the algae production could benefit from CO_2 originating from fermentation processes, and low temperature residual heat recovered from the core processes /Le & Lépine 2011/ and /Le Borgne 2014/.

However, since /Le Borgne 2014/ was not available by 30 September 2013 (project-internal deadline), this pathway could not be considered in the process integration work by Statoil. Therefore, this scenario cannot be evaluated quantitatively in this assessment due to a lack of detailed mass and energy flow data. Nevertheless, its advantages and disadvantages are discussed qualitatively.

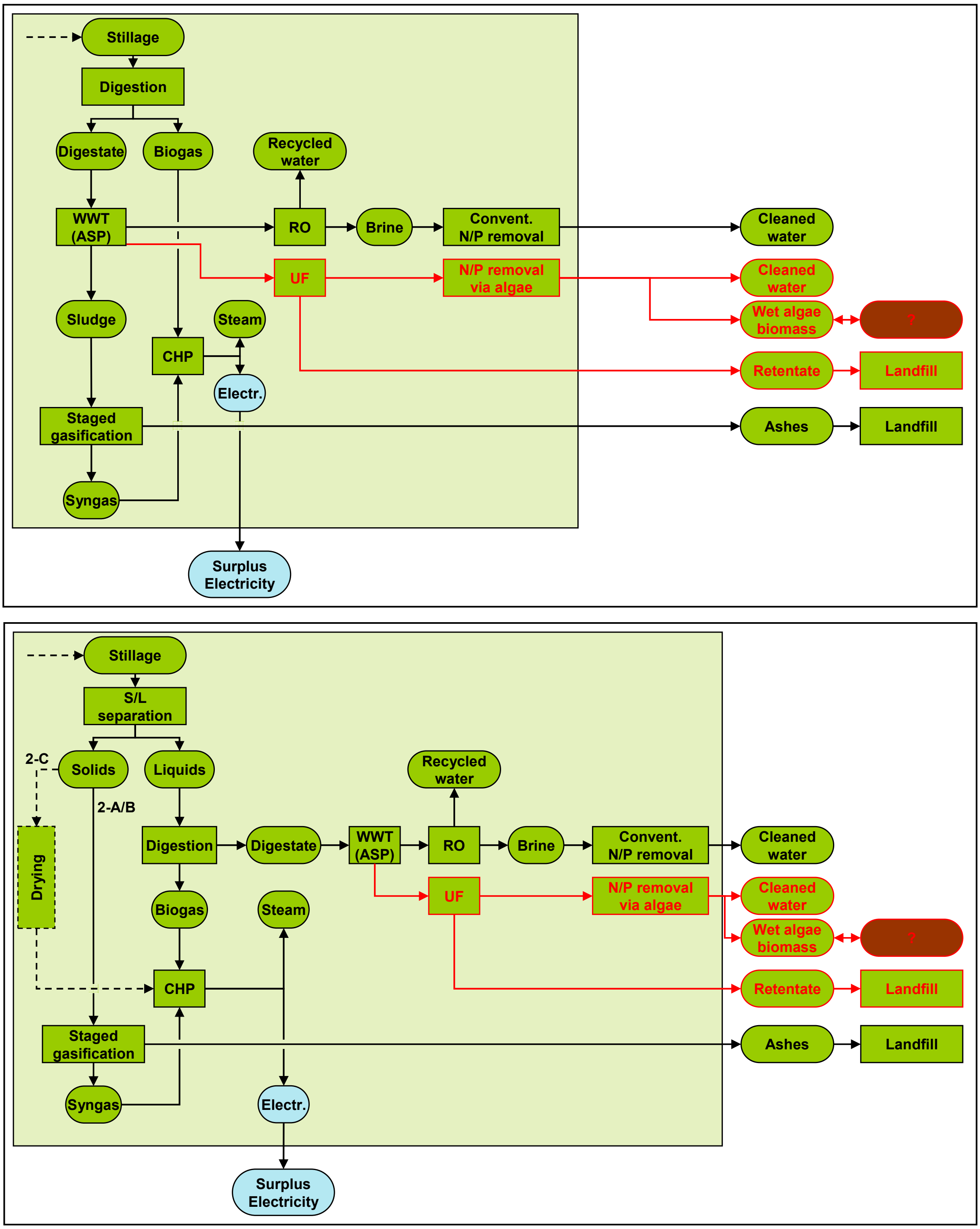


Fig. 3-5 Sensitivity analysis scenarios on co-product usage for biochemical route. Top: scenarios 1-A and 1-B; bottom: scenarios 2-A, 2-B and 2-C. Red elements indicate alternative process steps if algae production is integrated with the biorefinery. WWT (ASP): wastewater treatment by active sludge process, CHP: combined heat and power plant, RO: reverse osmosis, UF: ultrafiltration.

3.1.3.2 Thermochemical route

The thermochemical routes in the SUPRABIO concept are based on pyrolysis of lignocellulosic biomass. Scenarios differ in used feedstocks and final products. Additionally to wheat straw and poplar short rotation coppice, which can also be used by the assessed scenarios of the biochemical route, the thermochemical route can also use forestry residues as feedstock. The products of the thermochemical routes are Fischer-Tropsch (FT) fuels (synthetic diesel and a gasoline equivalent derived from bio-based naphtha) or dimethyl ether (DME), which is also used as transportation fuel.

Early implementation scenario:

I. Forest residues to FT fuels (2015)

Main scenarios (mature technology):

II. Forest residues to FT fuels (2025)

III. Forest residues to DME (2025)

IV. Straw to FT fuels (2025)

V. Poplar to FT fuels (2025)

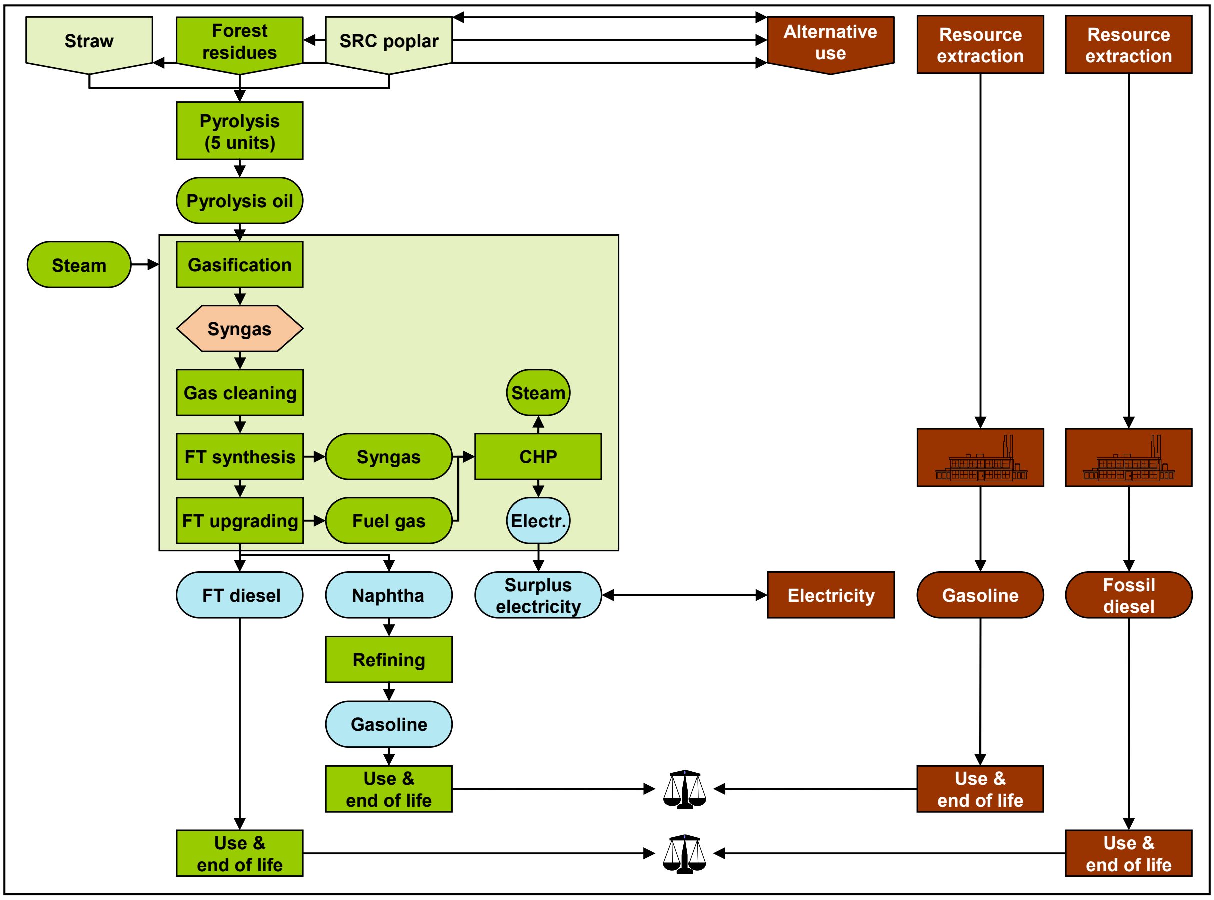


Fig. 3-6 Life cycle comparison between Fischer-Tropsch (FT) fuels from forest residues, straw or poplar short rotation coppice (SRC) (2025) and their reference products and processes (Scen. II, IV and V, resp.). CHP: combined heat and power plant

Simplified schemes of the whole life cycles of these processes, their products and the respective conventional reference processes and products can be found in Fig. 3-6 and Fig. 3-7.

The early implementation scenario (2015) is very similar to the mature technology scenario (2025). It is based on a smaller scale (40 kt/year instead of 400 kt/year) and operating conditions and performance parameters do not reach industrial level yet.

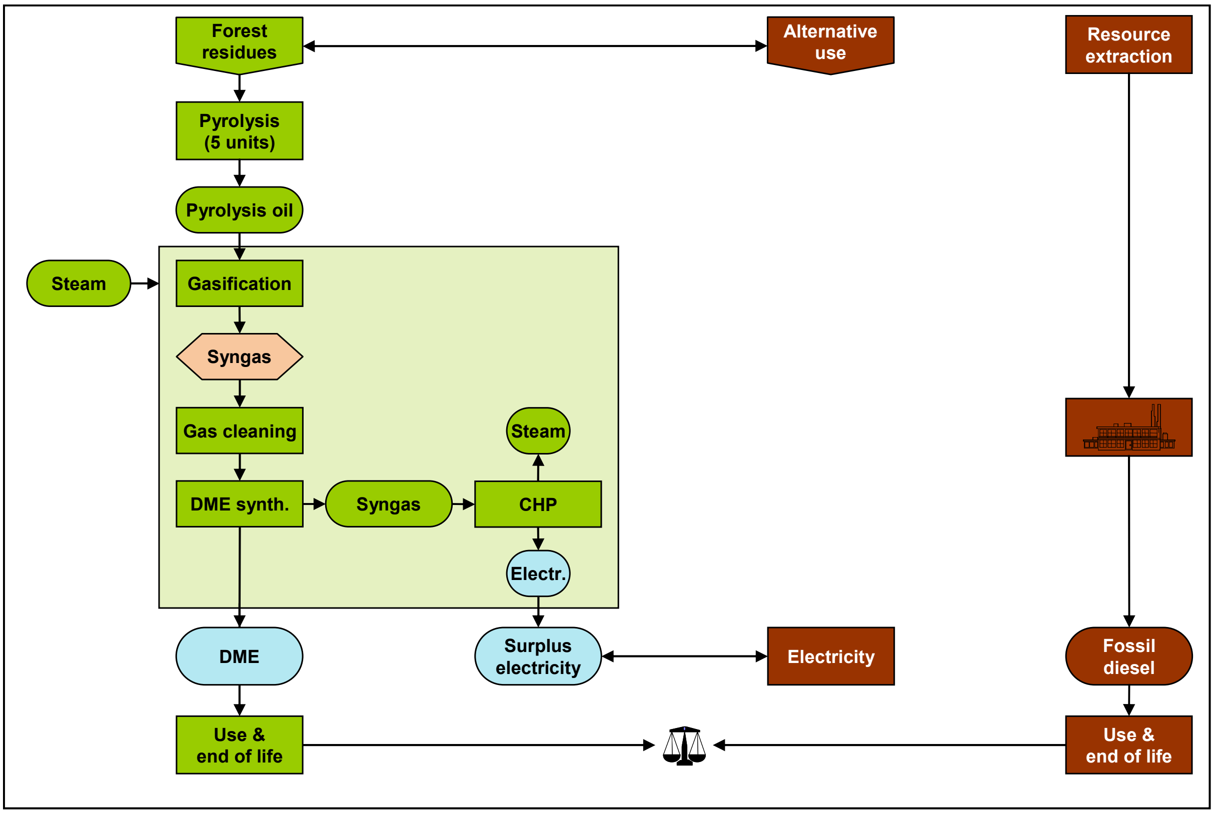


Fig. 3-7 Life cycle comparison between dimethyl ether (DME) from forest residues (2025) and its reference products and processes (Scenario III). CHP: combined heat and power plant.

Sensitivity analysis scenarios:

Several specific aspects of the thermochemical route, which are important for the overall performance of the process, are studied additionally in sensitivity analyses. One scenario investigates natural gas as an alternative energy input for the biorefinery. Another scenario analyses whether a central plant including one pyrolysis unit is better than the standard configuration with five distributed pyrolysis units. Two more scenarios concern crucial process parameters of the gasification unit within the biorefinery.

Based on scenario II: Forest residues to FT fuels (2025)

VI. Forest residues to FT fuels (2025) – Natural Gas

VII. Forest residues to FT fuels (2025) – Centralised

VIII. Forest residues to FT fuels (2025) – High pressure

IX. Forest residues to FT fuels (2025) – High pressure and quenching temperature

A life cycle scheme on these scenarios can be found in Fig. 3-8. For details on the processes including process flow sheets and mass and energy balances please refer to /Ochoa-Fernández et al. 2013/. A summary of the most important quantitative input data for the environmental assessment can be found in the annex in chapter 9.2.

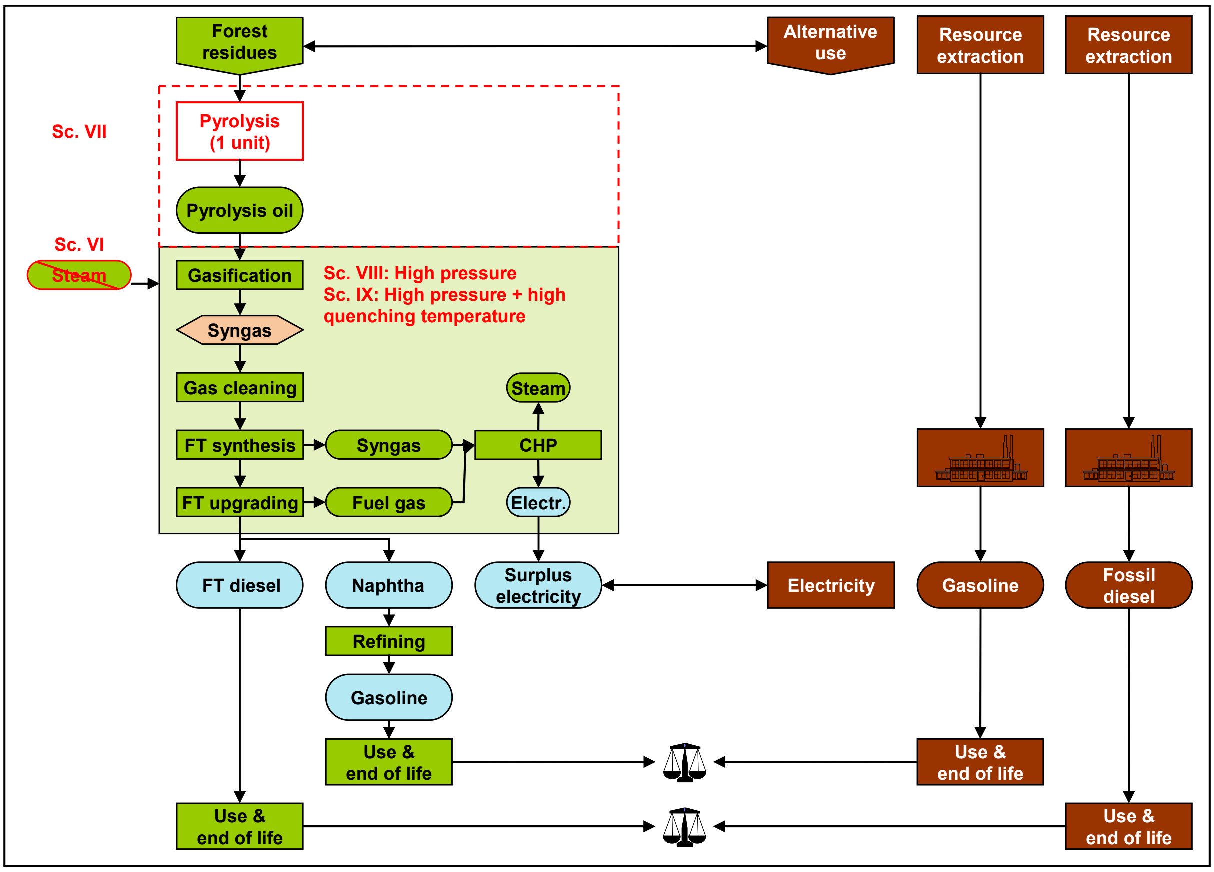


Fig. 3-8 Sensitivity analyses (Scenarios VI to IX). Differences to main scenario II (Forest residues to FT fuels, 2025) are indicated in red.

3.1.3.3 Other routes

Other routes are designed as add-ons to be integrated with the main biorefinery. They aim at using co-products of the biochemical or thermochemical core biorefinery (Fig. 3-9 and Fig. 3-10) but may alternatively also use a variety of other feedstocks in a stand-alone version.

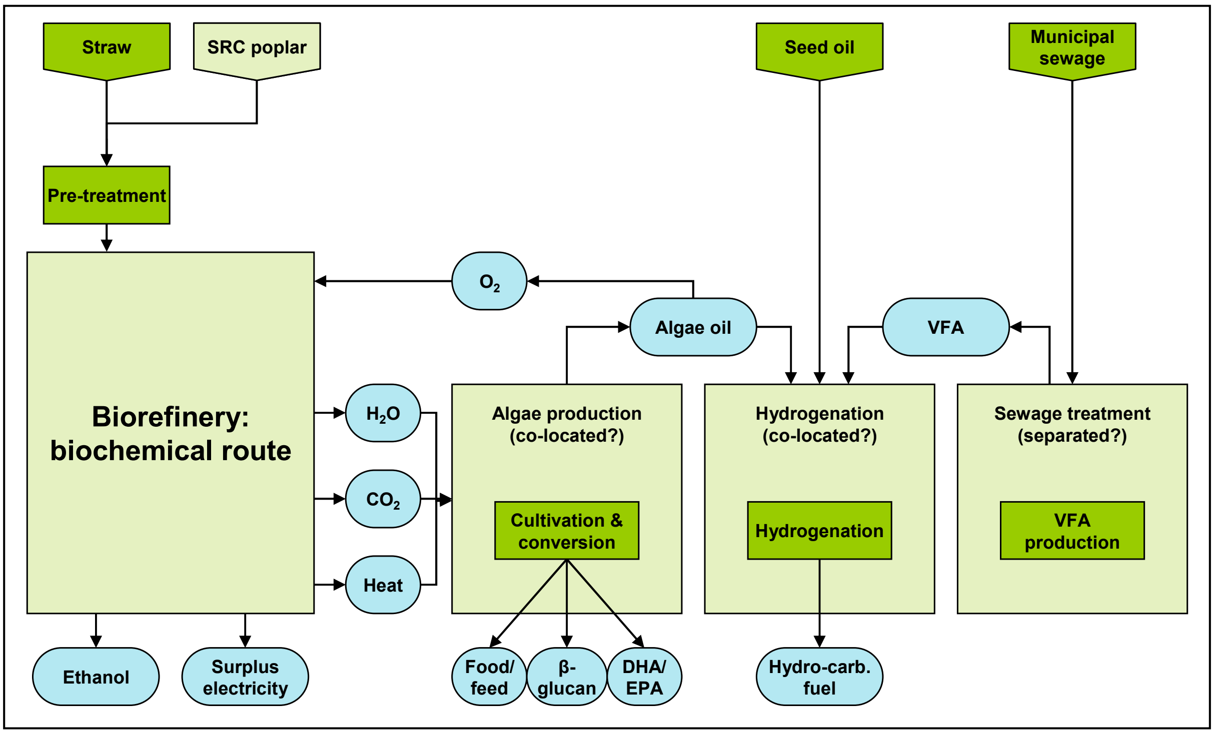


Fig. 3-9 Biochemical biorefinery and possible add-ons. For details and abbreviations please refer to the text.

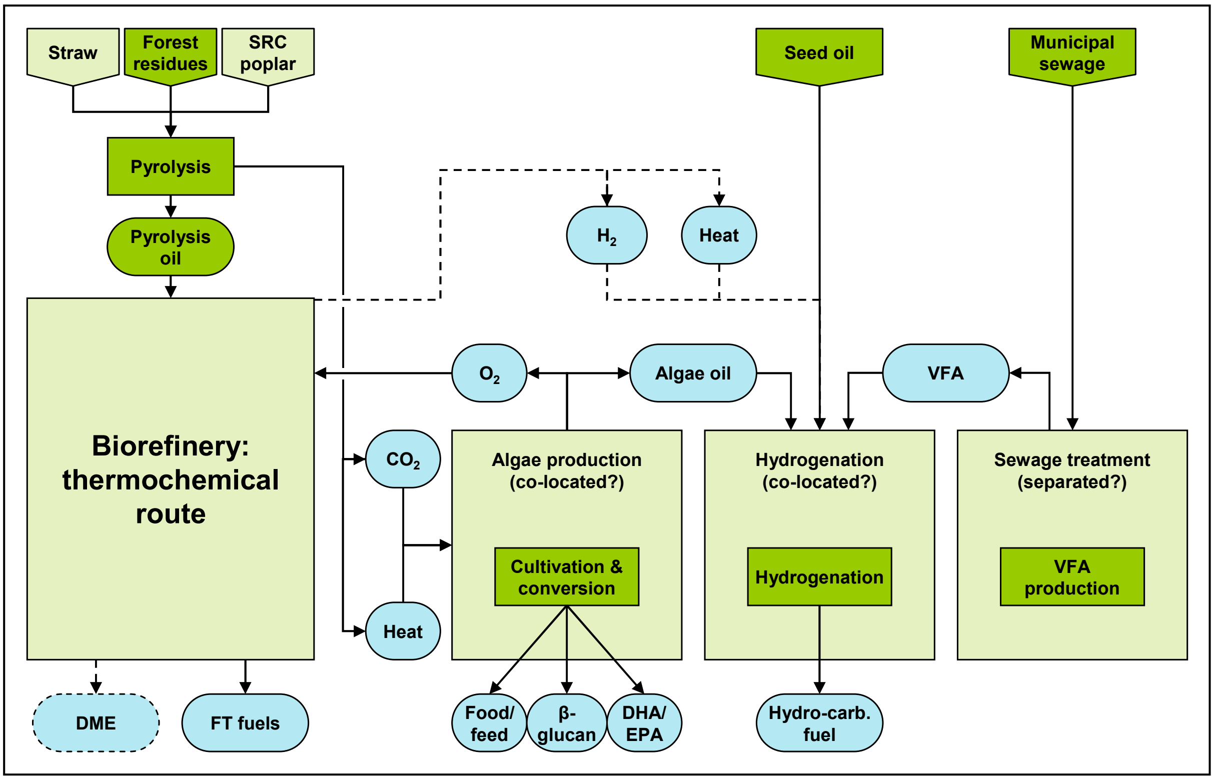


Fig. 3-10 Thermochemical biorefinery and possible add-ons. For details and abbreviations please refer to the text.

As there were no robust mass and energy balances available within the SUPRABIO project, these routes can only be evaluated in a qualitative way where possible. Please refer to /Nygård et al. 2013/ for technical details. The following other routes are part of the SUPRABIO biorefining concept:

Mixed alcohols from volatile fatty acids (VFA)

Short chained volatile fatty acids (VFA) are produced via fermentation from organic matter contained in municipal sewage. Then they are hydrogenated to yield mixed alcohols that can be used as biofuel. The required hydrogen was planned to be supplied by the core biorefinery. However, since /Barta 2013a/ and /Barta 2013b/ were not available by 30 September 2013 (project-internal deadline), this pathway could not be considered in the process integration work by Statoil. Therefore, this route cannot be evaluated in this assessment due to a lack of detailed mass and energy flow data.

EPA / DHA and β-glucan from algae

In SUPRABIO, the production of high-value dietary supplements from algae such as docosahexaenoic acid (DHA), its precursor eicosapentaenoic acid (EPA) and β-glucan was investigated. However, due to a change of partners, this work will only be completed by the end of the project. This means that at the time of writing this report, the algae production process and its potential links to the core biorefinery have not been defined yet. Therefore, this route cannot be evaluated in this assessment.

Seed oil hydrogenation

This route concerns the hydrogenation of seed oils (also called vegetable oils) to yield biofuels (HVO, hydrogenated vegetable oils). Feedstocks include rapeseed, oil palm, soybean or Jatropha. Hydrogenation of vegetable oils is a state-of-the-art process established at industrial scale, e.g. by Neste Oil who operates a plant in Porvoo, Finland, and a 800 kt plant in Rotterdam, the Netherlands.

The main advancement of SUPRABIO was the development of a staged introduction of hydrogen into the reactor. The required hydrogen and possibly also heat was planned to be delivered by the core biorefinery. A further integration potential was envisioned by using algae oils (see above) or volatile fatty acids (VFA, see above). However, since /Barta 2013a/ and /Barta 2013b/ were not available by 30 September 2013 (project-internal deadline), this pathway could not be considered in the process integration work by Statoil. Therefore, this route cannot be evaluated in this assessment due to a lack of detailed mass and energy flow data.

Nevertheless, seed oil hydrogenation is assessed generically as a stand-alone plant based on published data on existing HVO plants to outline the potentials and risks of this route. As there is no project-specific data involved in the assessment, this route is not listed as SUPRABIO scenario but as alternative to SUPRABIO to avoid misunderstandings.

3.1.4 Use and end of life

Use and end of life of all biorefinery products are taken into account in the sustainability assessment, too. Most SUPRABIO products are primarily used as biofuels. These are ethanol, butanol, FT diesel and dimethyl ether (DME). Hydrogenated vegetable oils (HVO), which are assessed generically in this study, are used as biofuel, too. For all fuels, combustion in a motor represents the use and end of life stage. Mixed acids are used as cereal grain preservatives. They remain on the cereals in the further animal feed production process. Therefore, there is no end of life treatment.

Depending on the scenario, co-products of SUPRABIO biorefineries can be surplus electricity and ashes from combustion of process residues. Electricity is fed into the power grid and ashes are landfilled.

3.1.5 Reference systems for SUPRABIO

The purpose of this environmental assessment is to compare the impacts of the whole life cycles of SUPRABIO biorefinery products to the impacts that would arise from alternative processes and products, which would be used if no SUPRABIO biorefinery was built. The comparison on the product level is based on equivalent utility of innovative and replaced conventional products (chapter 3.1.5.2). Furthermore, the alternative use of resources such as agricultural land and agricultural or forestry residues has to be considered: what would happen to them if they weren't used by the biorefinery. This is described in the chapter on reference systems (3.1.5.1).

3.1.5.1 Reference systems for land use and biomass use

The initial part of the assessment focussing on the SUPRABIO biorefinery concept is based on the precondition that sufficient biomass or agricultural land is available. Independent of how much unused biomass or agricultural land may be available in reality in 2015 or 2025, this precondition allows to independently assessing the SUPRABIO biorefinery and its optimisation options before comparing it to alternative use options of biomass or agricultural land in a second step (chapter 3.2). Thus, the implementation of the SUPRABIO biorefinery concept is compared to not extracting agricultural residues and forestry biomass or not using the agricultural land.

Nevertheless, these reference systems can still cause environmental benefits (e.g. remaining straw serves as fertiliser reducing the demand for mineral fertiliser) or environmental burdens (e.g. nitrogen deposited from the air on idle land causes environmental burdens). These environmental impacts of the reference system are credited to the SUPRABIO biorefinery, which leads to the reduction of its environmental impacts (if burdens are avoided) or to additional impacts (if benefits are prevented). These reference systems are part of the life cycles of the SUPRABIO scenarios.

Table 3-1 Feedstocks for the SUPRABIO biorefining concept and their reference systems

Feedstock type	Feedstock	Reference system
Agricultural residues	Wheat straw	Ploughing in, serves as fertiliser
Forestry residues	Residues such as branches or thin tops (non-stem wood)	Remain in forest to decompose
Agricultural biomass	Poplar short rotation coppice (SRC)	No production, land is laying idle (Europe: non-rotational fallow land without significant accumulation of carbon stocks)
	Rapeseed	Non-rotational fallow land (EU)
	Oil palm	a) Idle land b) Rainforest
	Soybean	a) Idle land b) Rainforest
	Jatropha	a) Idle land (good soil) b) Marginal land c) Woodland

3.1.5.2 Reference products

Reference products are conventional products that are replaced by biorefinery products. Their complete life cycles are assessed and compared to the complete life cycles of the SUPRABIO products.

For all biofuels, the reference products are equivalent amounts of fossil fuels. Depending on whether the biofuel is used in diesel or gasoline engines, conventional diesel or gasoline are replaced. The replaced amount is based on the distance that can be travelled using either fuel in a standard car. Mixed acids are compared to equivalent synthetic organic acids (butyric or propionic acid), which are made from fossil resources.

The co-product electric power replaces conventionally produced power in the grid. As this study follows a consequential approach and thus its influence on the energy sector has to be taken into account, power consumption is assessed following a marginal concept /Fraunhofer ISI 2009/, /UBA 2013/. According to this, additionally produced power of new plants such as biorefineries prevents either new power plants to be built or causes old power plants to be shut down earlier. Based on the assumption that renewable energies mainly compete with fossil energy sources rather than with each other due to political boundary conditions, the bandwidth of marginal energy sources ranges from natural gas to hard coal (see chapter 9.2.3 for details on LCA input data).

For all qualitative parts of the sustainability assessment, those steps in the life cycles of all reference products have to be identified, which are most relevant regarding environmental impacts. In the case of SUPRABIO, all replaced main products are largely produced from petroleum fractions. Thus, crude oil extraction and refining are key processes for all reference products and for some also petrochemical processes are important. Furthermore, some scenarios produce electricity as a co-product. In this case, extraction and conversion of other conventional energy resources such as coal, gas and uranium are relevant for the reference products' life cycles, too.

3.1.6 Overview of scenarios

3.1.6.1 Biochemical route

Table 3-2 SUPRABIO scenarios for the biochemical route

Number	Name
Early implementation	
I	Straw to Ethanol (2015)
Main scenarios (mature technology)	
II [= II-1-A]*	Straw to Ethanol (2025)
III	Poplar to Ethanol (2025)
IVa/b	Straw to Mixed Acids (2025)
Sensitivity analysis scenarios	
II-1-B	Straw to Ethanol (2025) – Gas engine
II-2-A	Straw to Ethanol (2025) – Gas turbine and early solids separation
II-2-B	Straw to Ethanol (2025) – Gas engine and early solids separation
II-2-C	Straw to Ethanol (2025) – Boiler and early solids separation

*: All main scenarios use gas turbines for energy production from co-products.

3.1.6.2 Thermochemical route

Table 3-3 SUPRABIO scenarios for the thermochemical route

Number	Name
Early implementation	
I	Forest residues to FT fuels (2015)
Main scenarios (mature technology)	
II	Forest residues to FT fuels (2025)
III	Forest residues to DME (2025)
IV	Straw to FT fuels (2025)
V	Poplar to FT fuels (2025)
Sensitivity analysis scenarios	
VI	Forest residues to FT fuels (2025) – Natural Gas
VII	Forest residues to FT fuels (2025) – Centralised
VIII	Forest residues to FT fuels (2025) – High pressure
IX	Forest residues to FT fuels (2025) – High pressure and quenching temperature

3.1.6.3 Other routes

HVO from rapeseed, oil palm, soybean and Jatropha are assessed on a generic level as a stand-alone plant. As these processes cannot be distinguished from competitors' processes, they are listed as alternatives to SUPRABIO (chapter 3.2).

3.2 Alternative biomass-based systems

Biomass and agricultural land are limited resources. There is considerable uncertainty regarding the extent of underutilised biomass and land potentials that are available for bioenergy, biofuels, biomaterials and bio-based chemicals production in 2025. Nevertheless, most studies agree that there will be at least some biomass and land available for these purposes but that it will not be sufficient to realise all expansion plans in the respective sectors. Therefore, SUPRABIO competes with alternative biomass-based systems for resources. These alternatives are assessed in this environmental assessment as well including their whole life cycles and the whole life cycles of the conventional (mostly fossil resource-based) products they replace (reference systems). This chapter introduces the assessed scenarios of alternative biomass-based systems and their reference systems.

The scenarios for alternative biomass-based systems are based on the same precondition that there is sufficient biomass and agricultural land available. Competition between alternatives and SUPRABIO scenarios is analysed by comparing the assessment results of all competing scenarios in a kind of meta-comparison in a second step.

3.2.1 Biomass

Biomass can be used in various alternative ways besides in a SUPRABIO biorefinery. For lignocellulosic feedstocks other than solid wood, the most important alternative is direct combustion for heat and power production. This is assessed for all lignocellulosic SUPRA-BIO feedstocks. Comparisons are made on a feedstock basis (per tonne of dry matter).

3.2.2 Agricultural land

If cultivated biomass is used as feedstock, agricultural land is required for its production. In that case, the land could also be used for alternative purposes. The alternative scenarios for energy and fuel production in Europe listed in Table 3-4 are analysed in this study. For a detailed description please refer to the annex (chapter 9.1).These comparisons are made on a land use basis (per hectare and year).

Table 3-4 Alternative uses of agricultural land in Europe (other than for SUPRABIO)

Feedstock	Product	Reference product
Sugar beet, wheat grains and maize grains	Bioethanol (transportation fuel)	Gasoline
Rapeseed	Biodiesel (transportation fuel)	Diesel
Rapeseed	Hydrogenated vegetable oil (HVO, transportation fuel)	Diesel
Maize (whole plant)	Biogas (CHP fuel)	Heat and power
Triticale (whole plant)	CHP fuel	Heat and power

Furthermore, production of hydrogenated vegetable oils (HVO) from following non-European feedstocks is assessed for comparison: palm oil, soy oil and Jatropha oil.

All reference products in these alternative scenarios are based on fossil feedstocks. They are assessed as described in chapter 3.1.5.2 for the reference products of SUPRABIO products.

4 Screening life cycle assessment

4.1 Methodology

4.1.1 Introduction to LCA methodology

The life cycle approach

Life cycle assessment (LCA) addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of emissions) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal. The approach is therefore often called cradle-to-grave, well-to-wheel (fuels) or farm-to-fork (food) (see also Fig. 2-2).

LCA methodology is laid down in important regulatory frameworks: two ISO standards and the ILCD Handbook. Both standards are taken into account.

The ISO standards 14040 and 14044

Life cycle assessment (LCA) is structured, comprehensive and internationally standardised through ISO standards 14040:2006 and 14044:2006 /ISO 2006/. The screening LCA in this study is carried out largely following these ISO standards on product life cycle assessment.

According to ISO standards, a LCA consists of four iterative phases:

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

In chapters 4.1.2 to 4.1.6 the LCA approach for SUPRABIO is described according to these elements.

The ILCD handbook

The ISO 14040 and 14044 standards provide the indispensable framework for life cycle assessment (LCA). This framework, however, leaves the individual practitioner with a range of choices, which can affect the legitimacy of the results of an LCA study. While flexibility is essential in responding to the large variety of questions addressed, further guidance is needed to support consistency and quality assurance. The International Reference Life Cycle Data System (ILCD) has therefore been developed to provide guidance and specifications that extend the ISO 14040 and 14044 standards for consistent and quality assured life cycle assessment data and studies. In contrast to the ISO standards on LCA, which have been available and used for many years, the ILCD Handbook was only launched recently /JRC-IES 2012/. Nevertheless, the screening LCA carried out for SUPRABIO takes into account the major requirements of the ILCD Handbook.

4.1.2 Goal definition

The goal and scope definition is the first phase of any life cycle assessment. The goal definition covers among others the identification of the intended application(s) and target audience(s). Furthermore, the decision-context is described and the commissioner is named.

Intended application(s) and target audience(s)

Several, separate applications are intended by this LCA study. Goal and scope questions to be answered by this study are listed in chapter 2.1.3. These questions comprise the applications of project-internal support of process design as well as information and support for external decision-makers in politics, industry and research.

Method, assumption and impact limitations

The selection of the impact categories must be consistent with the goal of the study and the intended applications of the results, and it must be comprehensive in the sense that it covers all the main environmental issues related to the system.

Impact categories not tick-marked in Table 2-1 are excluded. These are:

- Ionising radiation (not relevant in the case of SUPRABIO)
- Human toxicity and ecotoxicity (insufficient LCI data quality, see below)
- Resource depletion: water (covered by LC-EIA, cf. chapter 5)
- Land use (covered by LC-EIA, cf. chapter 5)

In the case of human toxicity and ecotoxicity, which cover an extensive list of substances, LCI data quality for 2025 is a limiting factor. The data available today is not suitable to derive results, which are balanced enough for decision support. Therefore, these categories are excluded from the LCA. Instead, important ecotoxicity impacts on biodiversity are covered within the LC-EIA part.

Reasons for carrying out the study and commissioner

This LCA study is carried out because the SUPRABIO consortium has decided to supplement the development of a biorefinery concept with a life cycle assessment (as part of an integrated assessment of sustainability). The study is commissioned by the EU Commission via the grant agreement.

Decision-context

The decision-context is one key criterion for determining the most appropriate methods for the so-called life cycle inventory (LCI) model, i.e. the LCI modelling framework (see chapter 4.1.4). The ILCD handbook differentiates three decision-context situations (see Table 4-1). These situations differ regarding the question whether the LCA study is to be used to support a decision on the analysed system (e.g. product or strategy),

- and, if so: by the extent of changes that the decision implies in the background system and in other systems because of market mechanisms. These can be "small" (small-scale, non-structural) or "big" (large-scale, structural).

- and, if not so: whether the study is interested in interactions of the depicted systems with other systems (e.g. recycling credits) or not.

Consequences are considered large scale if the annual additional demand or supply, triggered by the analysed decision, exceeds the capacity of the annually replaced installed capacity of the additionally demanded or supplied process, product, or broader function, as applicable.

Situation B is considered to apply for the main pathways of SUPRABIO, since its main applications are policy information and development. It is assumed that the implementation of a SUPRABIO biorefinery would have consequences that are so extensive that they overcome thresholds and – via market mechanisms – result in additionally installed or additionally decommissioned equipment / capacity (e.g. production infrastructure) somewhere else.

Table 4-1 Combination of two main aspects of the decision-context: decision orientation and kind of consequences in background system or other systems /JRC-IES 2012/

<table>
<tr><td rowspan="4">Decision support?</td><td rowspan="3">Yes</td><td colspan="2">Kind of process-changes in background system / other systems</td></tr>
<tr><td>None or small-scale</td><td>Large-scale</td></tr>
<tr><td>Situation A
“Micro-level decision support”</td><td>Situation B
“Meso/macro-level decision support”</td></tr>
<tr><td>No</td><td colspan="2">Situation C
“Accounting”</td></tr>
</table>

Comparisons intended to be disclosed to the public

This study includes comparisons of the overall environmental impact of two or more systems and is planned to be disclosed to the public. Among others, the performance of SUPRABIO systems is compared to other uses of the (same) raw material, e.g. the use of wheat straw for heat and power generation in a CHP plant (instead of using the wheat straw in the biorefinery). Usually, this aspect entails a number of additional mandatory requirements under ISO 14040 and 14044 on the execution, documentation, review and reporting of the LCA study due to the potential consequences the results may have for e.g. external companies, institutions, consumers, etc.

However, since these comparisons are made on a generic level, we think that statements regarding superiority, inferiority or equality of alternatives do not affect specific companies, institutions and stakeholders. Thus, these comparisons – in our opinion – can be disclosed to the public even without entirely fulfilling the ISO requirements.

4.1.3 Scope definition

During scope definition, the object of the LCA study (i.e. the exact product or other system(s) to be analysed) is identified and described. This has to be in accordance with the goal definition. The main objective of the scope definition is to derive the requirements on methodology, quality, reporting, and review.

Functional unit

The principal functional unit used in SUPRABIO is 1 tonne of dry biomass leaving the field. For questions related to land use by dedicated biomass crops, results are expressed per hectare and year of land use (ha · a).

System boundaries

System boundaries specify which unit processes are part of the product system and thus included into the assessment.

The screening LCA for SUPRABIO takes into account the entire value chain (life cycle) from the feedstock production to the distribution and usage of the final products (see Fig. 4-1).

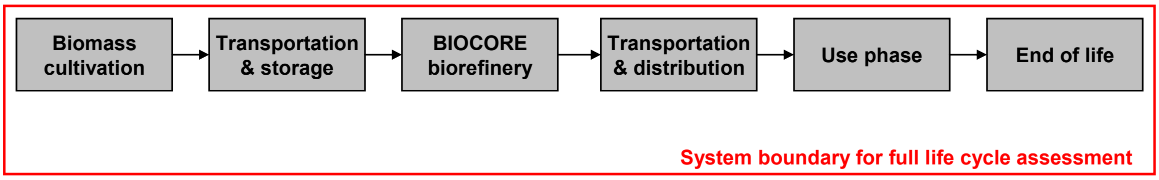


Fig. 4-1 System boundaries applied in the case of SUPRABIO

Infrastructure, i.e. the production and processing equipment, vehicles, buildings and streets connected with the crop's production and use is not included in the inventory, except for background data (generic LCI databases such as ecoinvent may include infrastructure with no possibility to exclude it). In many LCAs assessing bioenergy systems it was shown that infrastructure accounts for less than 10 % of the overall results (see /Nitsch et al. 2004/, /Fritsche et al. 2004/ and /Gärtner 2008/). Please note that this applies for the environmental assessment only: in the economic assessment for SUPRABIO, infrastructure is covered.

Biogenic carbon

Carbon dioxide (CO_2) emissions can originate from either (recent) biogenic or fossil carbon stocks. In the case of biofuels, the amount of CO_2 released into the atmosphere from direct biofuel combustion equals the amount of CO_2 that recently has been taken up by the plants (short carbon cycle). This release of biogenic CO_2 is considered carbon neutral, i.e. it does not fuel climate change. Therefore, the standard approach among LCA practitioners is to only take into account the fossil carbon. In contrast, the ILCD Handbook stipulates to take into account biogenic carbon emissions, too, but also the uptake of atmospheric carbon by plants (ILCD provision 7.4.3.7). Within SUPRABIO, biogenic carbon is accounted for, but for clarity reasons, biogenic CO_2 uptake and emissions are not displayed in the result graphs.

Direct land use change

Life cycle assessment in SUPRABIO covers direct land use change and related changes in organic carbon stocks of above- and below-ground biomass, soil organic carbon, litter and dead wood /IPCC 2006/. Changes in organic carbon stocks may occur in case woody biomass or straw that formerly remained in the field / in the forest is now extracted for biorefining. In this case the carbon stock changes and resulting release of greenhouse gases – mainly in the form of CO_2 – are integrated into the GHG balances. The methodologies described by the IPCC guidelines for national greenhouse gas inventories /IPCC 2006/ and the guidelines for the calculation of land carbon stocks for the purpose of Annex V to EU RED /EC 2010a/ are used.

As far as changes in soil organic carbon stocks are concerned, soil carbon sequestration, is not taken into account. This is because the potential to sequester carbon in soils is very site-specific and highly dependent on former and current agronomic practices, climate and soil properties /Larson 2005/. Moreover, there is no guarantee that the carbon is sequestered permanently, i.e. taken out of the carbon cycle. As there is no scientific consensus about this issue, carbon sequestration in agricultural soils is not accounted for.

Indirect effects

Establishing new biomass use systems may have indirect effects on environmental indicators by withdrawing resources from other (former) uses. One of the most common indirect effects is indirect land use change: If biomass formerly used for other purposes – e.g. as food or feed – is now used for biorefining, food or feed have to be produced elsewhere, potentially causing a clearing of (semi)natural ecosystems (=indirect land use change) and hence changes in organic carbon stocks and damages to biodiversity. Indirect land use changes are discussed qualitatively as there is no scientific consensus about an appropriate quantification yet.

Withdrawing biomass from other uses may affect not only land use patterns but also other goods and services. For example: if a SUPRABIO biorefinery turns out to be less efficient compared to another energetic biomass use option (e.g. CHP plants) in terms of replacing crude oil equivalents, but more efficient from an economic point of view SUPRABIO might withdraw biomass from other energetic use pathways and hence increase the net crude oil demand. This kind of indirect effects is covered by comparing SUPRABIO systems to alternative biomass and land use options.

Carbon storage in products and delayed emissions

Carbon storage time is expected to be much less than 100 years for all SUPRABIO products. As a result, delayed emissions are not addressed.

4.1.4 Settings for Life Cycle Inventory Analysis (LCI)

Technical reference, time frame and geographical coverage

See chapter 3.1.3.

Data sources

Since the different SUPRABIO systems are multi-input / multi-output systems, they require a multitude of data for calculating the different scenarios.

Primary data:

- Data on biomass pre-treatment and conversion processes within the SUPRABIO biorefinery are provided by the project partners via WP 5.

Secondary data:

- Biomass and energy provision were modelled by IFEU. A summary of this data can be found in chapter 9.2 in the annex.

- Data on background processes (e.g. upstream products and conventional reference products of the SUPRABIO products) are provided by IFEU. The principal source of secondary data is ecoinvent V2.2 /ecoinvent 2010/.

All processing steps are analysed based on estimates for industrial plants. Where no specific data are available, generic data is used.

Attributional vs. consequential modelling

The identification of the most appropriate LCI modelling principles and method approaches is closely linked to the classification of the LCA work as belonging to one of three distinct decision-context situations /JRC-IES 2012/. Since – according to chapter 4.1.2 – Situation B applies for SUPRABIO, consequential modelling is applied.

Solving multifunctionality

Closely related to the choice of the appropriate LCI modelling framework is the choice of how to solve multifunctionality of processes and products. If a process provides more than one function, i.e. delivering several goods and/or services (often also named simplified "co-products"), it is “multifunctional”. Biorefining typically entails multiple co-products with different functions, e.g. biofuels, biochemicals and/or bio-based products.

Since SUPRABIO is classified as belonging to Situation B (meso/macro-level decision support), the substitution approach is used. Additionally, allocation is applied in a sensitivity analysis, in which GHG balances are calculated according to the rules laid down in Annex V of the EU RED /EP & CEU 2009b/.

4.1.5 Settings for Life Cycle Impact Assessment (LCIA)

Impact categories and LCIA methods

Life Cycle Impact Assessment (LCIA) methods exist for midpoint and for endpoint level. This study follows a midpoint indicator approach. The midpoint indicators tick-marked in Table 2-1 are used. The selected impact categories are well-established categories in life cycle assessments /JRC-IES 2012/. The ReCiPe 2008 method /Goedkoop et al. 2013/ was chosen in the inter-project harmonisation process because it covers all impact categories in a consistent way.

Deviating from this principal selection, ozone depletion is assessed according to /Ravishankara et al. 2009/, which in contrast to the ReCiPe method takes the impact of N_2O emissions on ozone depletion into account. In all assessed scenarios, the contribution of N_2O emissions to ozone depletion is at least about 10-fold higher than the contributions of all other substances together according to this impact assessment method. The reason is that biomass related systems are assessed, which lead to considerable N_2O emissions throughout their life cycles. The exact impact of N_2O on ozone depletion is still debated in the scientific community but if the order of magnitude suggested by /Ravishankara et al. 2009/ is correct, then N_2O emissions are dominating this environmental impact for the assessed systems. Therefore, the ReCiPe impact assessment method, which does not take N_2O emissions into account, was considered to lead to distorted conclusions and the impact assessment method according to /Ravishankara et al. 2009/ was used instead.

Furthermore, the ReCiPe indicator “Fossil fuel depletion” was substituted by the indicator cumulative non-renewable energy demand (“Resource depletion non-renewable energy”) because the latter takes nuclear energy into account, too. Depletion of ores used for the production of nuclear energy is accounted for by the ReCiPe indicator “Mineral resource depletion”, which is not used in this study. A joint LCIA category for depletion of non-renewable energy resources yields more robust results in the context of this study because the share of power from nuclear power plants varies considerably within the reference area (EU and India). Therefore, this deviation from ReCiPe allows a more direct interpretation of results. To avoid confusion of cumulative non-renewable energy demand with the ReCiPe indicator, the former is expressed in the unit MJ per functional unit instead of kg oil equivalent per functional unit.

Normalisation

Normalisation is an optional element in LCAs. Hereby, the magnitude of the category indicator results relative to some reference information is calculated. In the SUPRABIO LCA study, the environmental advantages and disadvantages are in some cases put into relation with the environmental situation in the EU25+3. The reference information is the yearly average resource demand and the average emissions of various substances per capita in Europe, the so-called inhabitant equivalent (IE). The reference values are presented in Table 4-2 for all environmental impact categories.

Table 4-2 EU 25+3 inhabitant equivalents (IE) for the year 2000 /Goedkoop et al. 2013/, /Ravishankara et al. 2009/ and /Eurostat 2007/

Impact category	Inhabitant equivalent	
	Hierarchist	
Climate change	11215.12	kg / yr
Ozone depletion *	0.07	kg / yr
Photochemical oxidant formation	53.15	kg / yr
Particulate matter formation	14.90	kg / yr
Terrestrial acidification	34.37	kg / yr
Freshwater eutrophication	0.41	kg / yr
Marine eutrophication	10.10	kg / yr
Resource depletion: Non-renewable energy *	82.09	GJ / yr

*: As described above, these indicators deviate from the ReCiPe methodology and thus adapted normalisation factors were used.

Due to the uncertainty related to future emissions of various substances, the IE are calculated based on 2000 emissions. These values are subsequently used to normalise data which are calculated for 2015 and 2025 (time frame for SUPRABIO systems). The resulting bias for 2015 will probably be less pronounced than for 2025.

Weighting

Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choices. It may include aggregation of the weighted indicator results. No weighting is applied.

4.1.6 Interpretation

The interpretation of LCA results can be found in this report in chapter 6.

4.1.7 Greenhouse gas balances according to the RED

In the light of a controversial discussion on the net benefit of biofuels and bioenergy, the European Renewable Energy Directive (2009/28/EC, RED) – which sets out a mandatory target for the share of renewable energy in the transport sector (10 % by 2020) – has established a number of mandatory sustainability criteria, which biofuels and bioliquids have to meet to be able to be counted towards the target (Article 17(2) to 17(6)). The climate change-related criteria are most prominent: the greenhouse gas emission (GHG) saving from the use of biofuels and bioliquids – including emission from direct land-use changes (dLUC) – shall be at least 35 % compared to the fossil fuel comparator (Article 17(2)). From 2017 and 2018, the GHG emission saving shall be at least 50 % (all biofuels) and 60 % (biofuels from new installations), respectively. Further details are found in Article 19 and Annex V, of which the latter specifies the rules for calculating the GHG impact.

Although applying life cycle thinking, the rules in Annex V differ considerably from the ISO standards 14040 and 14044 /ISO 2006/. Since the latter leave the individual LCA practitioner with a range of choices, a more pragmatic (and thus less scientific) approach was chosen for political and legal reasons which enables allows economic operators to unequivocally show that the sustainability criterion regarding GHG emission savings has been fulfilled.

In the context of the RED, GHG emissions from fuels are expressed in terms of g CO_{2eq} / $MJ_{biofuel}$. According to the Annex V, the GHG emission saving from biofuels is calculated as:

SAVING = (EF – EB)/EF,

where

EB = total emissions from the biofuel or bioliquid; and

EF = total emissions from the fossil fuel comparator.

The resulting percentage is expressing the relative savings achieved by the biofuel compared to the fossil fuel comparator.

Moreover, Annex V contains so-called ‘default values’ for the GHG emissions associated with a number of liquid biofuels. However, since the underlying basic data was not given in the RED and the rules in given Annex V were interpreted differently. Despite the Communication from the Commission /EC 2010b/, the CEN standard EN 16214-4:2013 /CEN 2013/ and the BioGrace GHG calculation tool and calculation rules /BioGrace 2013/, there are still a number of open issues, especially in the case of 2^{nd} generation biofuels.

Nevertheless, it was decided to perform the GHG calculations according to the rules laid down in Annex V for the biofuels investigated in SUPRABIO. The following procedures were applied where rules were ambiguous:

- If digestate produced in the biorefinery is applied as fertiliser and counted as an input material (for non-residue biomass) then only the net required fertiliser (minimum: zero) is taken into account.

- In the biochemical biorefinery, the stillage is further converted into biogas and syngas, which are then used as energy carriers for internal production of heat and power. Due to this further conversion step, we classified biogas and syngas as co-products instead of as residues. For this reason, greenhouse gas emissions are partially allocated to excess electricity, which is exported. In contrast, outputs of the thermochemical process (mainly syngas) are classified as residues because they are not modified. Thus, no allocation takes place but a credit for hypothetical power from these residues is given (which is essentially zero).

4.2 Results: SUPRABIO vs. conventional systems

This chapter compares potential future SUPRABIO biorefineries to conventional systems, which provide equivalent products. Biochemical and thermochemical routes are first analysed separately (chapters 4.2.1 and 4.2.2, respectively) and then compared to each other (chapter 4.2.3).

As a first step, these comparisons are based on the precondition that sufficient biomass and land is available. For comparisons to competing biomass and land use options, which take limited availability of these resources into account, please refer to chapter 4.3.

4.2.1 Biochemical routes

First, the main scenario “Straw to Ethanol (2025)” is analysed in detail in chapter 4.2.1.1. Deviating results for further scenarios and sensitivity analyses of the biochemical route are discussed in chapters 4.2.1.2 to 4.2.1.5. Finally, greenhouse gas emission savings calculated according to the Renewable Energy Directive (RED) are provided as additional information in chapter 4.2.1.6.

4.2.1.1 Main scenario: Straw to Ethanol 2025

In this chapter, the main scenario “Straw to Ethanol (2025)” is analysed in detail. First of all, it can be seen that provision of biomass causes very low expenditures compared to conversion of biomass in the biorefinery[1] (see black bar in Fig. 4-2 exemplarily for greenhouse gas emissions). The biggest expenditures are caused by provision of material inputs other than biomass to the conversion process (light blue bar in Fig. 4-2). A more detailed illustration of biorefinery-related emissions shows that major shares of these expenditures are caused by provision of enzymes and nutrients for fermentation (Fig. 4-3). Furthermore, pre-treatment requires a considerable amount of energy and thus expenditures[2]. All these expenditures are required to make sugars in lignocellulosic biomass available to further fermentation processes. Thus, specific advantages of 2nd generation bioethanol production (low impact biomass provision) come along with specific disadvantages (high impact biomass conversion). Furthermore, separation of bioethanol from the fermentation broth causes a big share of the greenhouse gas emissions (dark blue bar in Fig. 4-2). This is frequently observed for biochemical processes.

Besides the main product bioethanol, energy is produced as co-product from biomass residues (mainly lignin). It is partially used internally to cover the whole electricity demand and a big part of the steam demand. In Fig. 4-2, the total demand of process energy is part of the expenditures and the internally provided share is displayed as compensating credit.

1 For clarity, CO_2 emissions from renewable resources are not displayed in Fig. 4-2 and all following figures because exactly the same amount of CO_2 has been taken up during growth of the biomass.

2 Please note that expenditures related to energy consumption in the biorefinery are displayed as if all energy would be externally provided. Consequently, internally produced and consumed energy receives credits as if it replaced externally produced energy. This highlights process optimisation potentials because externally produced energy could actually be replaced if internal processes consumed less.

Substantial amounts of surplus electricity from internal energy generation are fed into the grid.

The net life cycle greenhouse gas emissions for bioethanol are much smaller than the net emissions of the reference product gasoline, which leads to an overall advantage of the SUPRABIO biorefinery scenario over its conventional reference products if sufficient biomass is available.

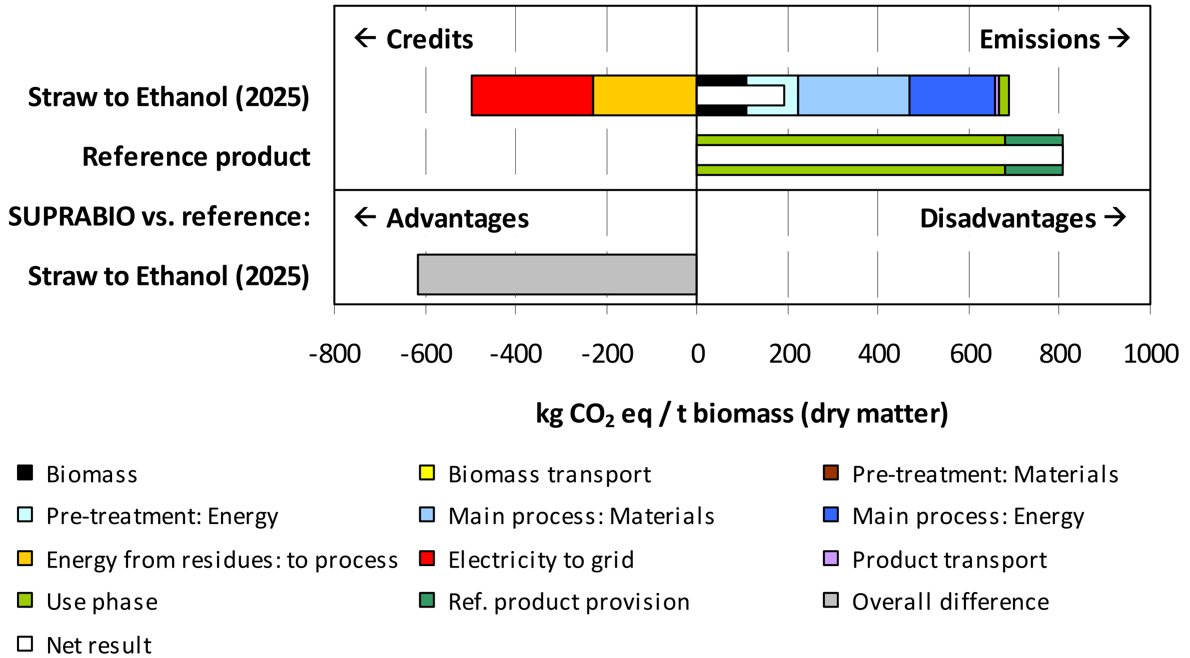


Fig. 4-2 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenario “Straw to Ethanol (2025)” (scenario II) and its reference product gasoline in the environmental impact category climate change. Both life cycles are compared in form of an overall difference.

How to read Fig. 4-2:

The production and use of bioethanol from 1 tonne of wheat straw (dry matter content) causes the emission of about 690 kg of greenhouse gases (first bar, emissions, expressed in CO_2 equivalents). On the other hand, about 500 kg of greenhouse gases are saved (credits) by the replacement of energy from external (fossil) sources. This results in net greenhouse gas emissions of about 190 kg CO_2 eq. per t of wheat straw (white overlay bar). Compared to an equivalent amount of fossil fuels (second bar), bioethanol from 1 t of wheat straw saves overall about 620 kg CO_2 eq. (third bar).

The environment is affected in many other ways besides climate change by bioethanol or alternatively gasoline production and use. Fig. 4-4 shows an overview of all relevant environmental impacts assessed in this study. Results are shown compared (normalised) to the impacts caused by an average European citizen per year, the so-called inhabitant equivalent (IE). This is a way of comparing the magnitude of different impacts – but not their severity – without necessarily subjective weighting.

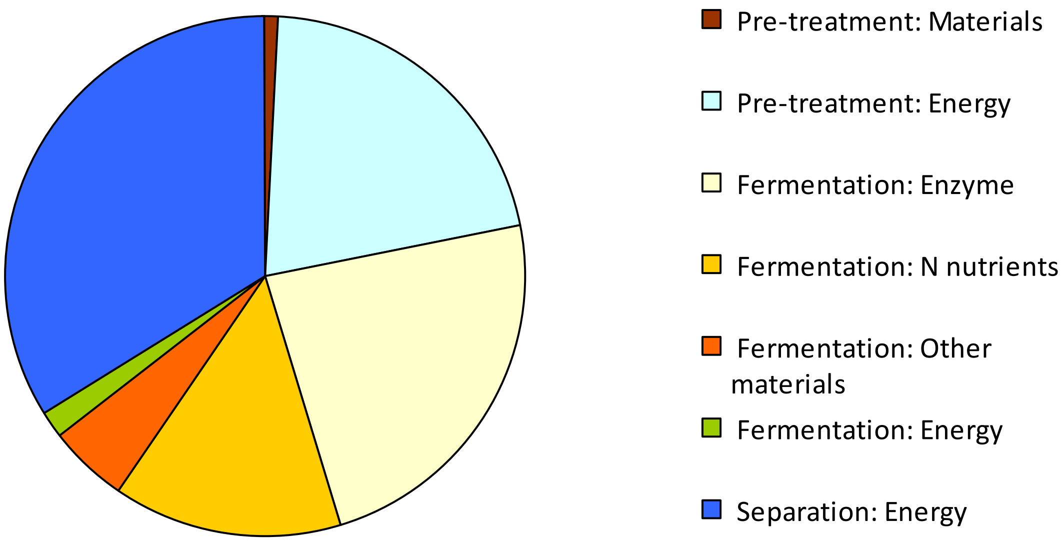


Fig. 4-3 Detailed display of expenditures connected to the life cycle step of the biorefinery in the scenario “Straw to Ethanol (2025)” and for the environmental impact category climate change.

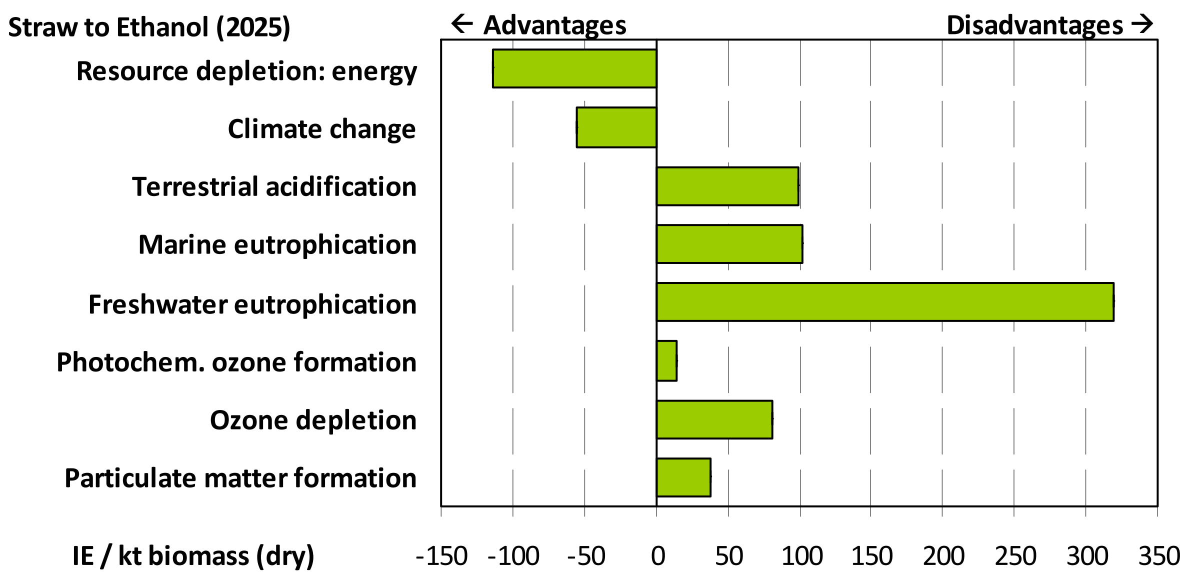


Fig. 4-4 Overall differences between environmental impacts of bioethanol life cycle (scenario II, Straw to Ethanol 2025) and gasoline life cycle. Results from all assessed environmental impact categories are normalised using inhabitant equivalents (IE) and compared to each other.

In the scenario "Straw to Ethanol (2025)", production and use of bioethanol causes overall advantages compared to gasoline regarding depletion of non-renewable energy resources and climate change. However, it causes additional environmental burdens in all other impact categories. One reason why bioethanol causes higher emissions than gasoline in these categories is that nutrient and especially nitrogen cycles are strongly affected by bioethanol production and use. This is exemplarily shown in Fig. 4-5 for the impact category terrestrial acidification: In contrast to the impact category climate change, acidifying emission during the use phase (combustion) of biofuel and fossil fuel are comparable (Fig. 4-5, light green bar). Furthermore, internal combustion of biomass residues can cause significant impacts on acidification (Fig. 4-5, yellow bar). Finally, provision of nitrogen-containing material inputs contributes substantially to life cycle emissions in this category[3]. These inputs are mainly enzymes and nutrients for fermentation (both part of "Main process: Materials") as well as biomass. This emphasises that nitrogen within the process causes environmental burdens twice: first due to its provision (energy demand, losses) and second due to its end of life (combustion emissions, emissions from use as fertiliser). Thus, nitrogen-containing inputs should be minimised as far as possible – also because nitrogen is not required as component of the main product but only to sustain microbial growth.

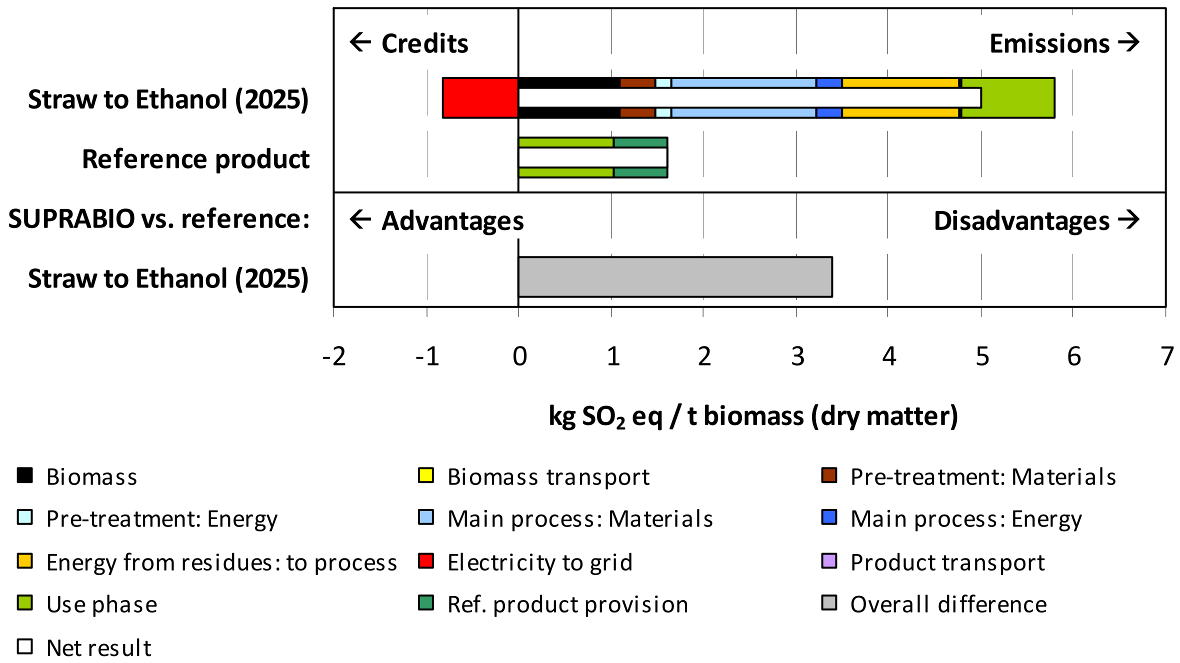


Fig. 4-5 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenario "Straw to Ethanol (2025)" (scenario II) and its reference product gasoline in the environmental impact category terrestrial acidification. Both life cycles are compared in form of an overall difference.

[3] The assessed process has not been optimised yet for minimal inputs of some of these materials such as ammonia. Thus, there probably is a significant reduction potential.

4.2.1.2 Influence of product: Straw to Mixed Acids (2025)

The production of mixed acids is an alternative biochemical fermentation route that converts sugars into propionic and butyric acid. Due to uncertainty and variability related to a possible industrial scale process, two sub-scenarios were analysed with the major component being either propionic or butyric acid to cover the range of possible outcomes (see Fig. 4-6). Compared to ethanol production, much more energy is required for mixed acid production. This also results in no surplus power to be exported. The main consumer of energy is the purification process to recover the acids from the fermentation broth. Nevertheless, expenditures for material inputs are lower and these already occur in the pre-treatment step. Furthermore, the reference product, propionic acid from fossil resources, potentially causes higher greenhouse gas emissions than gasoline, the reference product for bioethanol.

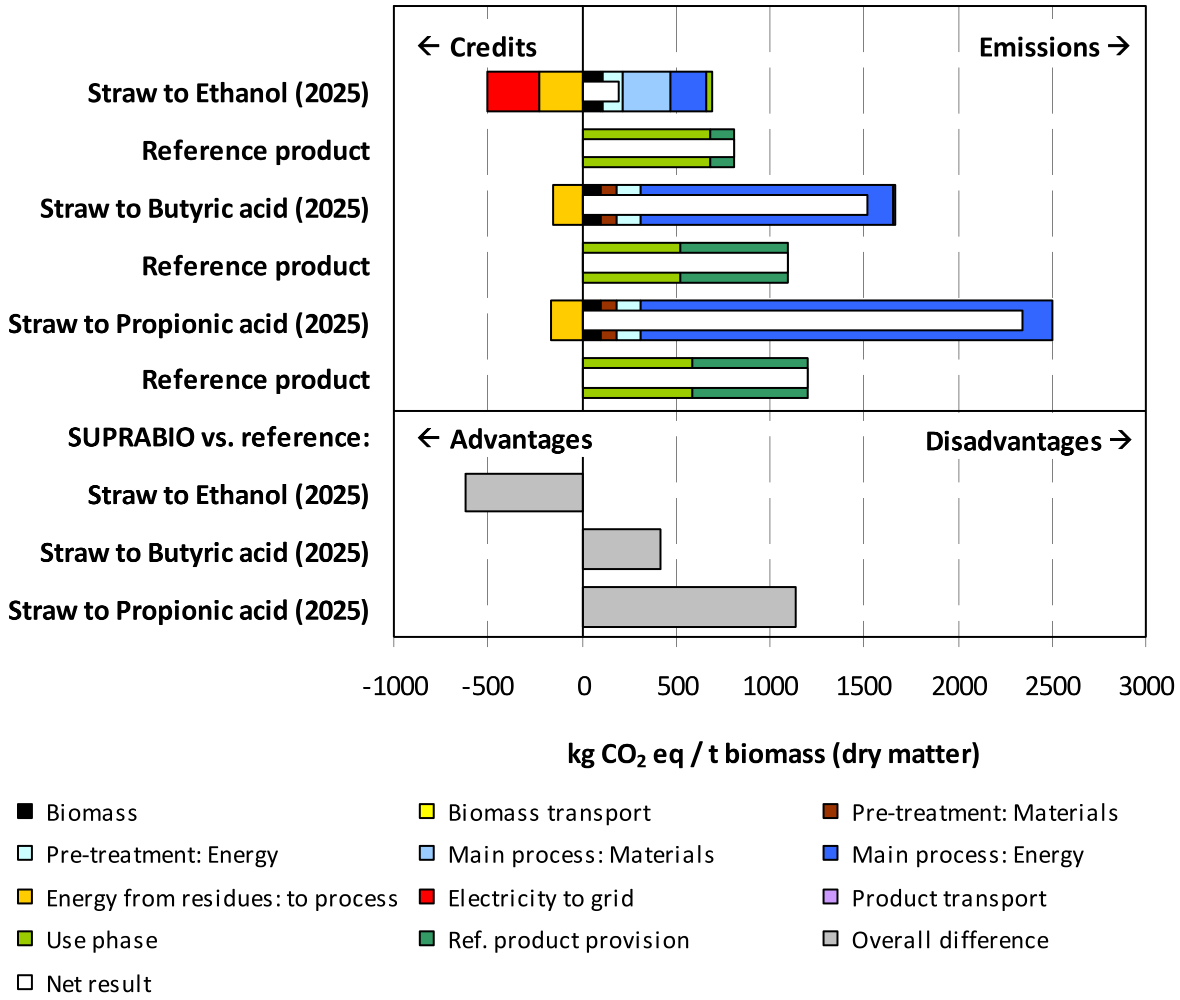


Fig. 4-6 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenarios “Straw to ethanol (2025)”, “Straw to butyric acid (2025)” and “Straw to propionic acid (2025)” (scenarios II, IVa and IVb, respectively) and their reference products in the environmental impact category climate change. Pairs of life cycles are compared in form of an overall difference.

Although functional equivalences of butyric acid and impurities like acetic acid to conventional propionic acid were evaluated based on best case settings for the bio-based product, the high energy demand leads to overall disadvantages of mixed acids compared to the conventional product in all environmental impact categories (see also annex, chapter 9.3 for further environmental impact categories). This process can only become environmentally beneficial if the energy demand is drastically reduced. As a potential optimisation strategy, it might be tested if the product has to be purified at all or if the fermentation broth can be used for cereal grain preservation after only minor treatment such as inactivation and / or filtration.

4.2.1.3 Influence of feedstock: Poplar to Ethanol (2025)

In general, the pattern of results is very similar for bioethanol production and use from straw and poplar short rotation coppice (Fig. 4-7).

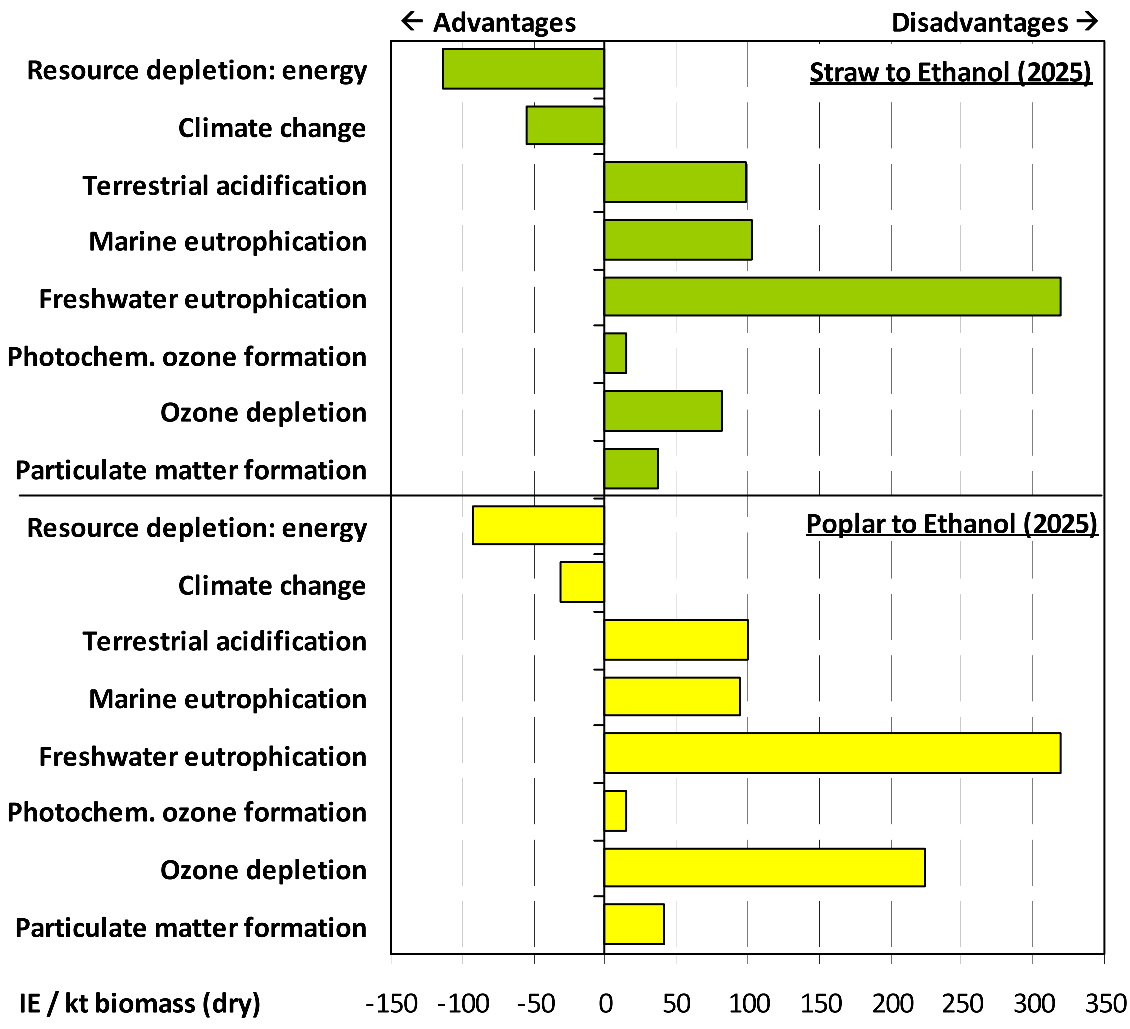


Fig. 4-7 Overall differences between environmental impacts of bioethanol life cycles (scenario II, Straw to Ethanol 2025 and scenario III, Poplar to Ethanol 2025) and of the gasoline life cycle. Results from all assessed environmental impact categories are normalised using inhabitant equivalents (IE) and compared to each other.

For poplar as a feedstock, advantages are slightly higher and disadvantages to some degree lower than for straw-based ethanol. This is mainly due to a higher amount of energy produced from residues. However, this comparison has to be interpreted carefully because poplar conversion is less tested to date and thus less certain process data is available. Nevertheless, straw as a residue and poplar short rotation coppice as cultivated biomass represent independent resources that do not compete with each other e.g. for agricultural land. Therefore, based on the aspects analysed here, both feedstocks should be used independently of each other if e.g. climate change mitigation is valued higher than additional burdens related to e.g. acidification. However, these are not the only factors to take into account. For example, both feedstocks can have a different risk of causing unwanted effects elsewhere. Please refer in this regard to the discussion of indirect land use change (iLUC) in chapter 4.3.2. Furthermore, both feedstocks differ substantially in their local environmental impacts (chapter 5.2).

4.2.1.4 Early implementation: Straw to Ethanol (2015)

In order to realise highly optimised biorefinery concepts in the future, first projects have to be launched in coming years. This scenario analyses which environmental impacts could be associated with such a large scale early implementation.

In the scenario Straw to Ethanol (2015), the pre-treatment requires more inputs because hydrolysis of cellulose and hemicellulose and fermentation have to be done separately (separate hydrolysis and fermentation, SHF) whereas later scenarios are based on a simultaneous saccharification and fermentation (SSF). This and a slightly lower efficiency lead to higher impacts in this scenario and thus lower overall advantages regarding climate change mitigation (Fig. 4-8). Nevertheless, the pattern of advantages and disadvantages is the same as for the main scenario Straw to Ethanol (2025), which is based on mature technology (see also annex, chapter 9.3 for further environmental impact categories).

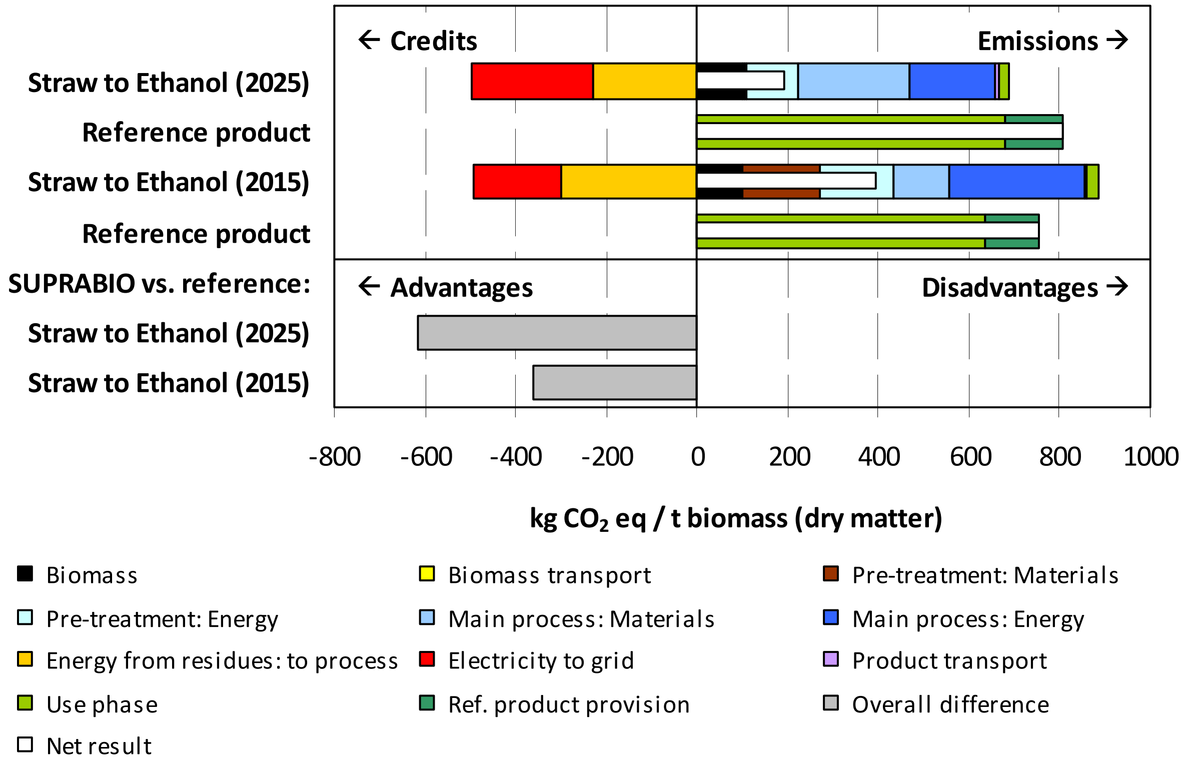


Fig. 4-8 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenarios “Straw to Ethanol (2025)” and “Straw to Ethanol (2015)” (scenarios II and I, respectively) and their reference products gasoline in the environmental impact category climate change. Pairs of life cycles are compared in form of an overall difference.

4.2.1.5 Sensitivity analyses and optimisation potential

Waste water treatment and energy recovery

Two different optimisation options related to internal energy provision from process residues have been studied as detailed in the system description (chapter 3.1.3.1).

The first is the installation of different equipment for conversion of gases to steam and electricity (syngas from solid co-products and biogas from liquid co-products). Although a gas engine produces more net electricity (and thus more electricity is fed into the grid), it does not provide steam that could be used in the process. Therefore, more steam is acquired from external production. If this results in an overall environmental benefit or not, depends on energy sources and efficiencies of external production of (replaced) power and (additionally acquired) steam. Under standard conditions as described in the methodology section, a gas engine shows slight disadvantages compared to a gas turbine in some impact categories like climate change (Fig. 4-9) and slight advantages in others such as particulate matter formation. A steam turbine, which is used in some plant configurations (early solids separation with direct combustion instead of gasification), produces a still different ratio of power and steam. This leads to advantages or disadvantages for the same reasons depending on external influences. Thus, there is no clear preference for either technology from an environmental perspective although a gasification of solids should be advantageous under most conditions.

The second optimised parameter is related to the process design of co-product treatment. Either solids can be separated after anaerobic digestion (main scenarios) or afterwards. The environmental impacts are very similar, if the same energy conversion equipment is used.

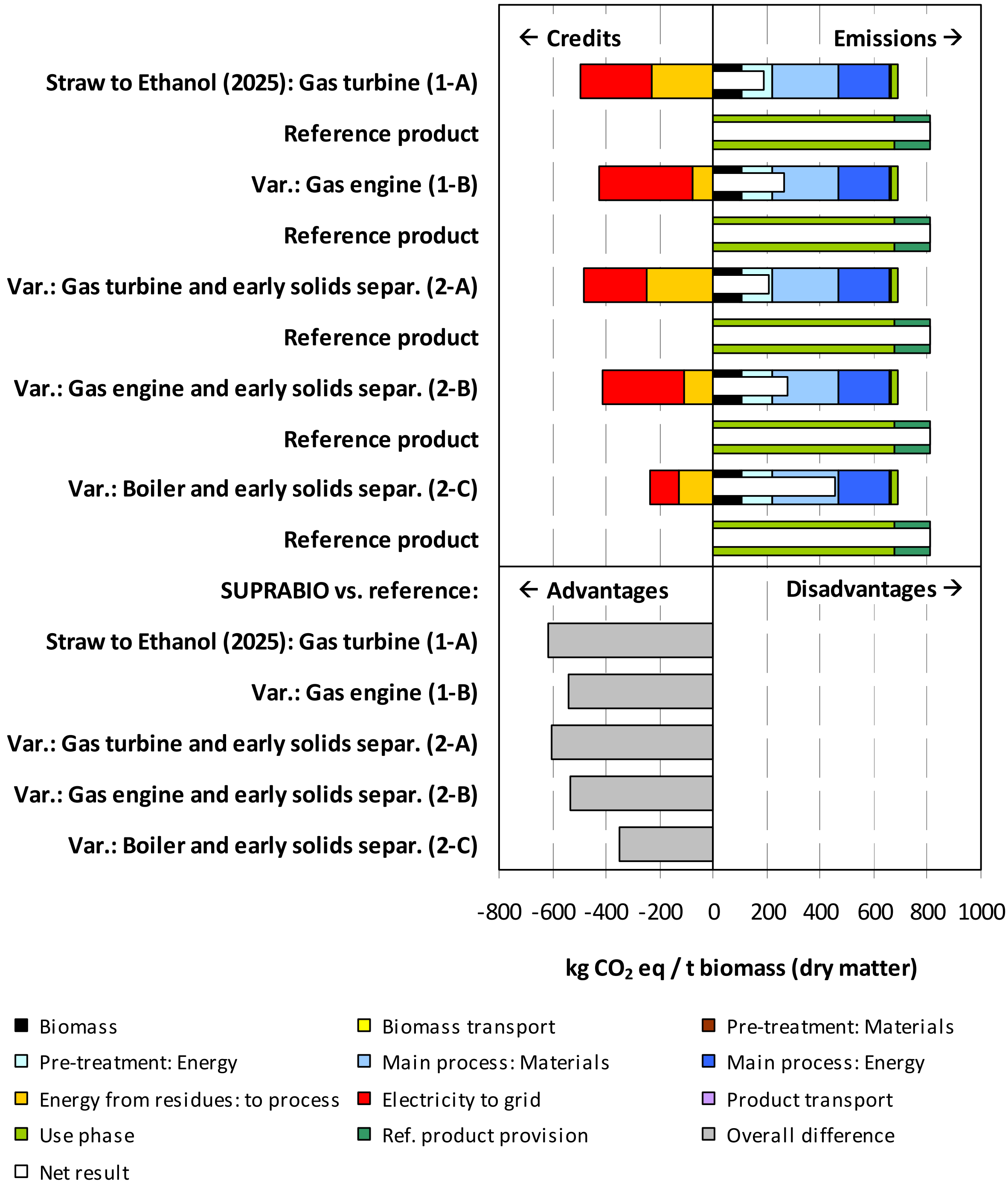


Fig. 4-9 Variations of the SUPRABIO scenario "Straw to Ethanol (2025)" (scenarios II-1-A, II-1-B, II-2-A, II-2-B and II-2-C) and their exemplary impacts on climate change. Pairs of life cycles are compared in form of an overall difference.

Enzymes

Another important source of variability but also uncertainty is enzyme provision and use. In this case, not the biorefinery process itself is affected but the preceding process of enzyme provision (cellulases and hemicellulases). In the boundary conditions of this sensitivity analysis, the performance of enzymes cocktails is increased to reflect potential improvements until 2025, which reduces the required amount. Furthermore, the environmental impacts of enzyme provision are reduced reflecting improvements in process efficiency. Under such conditions, the reduction of enzyme-related expenditures by about 40 % seems plausible. This leads to a slight improvement of the overall performance of ethanol production (Fig. 4-10). Improvements in a similar rage may also be possible if the amount of nitrogen could be reduced, which is added to the process (see Fig. 4-3 for its contribution to greenhouse gas emissions). However, further studies are required to evaluate to which degree this can be optimised.

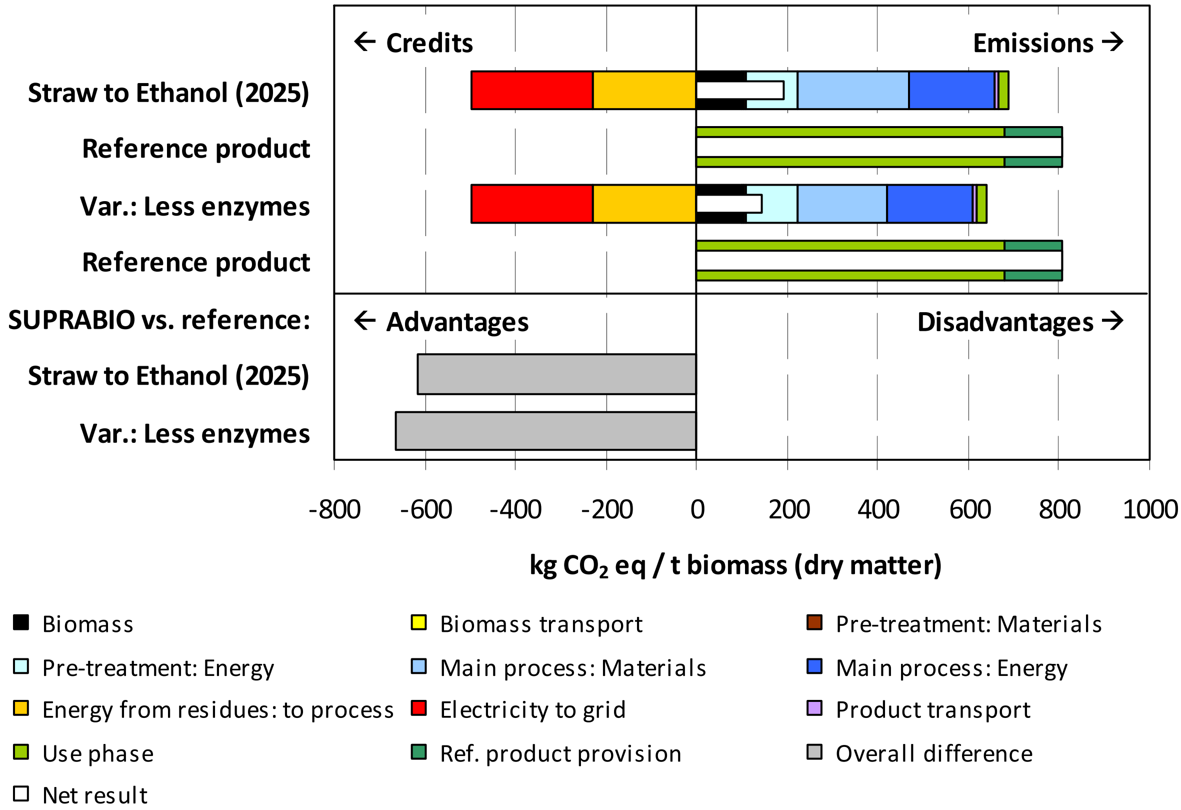


Fig. 4-10 Variation of enzyme provision and consumption in the SUPRABIO scenario "Straw to Ethanol (2025)" (scenario II) and its exemplary impact on climate change. Pairs of life cycles are compared in form of an overall difference.

Qualitative analysis of integrated algae production

There is a potential to integrate algae production into a biochemical biorefinery (see Fig. 3-5 for a scheme). According to the SUPRABIO scenario, pre-cleaned wastewater containing nutrients, low temperature residual heat and potentially also CO_2 are received by the algae production unit from the biochemical core biorefinery. This option has been studied within SUPRABIO but due to complex interactions between both biorefinery parts, models did not reach a state to support a quantitative environmental or economic assessment. For example, algae production was not optimised for any specific product but energy use of algae biomass in a biogas plant was not assessed in detail as fallback option.

From the perspective of algae production, it seems promising to receive crucial inputs such as water, nutrients and heat as co-products with low environmental burdens. However, these burdens are expected to still be all but negligible:

- The diversion of wastewater streams from the core biorefinery cause a lack of recycled water and instead equal amounts of fresh water have to be provided. Thus, the overall water balance is not affected much, if at all, but only part of the efforts for wastewater treatment can be saved.
- The effects of transferring residual low temperature heat to algae production are hard to estimate, e.g. whether this would increase external energy demand to a certain degree. Without a complete heat integration analysis of a concrete plant at a concrete location including potential other heat consumers such as biomass drying units it is not even clear if sufficient amounts of residual heat exist at all to cover the site-specific heating demand of algae production. Therefore, synergy effects may be anything from very high to not existent.
- Nutrient and CO_2 diversion do not cause additional expenditures within the core biorefinery but save some of the expenditures for wastewater treatment. However, nutrient composition is not optimised for algae production and amounts are probably not sufficient. Furthermore, residues from algae production (e.g. after product extraction or energy use in a biogas plant) will likely contain even more nutrients and have to be treated instead. In case these could be recycled, there would be no need for nutrient import from the core biorefinery. CO_2-containing streams may still have to be purified and / or pressurised. More optimal CO_2 sources may exist.
- Finding a suitable location for a biorefinery is a challenge because biomass potentials in the surroundings have to be sufficient and made available both logistically and in terms of contracting. This challenge will grow if further parameters have to be optimised for algae production in the same location such as solar irradiation and increased water demand.

In summary, potential synergies of algae production with a biotechnological biorefinery are still confronted with challenges especially as two innovative technologies with still unknown variability of process parameters should be combined. As far as it can be judged based on present concepts, environmental benefits from such potential synergies are estimated to be rather gradual than decisive.

4.2.1.6 Greenhouse gas balances according to the RED

The European Renewable Energy Directive (RED) specifies in its Annex V rules how to calculate greenhouse gas emissions from biofuels. Furthermore, minimum savings compared to a fossil fuel comparator are given that have to be fulfilled in certain years. If these savings are reached, the biofuel can be counted towards the mandatory blending targets. Thus, savings according to the RED are important parameters for marketing biofuels.

As already mentioned in chapter 4.1.6, there are still a number of open issues regarding the calculation rules. The procedures applied in ambiguous cases can be found in chapter 4.1.6.

As Fig. 4-11 shows, only mature 2nd generation ethanol processes are likely to reach the specified minimum GHG savings. Furthermore, also these mature processes show substantially higher emissions than the so-called default values provided by Annex V of the RED. Since full details about the calculations of the default values are not publicly available yet, it cannot be analysed where these differences originate from[4]. Nevertheless, savings around 60 % for mature 2nd generation ethanol technology seem to be a reasonable result since, to our knowledge, no substantially better values (calculated in the same way) have been reported for any 2nd generation ethanol process that is similarly close to industrial scale implementation. Instead, optimistic expectations formulated in earlier phases of technology development probably need to be lowered. In any case, GHG balances according to the RED are not a good basis for political decisions (see also remarks in chapter 4.2.2.6 and discussion in chapter 4.4, section “Comparison of routes and alternatives”) and we would like to refer to chapter 6 regarding future potentials of this technology.

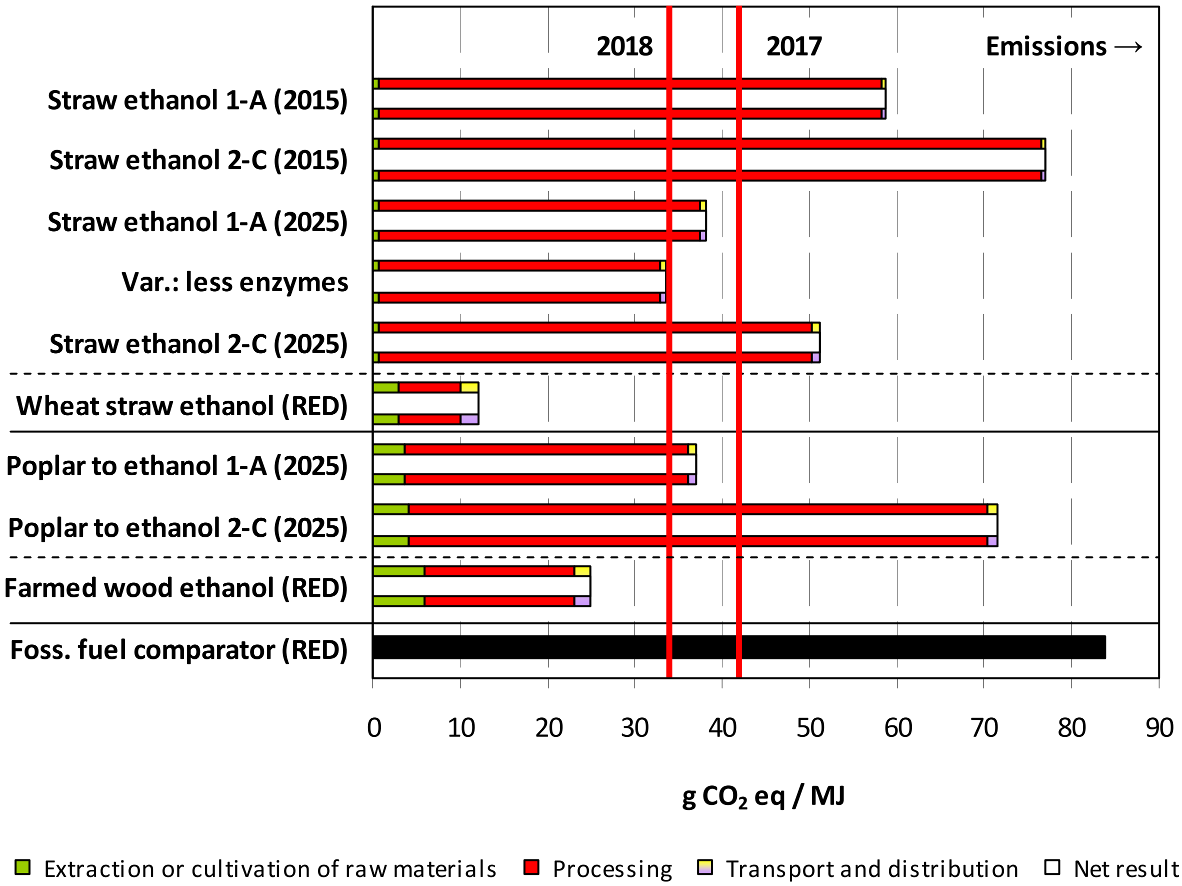


Fig. 4-11 Greenhouse gas emissions according to the RED for various ethanol scenarios compared to default emissions of biofuels and fossil fuel given by the RED. The red lines indicate 50 % and 60 % savings, which are specified as minimum savings for biofuels in 2017 (all biofuels) and 2018 (biofuels from new installations), respectively.

4 Although it seems that e.g. emissions from biomass combustion or enzyme provision may have been underestimated simply because less information was available at that time.

Contributions of the life cycle stages to the overall results show that processing causes the major share of GHG emissions (Fig. 4-11). Energy and material inputs both contribute substantially to these emissions. Further reductions of these emissions could be achieved e.g. through the reduction of enzyme consumption. Overall life cycle greenhouse gas emissions for these scenarios mainly consist of CO_2 from fossil sources (CO_2 from renewable sources is not counted) and N_2O (Fig. 4-12). A source of uncertainty is a part of the life cycle N_2O emissions that arises from on-site combustion of biogas, syngas or solids from fermentation residues. Depending on nitrogen content and combustion conditions, such emissions can be negligible (as in scenarios 1-A, in which almost all N_2O emissions stem from other life cycle steps) or substantial (as in scenarios 2-C). Settings in scenarios had to be based on estimations as data for the particular technologies and operating conditions were not available. For example, N_2O emission data from sewage sludge combustion was used to approximate N_2O emissions from combustion of solids with similar moisture and nitrogen content. Furthermore, there is a considerable optimisation potential regarding nitrogen inputs into the process, which are partially responsible for the life cycle N_2O emissions. The process is not yet optimised regarding several N-containing inputs such as ammonia. Thus, the ethanol production process has the potential to achieve 60 % greenhouse gas emission savings compared to the fossil reference value given by Annex V of the RED, but further optimisation including but not limited to N_2O emissions is required to realise this potential.

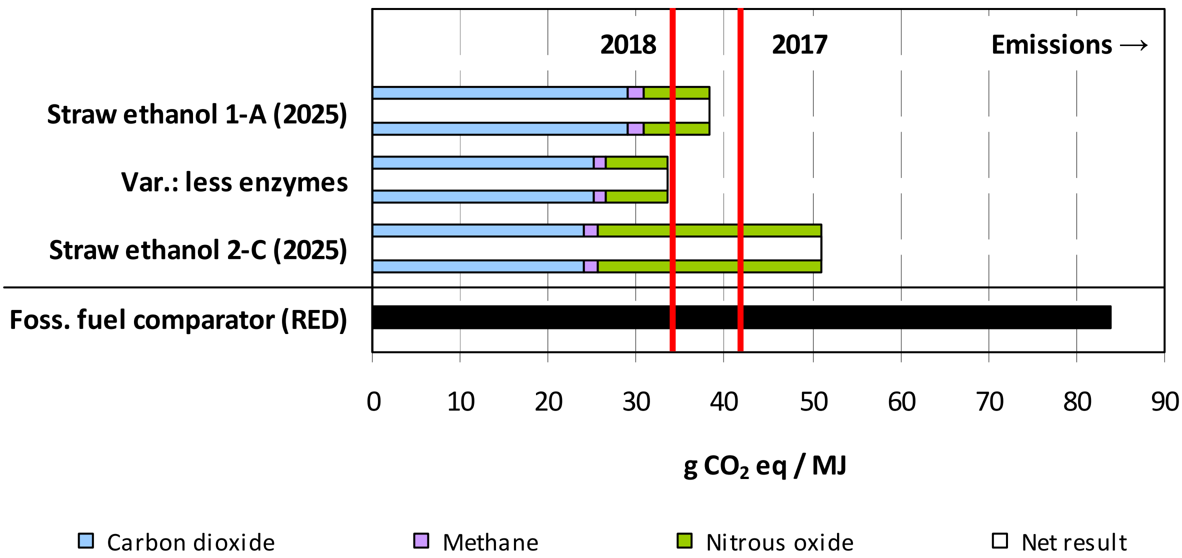


Fig. 4-12 Contribution of individual greenhouse gases (CO_2, CH_4, N_2O) to total greenhouse gas emissions according to the RED for selected ethanol scenarios. The red lines indicate 50 % and 60 % savings, which are specified as minimum savings for biofuels in 2017 (all biofuels) and 2018 (biofuels from new installations), respectively.

4.2.2 Thermochemical routes

First, the main scenario “Forest residues to FT fuels (2025)” is analysed in detail in chapter 4.2.2.1. Deviating results for further scenarios and sensitivity analyses of the biochemical route are discussed in chapters 4.2.2.2 to 4.2.2.5. Finally, greenhouse gas emission savings calculated according to the Renewable Energy Directive (RED) are provided as additional information in chapter 4.2.2.5.

4.2.2.1 Main scenario: Forest residues to FT fuels (2025)

The scenario “Forest residues to FT fuels (2025)” describes the conversion of forest residues into synthetic diesel and a gasoline equivalent derived from bio-based naphtha using distributed pyrolysis followed by central gasification and Fischer-Tropsch synthesis. This main scenario of the thermochemical route is analysed in this chapter in detail.

A big share of expenditures along the whole life cycle is caused by the energy demand of the conversion process (see Fig. 4-13 exemplarily for the impact on climate change). The unit processes contributing most to this energy demand are water gas shift reaction and acid gas removal (Fig. 4-14). However, all required electricity and a big part of the required steam is produced internally via combustion of process residues (Fig. 4-13, yellow bar)[5]. A big amount of surplus electricity is fed into the grid (Fig. 4-13, red bar). Depending on the scenario and environmental impact category, the avoided environmental burdens due to internal energy production can compensate for more or less all expenditures throughout the whole life cycle (Fig. 4-13, white overlay bar). This also underlines that electricity is an important co-product. Thus, the high energy consumption within the biorefinery has to be highly optimised because a moderate increase might reduce surplus electricity production to zero. The main consumers on a unit process level and thus main optimisation targets are the gas cleaning and water gas shift units (Fig. 4-14). Overall, about 300 kg of CO_2 equivalents are saved per t of input biomass if FT liquids produced according to this scenario are used instead of conventional fossil fuels.

Remarkably, the production and use of FT fuels from forest residues does not cause big environmental burdens in any impact category. If there are significant additional emissions such as in the category ozone depletion, they are still small compared to the annual emissions caused by average European citizens (Fig. 4-13 and Fig. 4-15). One important reason for this result is that the scenario analysed here is based on not applying compensatory fertilisation to forests after biomass extraction. However, this may be necessary on certain sites with intensive forest management including high extraction rates of forest residues (/Weis & Göttlein 2011/, /Weis & Göttlein 2012/). Therefore, significant additional emissions in an order of magnitude as observed for the use of wheat straw instead of forest residues may arise in certain cases (see Fig. 9-2 in the annex for a comparison).

[5] Please note that expenditures related to energy consumption in the biorefinery are displayed as if all energy would be externally provided. Consequently, internally produced and consumed energy receives credits as if it replaced externally produced energy. This highlights process optimisation potentials because externally produced energy could actually be replaced if internal processes consumed less.

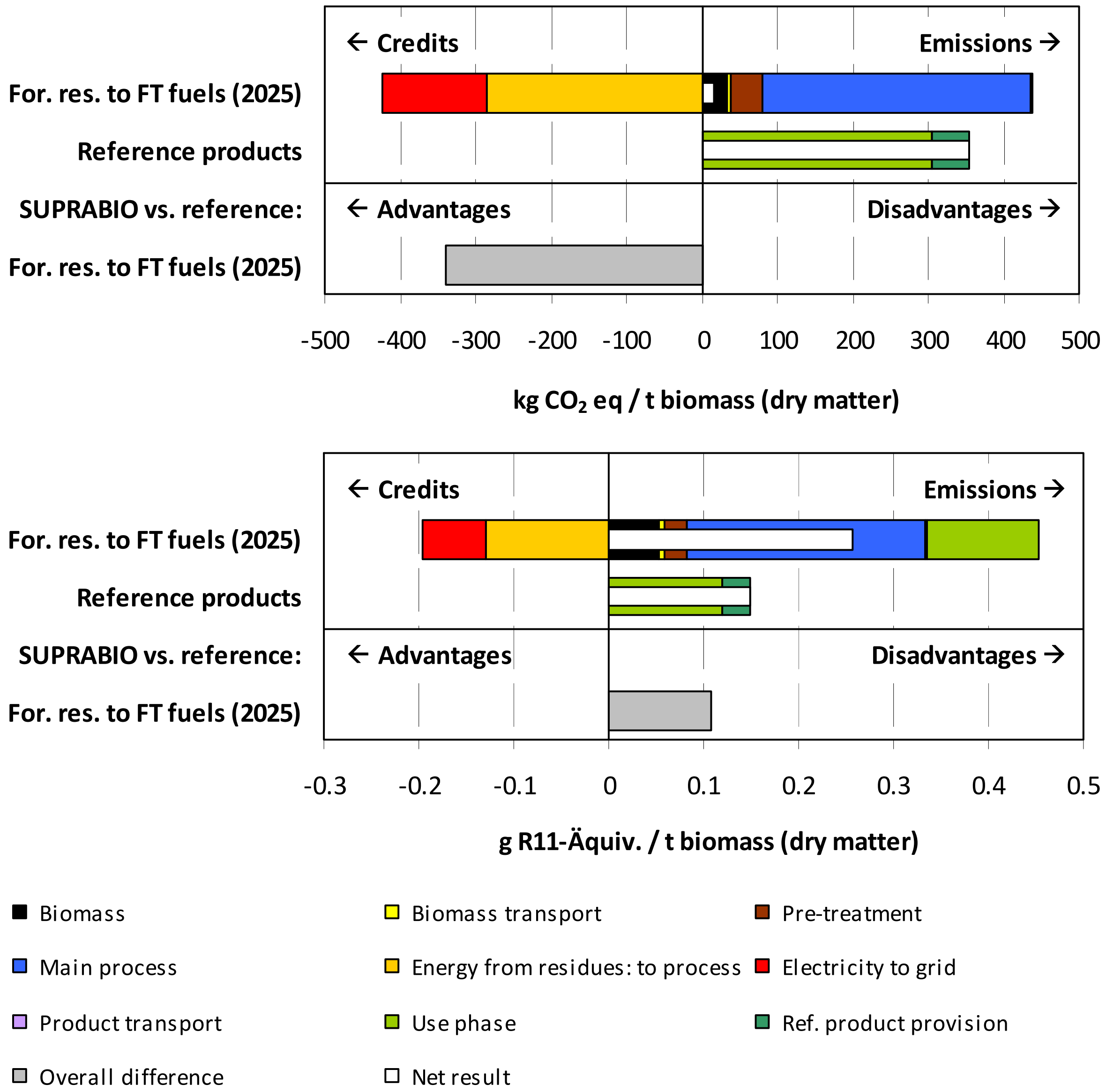


Fig. 4-13 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenario “Forest residues to FT fuels (2025)” (scenario II) and its reference products (diesel and gasoline) in the environmental impact categories climate change and ozone depletion. Both life cycles are compared in form of an overall difference.

How to read the upper panel in Fig. 4-13:

The production and use of FT fuels from 1 tonne of forest residues (dry matter content) causes the emission of about 440 kg of greenhouse gases (first bar, expenditures, expressed in CO_2 equivalents). On the other hand, about 420 kg of greenhouse gases are saved (credits) by the replacement of energy from external (fossil) sources. This results in net greenhouse gas emissions of about 20 kg CO_2 eq. per t of forest residues (white overlay bar). Compared to an equivalent amount of fossil fuels (second bar), FT fuels from 1 to of forest residues save overall about 340 kg CO_2 eq. (third bar).

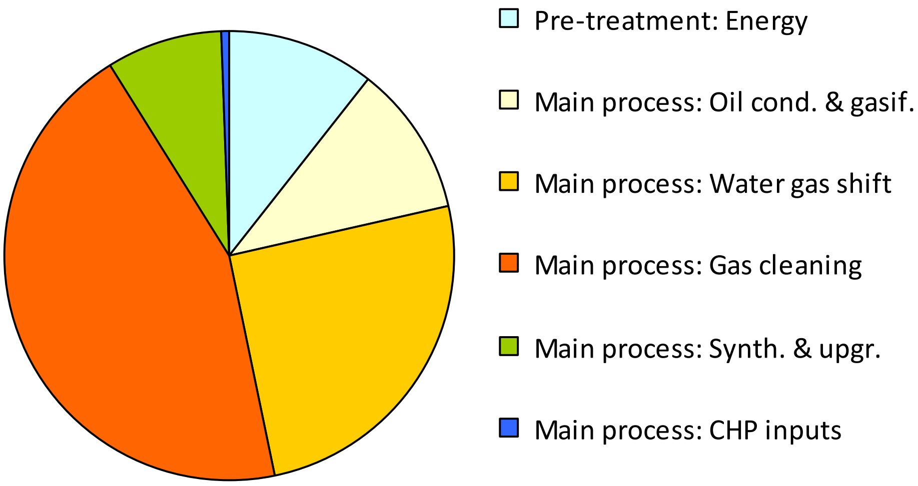


Fig. 4-14 Detailed display of expenditures connected to the life cycle step of the biorefinery in the scenario “Forest residues to FT fuels (2025)” and for the environmental impact category climate change.

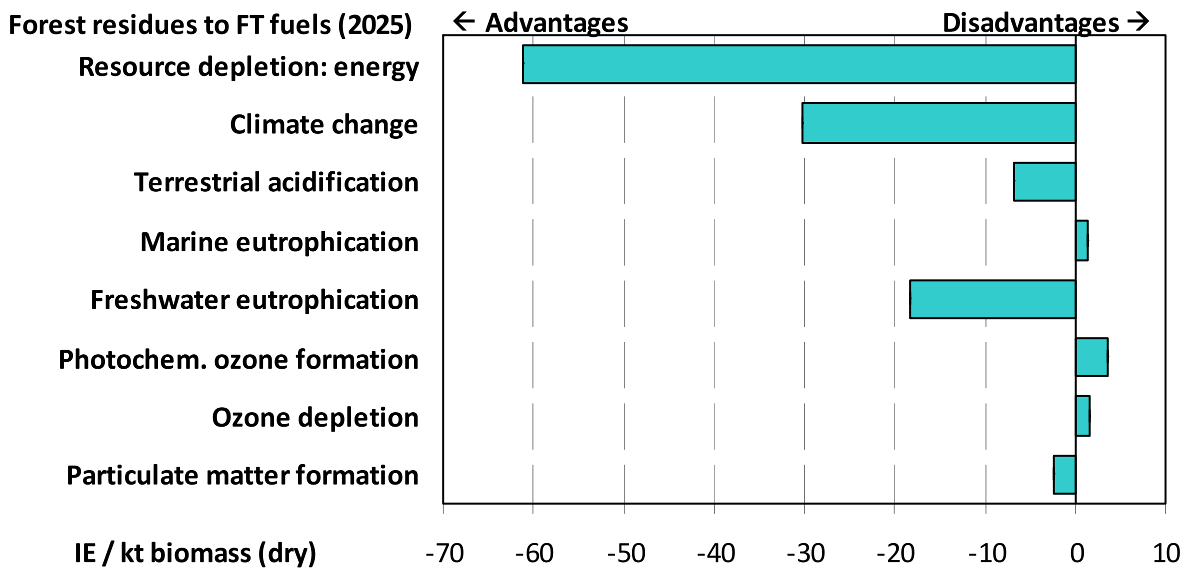


Fig. 4-15 Overall differences between environmental impacts of FT fuels life cycle (scenario II, Forest residues to FT fuels 2025) and the reference products’ life cycles. Results from all assessed environmental impact categories are normalised using inhabitant equivalents (IE) and compared to each other.

4.2.2.2 Influence of product: Forest residues to DME (2025)

Instead of Fischer-Tropsch fuels, an alternative synthetic fuel (dimethyl ether, DME) can be produced from gasified pyrolysis oil. In this case, energy consumption of the main process is slightly higher on the one hand and less energy can be produced from residues (Fig. 4-15). On the other hand, the product has a higher energy content and thus more conventional fuel is replaced (reference product). Overall, this leads to smaller advantages for DME over its reference product than for FT fuels. Also in all other impact categories, DME performs not as well as FT fuels (see annex, chapter 9.3). As most process steps are shared between FT fuel and DME production, most optimisation measures will affect both processes in a similar way. Therefore, the advantage of the assessed FT fuels over DME is likely to be robust.

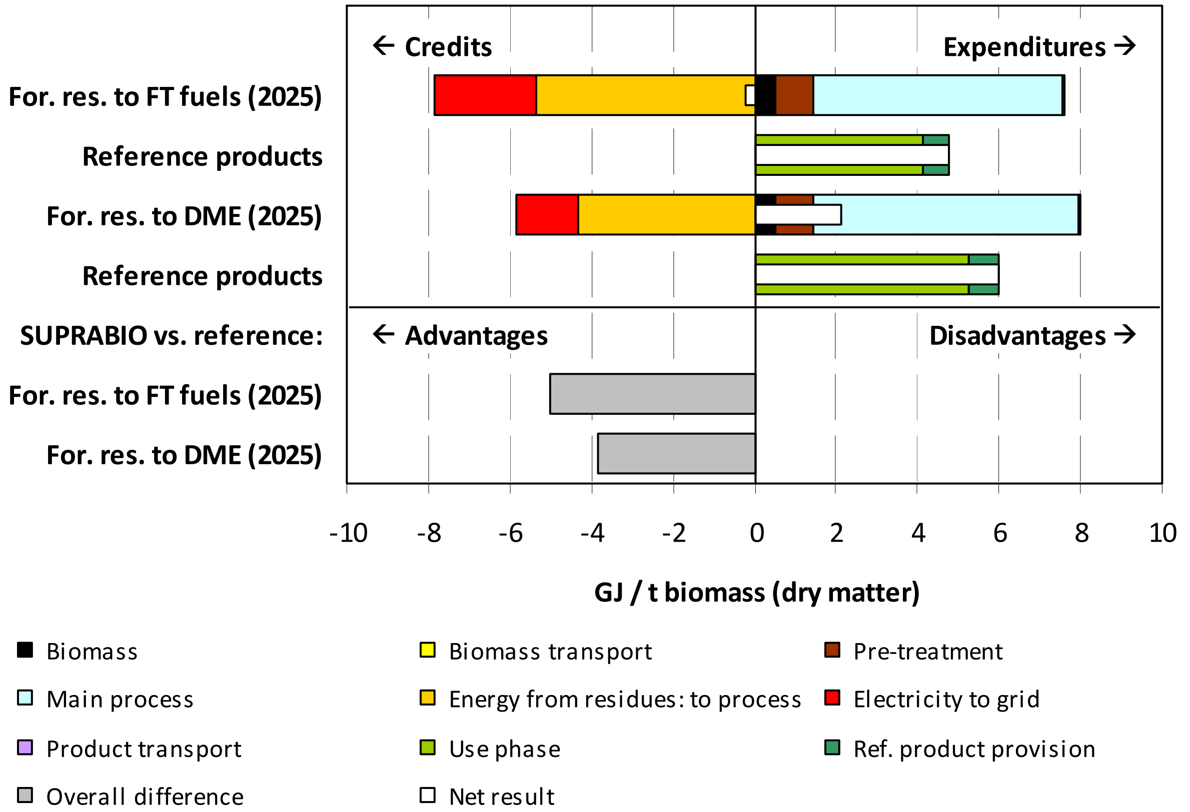


Fig. 4-16 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenarios “Forest residues to FT fuels (2025)” and “Forest residues to DME (2025)” (scenarios II, III) and their reference products in the environmental impact category non-renewable energy demand. Pairs of life cycles are compared in form of an overall difference.

4.2.2.3 Influence of feedstock: Straw / Poplar to FT fuels (2025)

Generally, the feedstocks forest residues, wheat straw and poplar short rotation coppice do not compete with each other for resources needed for their production. Therefore, all resources should be used independently of each other if advantages outweigh disadvantages.

As Fig. 4-17 shows, only the life cycle of scenario “Forest residues to FT fuels” does not show any major disadvantages. Both other feedstocks cause additional emissions in several categories. Compared to average emissions of a European citizen, additional burdens are especially pronounced for eutrophication. These burdens mainly originate from fertilisation required for biomass production or compensatory fertilisation after residue extraction (Fig. 4-18). If straw is used instead of forest residues, savings in non-renewable energy demand are remarkably high at similar savings of greenhouse gas emissions (Fig. 4-17).

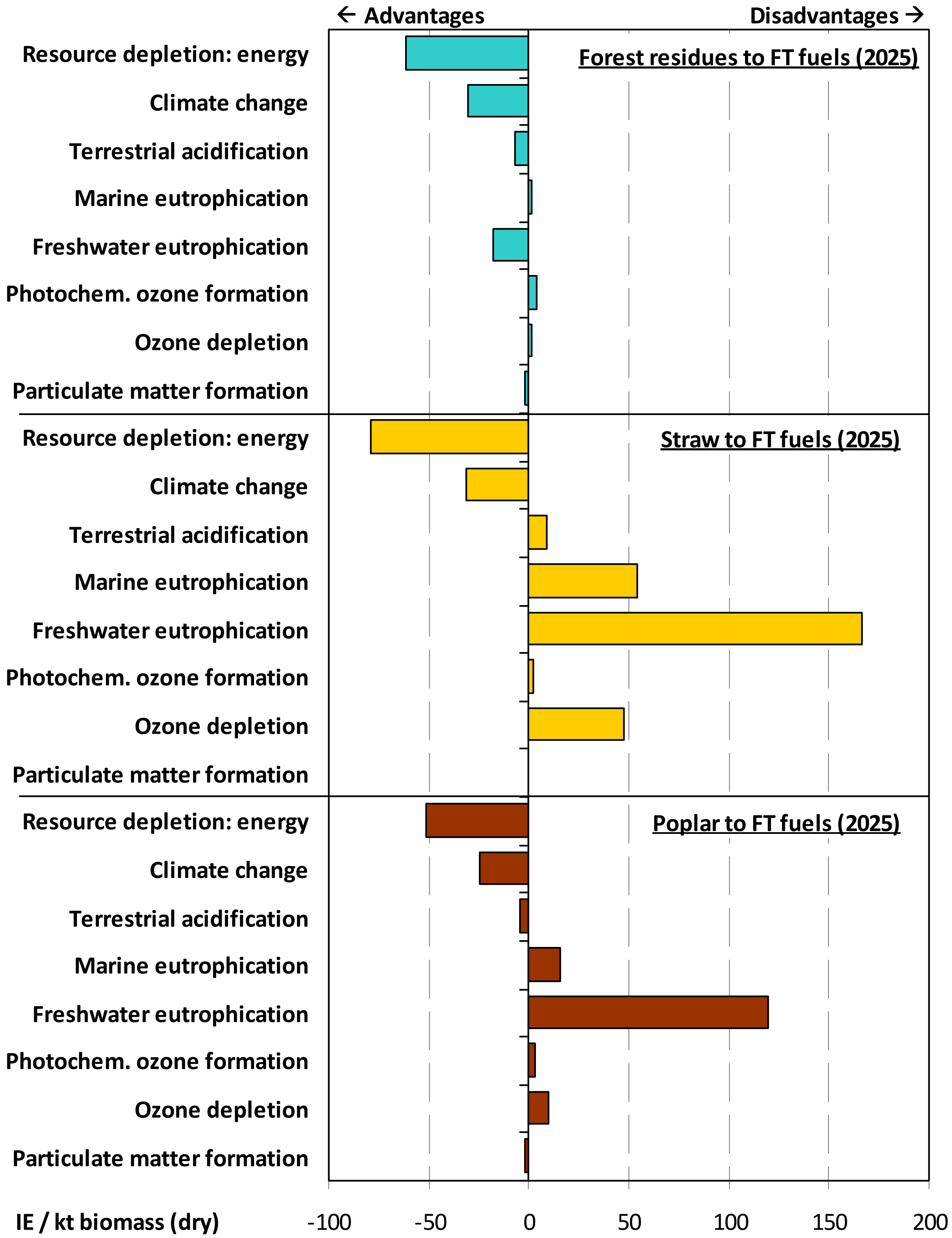


Fig. 4-17 Overall differences between environmental impacts of the life cycles of FT fuels from different feedstocks (scenarios II, IV and V) and the reference products' life cycles. Results from all assessed environmental impact categories are normalised using inhabitant equivalents (IE) and compared to each other.

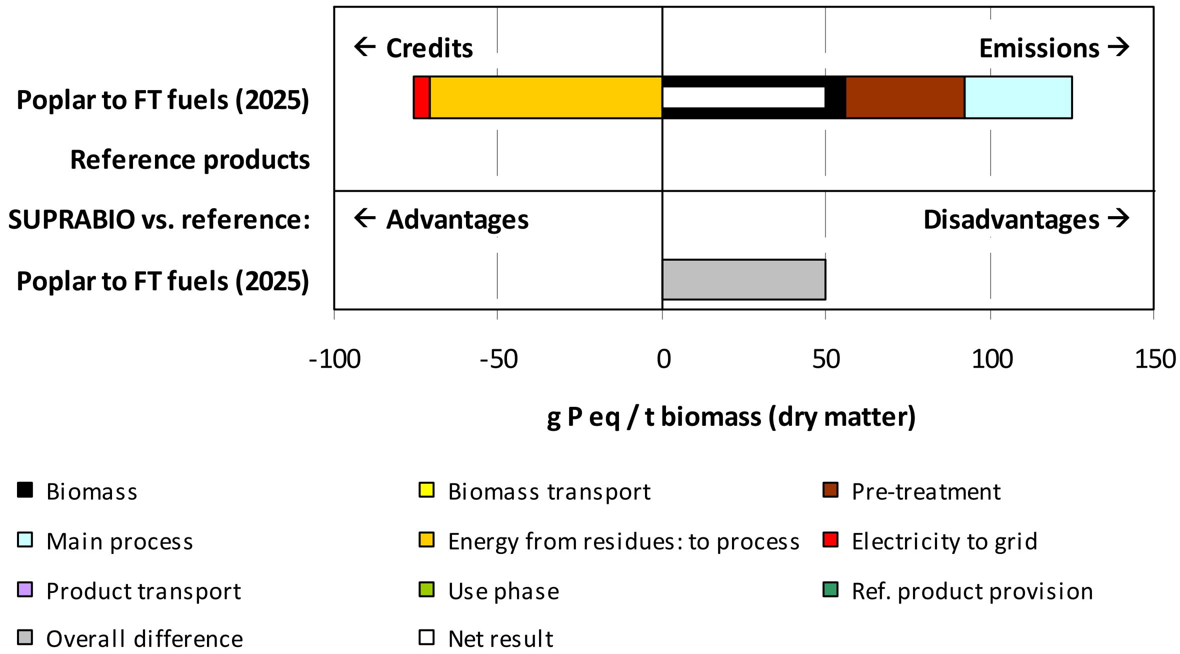


Fig. 4-18 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenario "Poplar to FT fuels (2025)" (scenario V) and its reference products (diesel and gasoline) in the environmental impact category freshwater eutrophication. Both life cycles are compared in form of an overall difference. Note: Used datasets for fossil fuel provision (reference products) do not show any emissions relevant for this category.

The fact that savings in non-renewable energy demand are remarkably high at similar savings of greenhouse gas emissions is due to two effects: First, greenhouse gas emission savings using straw would be higher, too, if no fertiliser would be required, which causes emissions of the greenhouse gas N_2O during production and application. Second, straw shows a lower efficiency of fuel production especially due to losses in the pyrolysis step. This leads to a higher production of electricity from process residues (Fig. 4-19). The nevertheless better to similar results show that a low fuel yield is not necessarily disadvantageous for the environmental performance. Electricity production – even at lower efficiencies from partially liquid residues – still leads to high credits as long as substantial amounts of harmful coal power are replaced. Partially better results at lower fuel yields are in agreement with comparisons of fuel production to electricity production via direct combustion, which achieves much higher mitigations of environmental burdens (see also chapter 4.3.1).

Although life cycle inventory data in many cases still needs improvement especially regarding emissions causing freshwater eutrophication, results on agricultural emissions are relatively robust under given conditions. As discussed in chapter 4.2.2.1, local conditions such as soil quality may however deviate from general parameters set in the assessed scenarios. Therefore, choice of feedstocks depends on local conditions. On sites that match standard conditions set for the assessed scenarios, a preference for forest residues exists due to smaller disadvantages (and similar advantages) based on aspects assessed here. However, other aspects have to be taken into account, which are not subject of this part of the environmental assessment but may be more relevant for the choice of feedstocks as discussed in chapter 4.2.1.3.

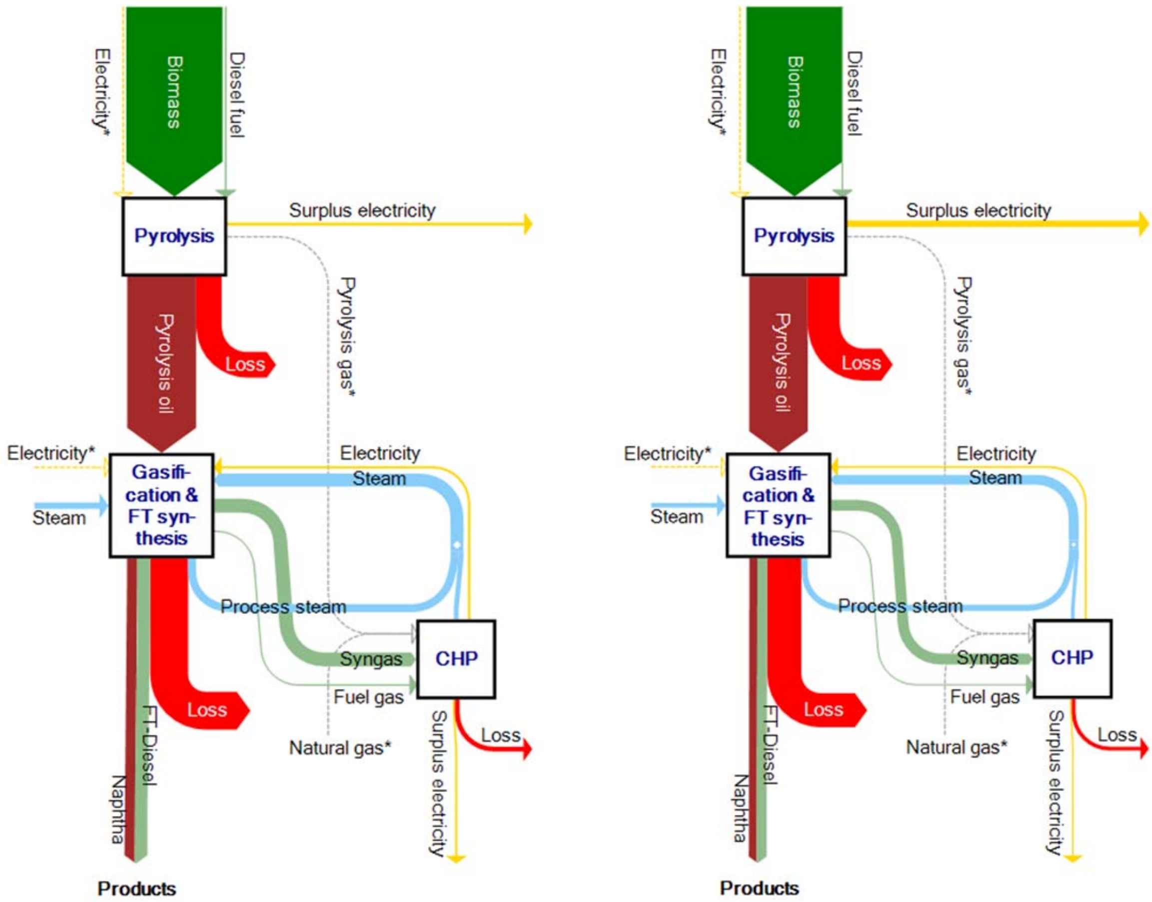


Fig. 4-19 Flows of final energy within the thermochemical biorefinery for “Forest residues to FT fuels (2025)” (left) and “Straw to FT fuels (2025)” (right) (scenarios II and IV, respectively). * Flows of input electricity, pyrolysis gas and natural gas are zero in these scenarios (→dotted lines)

4.2.2.4 Early implementation: Forest residues to FT fuels (2015)

The early implementation scenario “Forest residues to FT fuels (2015)” shows a lower conversion efficiency and thus replaces less conventional fuel (Fig. 4-20). This leads to a higher amount of process residues and thus energy production, which partially compensates the environmental effect of the reduced conversion efficiency. Overall, the early implementation scenario shows therefore slightly inferior results compared to the mature technology scenario. This can also be observed for other environmental impact categories (see annex, chapter 9.3). Decisive differences do not exist between these scenarios.

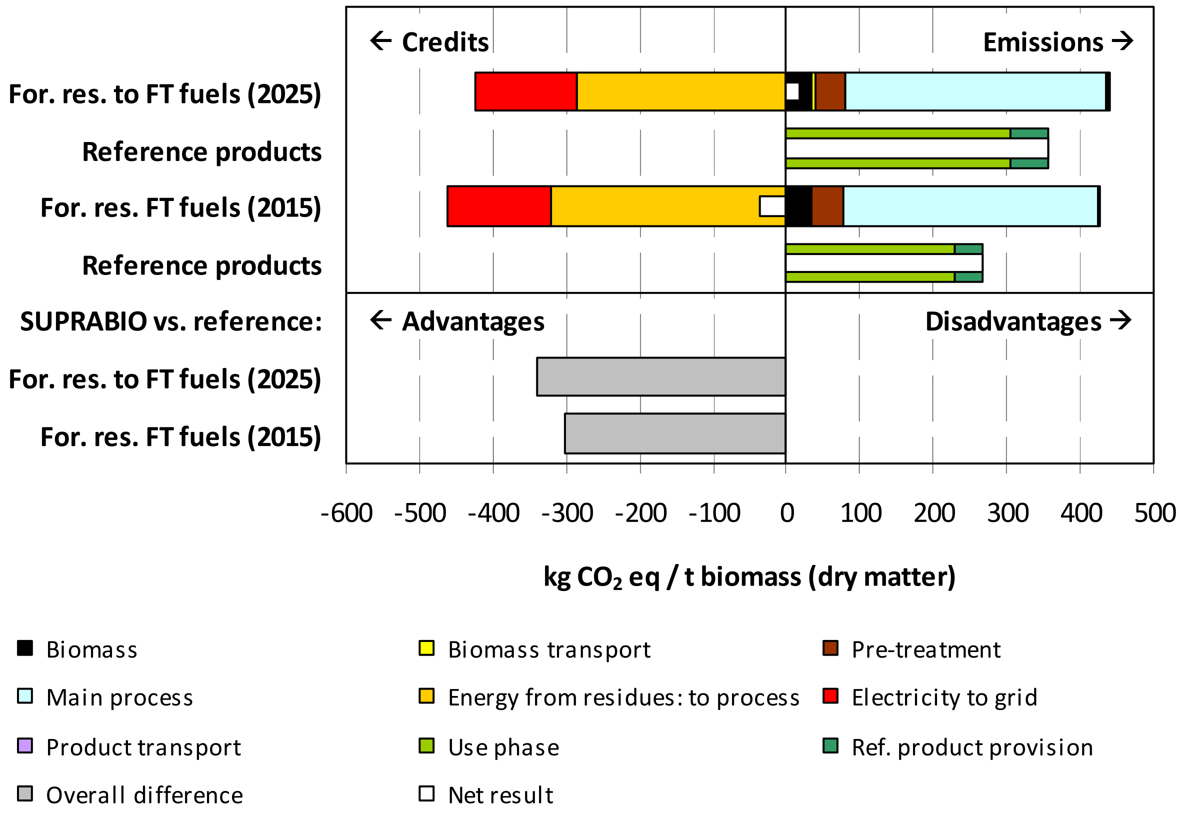


Fig. 4-20 Contributions of individual life cycle steps to the overall net results of scenarios "Forest residues to FT fuels (2025)" and "Forest residues to FT fuels (2015)" (scenarios II and I, respectively) and their reference products in the environmental impact category climate change. Pairs of life cycles are compared in form of an overall difference.

4.2.2.5 Sensitivity analyses and optimisation potential

The production of FT fuels via pyrolysis and gasification offers the option to perform the pyrolysis step in several small distributed units. Since pyrolysis oil has a higher energy density than biomass, transportation volume is reduced. All main scenarios are based on the configuration of five smaller distributed pyrolysis units that deliver pyrolysis oil to one central plant. Alternatively, biomass could be directly transported to an integrated central plant including one big pyrolysis unit. These options are compared in this sensitivity analysis.

Fig. 4-21 shows that greenhouse gas emissions connected to biomass (and pyrolysis oil) transportation are higher but still negligible if one integrated centralised plant is used. However, one centralised plant offers a higher potential for heat integration (reuse of heat at lower temperatures) and more efficient energy generation from process residues. This causes substantial greenhouse gas emission savings. Similar results are observed for all other environmental impact categories. Thus, one central plant including a single integrated pyrolysis unit should be preferred based on global / regional environmental impacts.

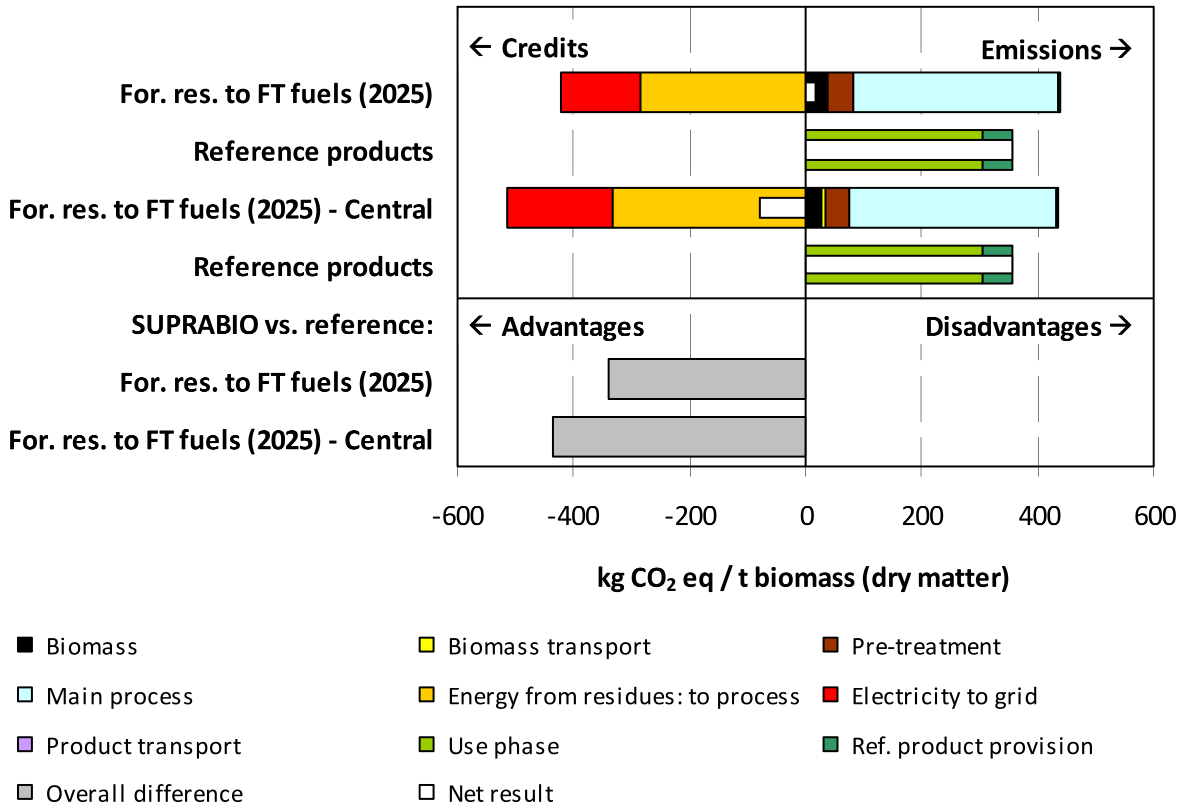


Fig. 4-21 Variation of scenario "Forest residues to FT fuels (2025)" with one central pyrolysis unit instead of 5 distributed ones (scenario VII) and its exemplary impact on climate change. Pairs of life cycles are compared in form of an overall difference. Biomass transport includes pyrolysis oil transport.

Besides the option to choose a central or distributed biorefinery concept, there are several other process design options. One option is to produce all required process heat internally by burning additional natural gas in the internal CHP plant, which uses a gas turbine, instead of acquiring steam from external heat plants. This creates on the one hand more emissions from natural gas combustion (Fig. 4-22, light blue bar) but on the other hand avoids more emissions due to a higher amount of exported electricity. The efficiency gain through an increased share of co-production in energy generation thus reduces greenhouse gas emissions and other environmental impacts. Another option is to use gasifiers that operate at higher pressures ("HP") and additionally keeping the syngas at a higher temperature after quenching in order to avoid heating it up again for the water gas shift reaction ("HP&HT"). Both these options substantially reduce process energy consumption of the most energy intensive unit processes water gas shift and gas cleaning. Furthermore, product output increases slightly. Despite lower GHG emission savings through energy production from residues, these scenarios result in higher overall advantages regarding climate change. Other impact categories show improvements, too, or are not affected by the modifications.

In general, all improvements analysed here could be implemented at the same time in an optimised design. However, the overall improvement will be lower than the sum of the individual improvements because e.g. more efficient steam provision is less of advantage if less steam is needed. Due to the lack of data on an overall optimised thermochemical plant design that takes these interactions into account, no further analysis can be conducted.

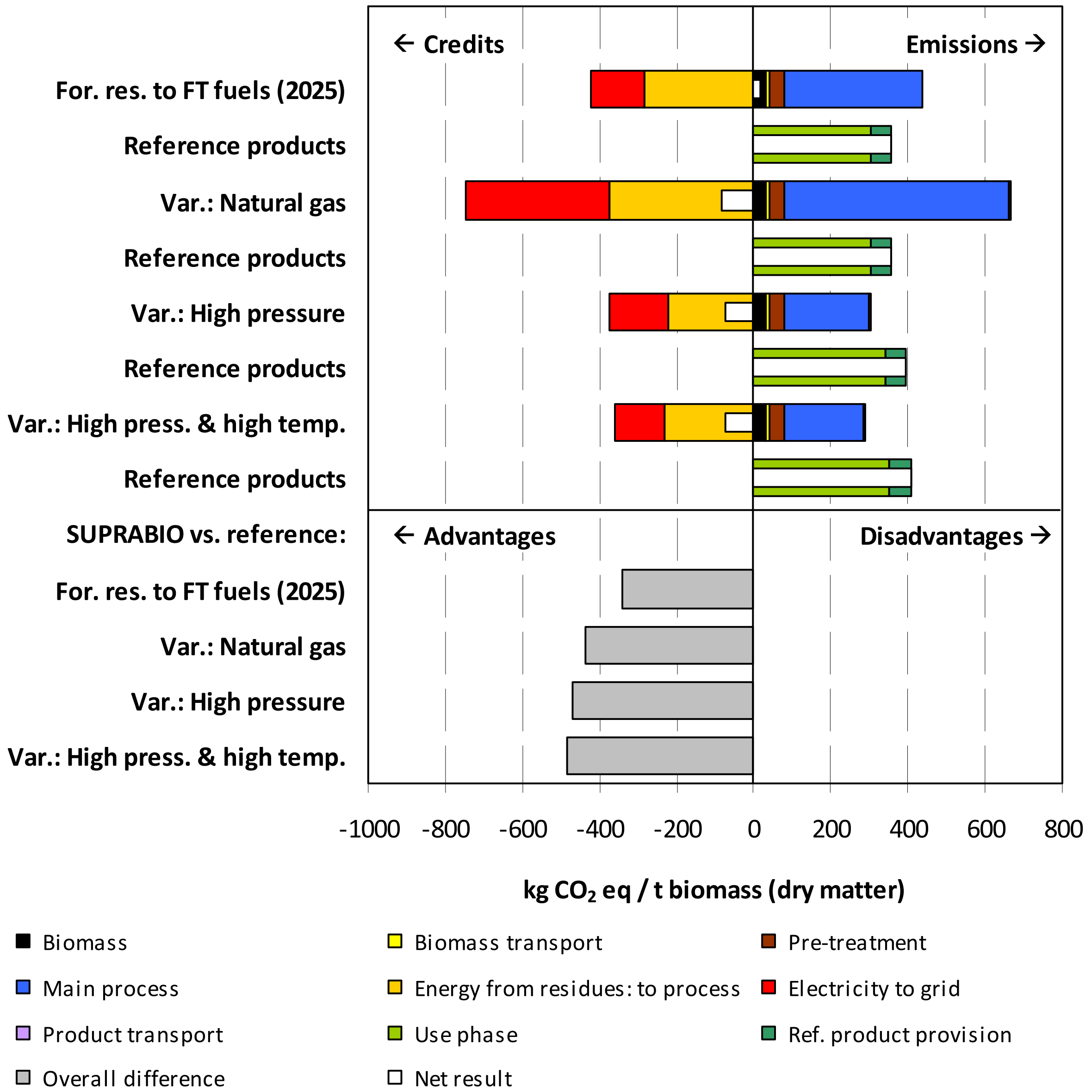


Fig. 4-22 Variation of scenario “Forest residues to FT fuels (2025)” with steam co-production from natural gas (“NG”, scenario VI), higher gasification pressures (“HP”, scenario VIII) and additionally higher quenching temperatures (“HP&HT”, scenario IX) and their exemplary impacts on climate change. Pairs of life cycles are compared in form of an overall difference.

4.2.2.6 Greenhouse gas balances according to the RED

In addition to the screening LCA, greenhouse gas balances for FT fuels and savings compared to fossil fuels have also been calculated according to Annex V of the RED. Like for ethanol from biochemical processes (chapter 4.2.1.6), these calculations are based on a number of further settings specified in chapter 4.1.7, where RED calculation rules are ambiguous.

FT fuels from forest residues produced according to the assessed scenarios can safely achieve the minimum GHG savings if they are optimised (Fig. 4-23). In the highly optimised scenario employing high pressure and high temperature (HP&HT), results even get rather close to default values for FT diesel from waste wood as given by the RED. Considerable differences regarding forest residue / waste wood provision between assessed scenarios and RED defaults are not surprising as sources and thus necessary efforts for extraction are very heterogeneous. Remarkably, GHG emissions from processing can be reduced to very low values as there are no energy intensive material inputs and all process energy can be provided from internal residue combustion if optimised accordingly.

When comparing the scenarios “Forest residues to FT fuels (2015)” and “Forest residues to FT fuels (2025)”, a different ranking compared to the assessment following ISO standard is apparent. The reason is that less fuel but more energy from residues is produced in the 2015 scenario. This leads to higher savings per unit of fuel (e.g. per MJ) but to lower savings per unit of input biomass. As the amount of available biomass but not the amount of fuel consumed in the EU is limiting the achievable overall climate change mitigation, decisions should be based on figures related to input-related reference units (such as per t biomass). Differences happen to be limited in this particular example but (amongst other differences) the same effect occurs when comparing FT fuels to ethanol (see also Fig. 4-27).

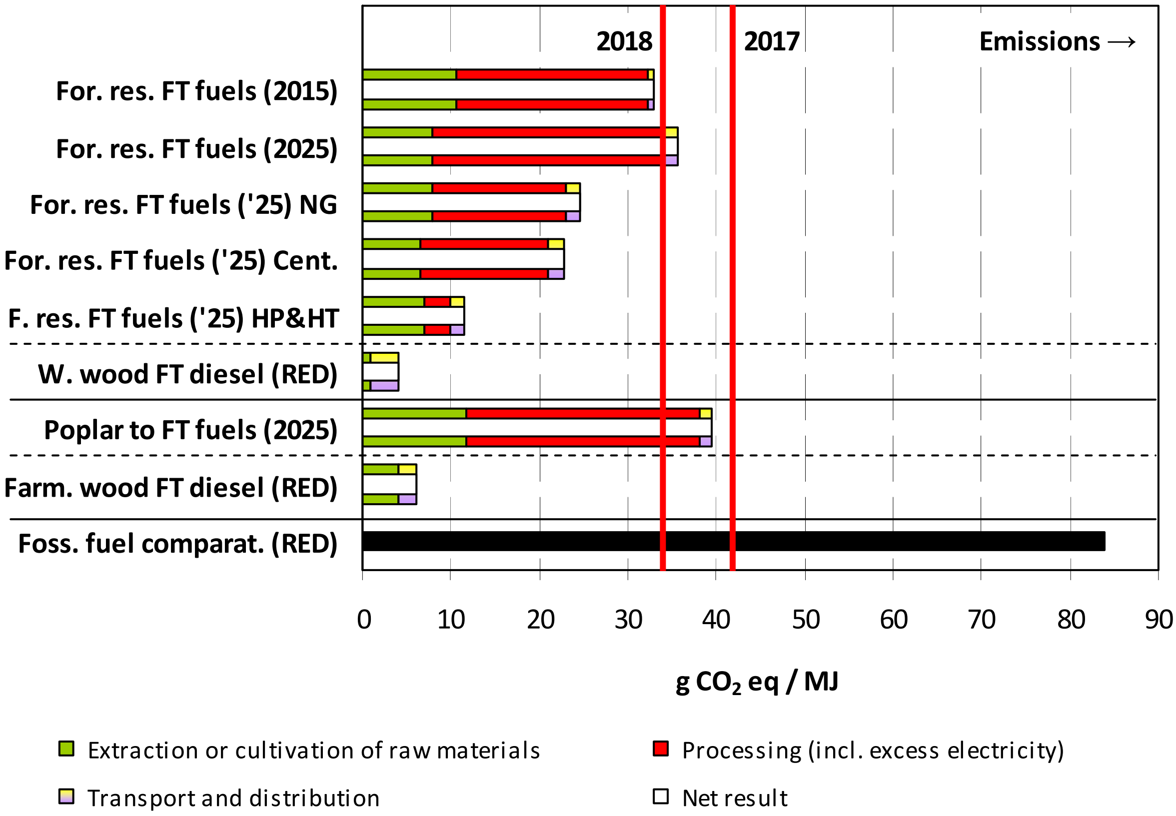


Fig. 4-23 Greenhouse gas emissions according to the RED for various FT fuels scenarios compared to default emissions of biofuels and fossil fuel given by the RED. The red lines indicate 50 % and 60 % savings, which are specified as minimum savings for biofuels in 2017 (all biofuels) and 2018 (biofuels from new installations), respectively. W. wood: waste wood, farm. wood: farmed wood, foss. fuel comparat.: fossil fuel comparator.

4.2.3 Comparison biochemical vs. thermochemical routes

This chapter deals with the question: Which are advantages and disadvantages of the best assessed biochemical and thermochemical biorefinery designs regarding global and regional environmental impacts?

In the previous chapters, the main biochemical scenarios producing bioethanol and the thermochemical scenario producing FT fuels using a modified gasifier design with high pressures and temperatures have been found to show best results in the applied screening life cycle assessment. A direct comparison of these scenarios is only possible with limitations because the optimised FT fuels scenario was only modelled for forest residues as a feedstock and this feedstock is not suitable for ethanol production. Additionally, further improvements of both scenarios are possible through potential improvements of external enzyme production and reduction of nutrient input for the biochemical route and through a combination of optimised energy use and provision options for thermochemical pathways. Yet, these improvements cannot be influenced by the biorefinery operator or could not be quantified due to a lack of data. Nevertheless, general advantages and disadvantages of both routes can be deduced from assessed scenarios, which were defined based on available data:

- One advantage of the thermochemical route is that it can utilise a wider range of feedstocks. Here, forest residues have been assessed as one example.
- Generally, ethanol production has a higher biomass to fuel conversion efficiency than FT fuels production (Fig. 4-25) and thus more emissions can be avoided through reference product replacement (Fig. 4-24, emissions reference product). However, bioethanol production also causes higher emissions per tonne of biomass input (Fig. 4-24, emissions SUPRABIO product). One main reason is the demand of ethanol production for process inputs besides biomass such as nitrogen nutrients or enzymes.
- The thermochemical process involves much less nitrogen in inputs and outputs than the biochemical processes. This causes lower emissions especially in those impact categories, which are affected by some of the nitrogen-related emissions (NOx / NH_3 / N_2O etc.) such as terrestrial acidification or ozone depletion. This can be seen for inputs (Fig. 4-24, Main process: Materials) and outputs such as emissions from residue combustion (Fig. 4-24, part of Energy from residues: to process).

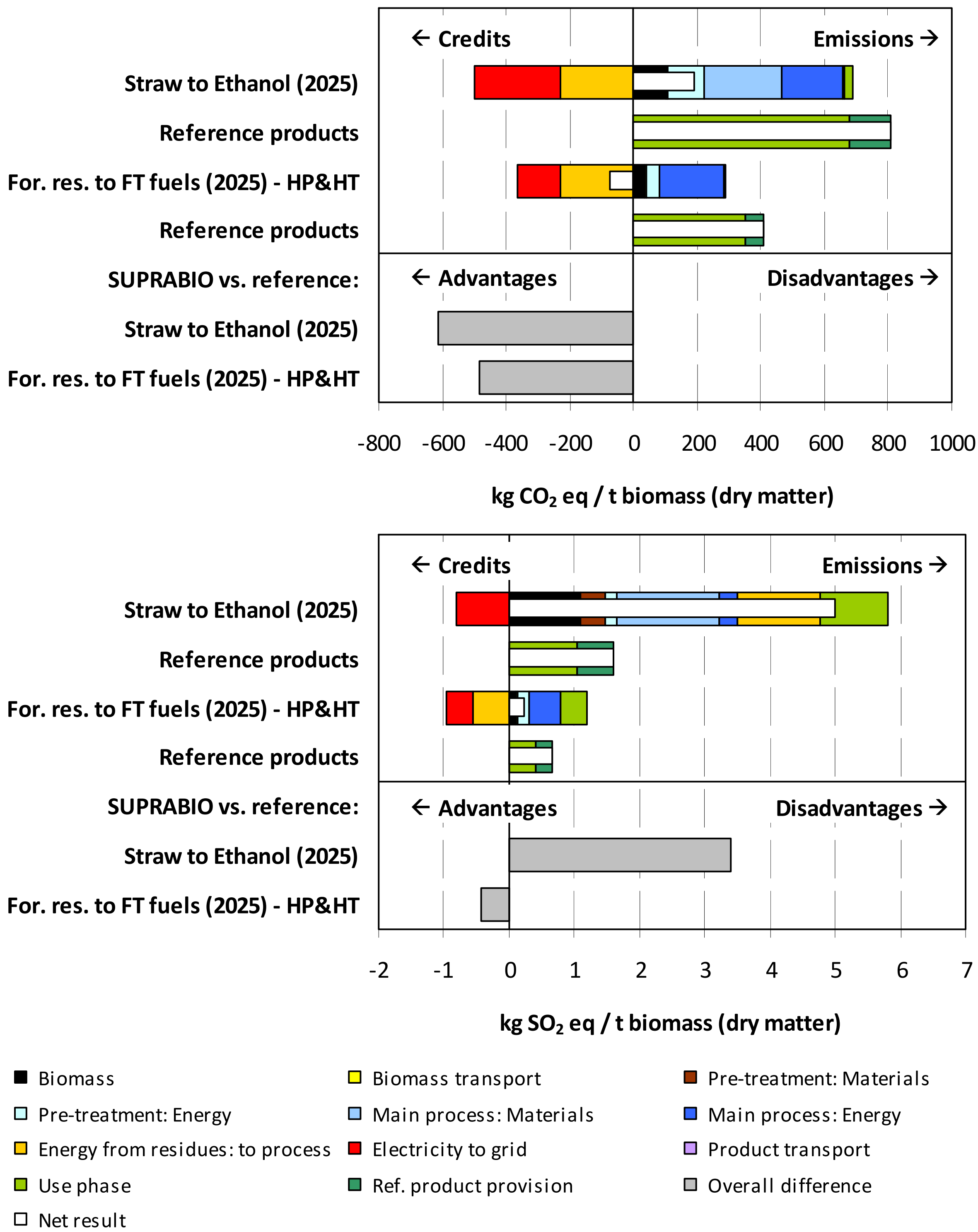


Fig. 4-24 Comparison of best assessed biochemical and thermochemical scenarios. Impacts on climate change and terrestrial acidification are displayed per tonne of feedstock. Please note that different feedstocks are used in each scenario.

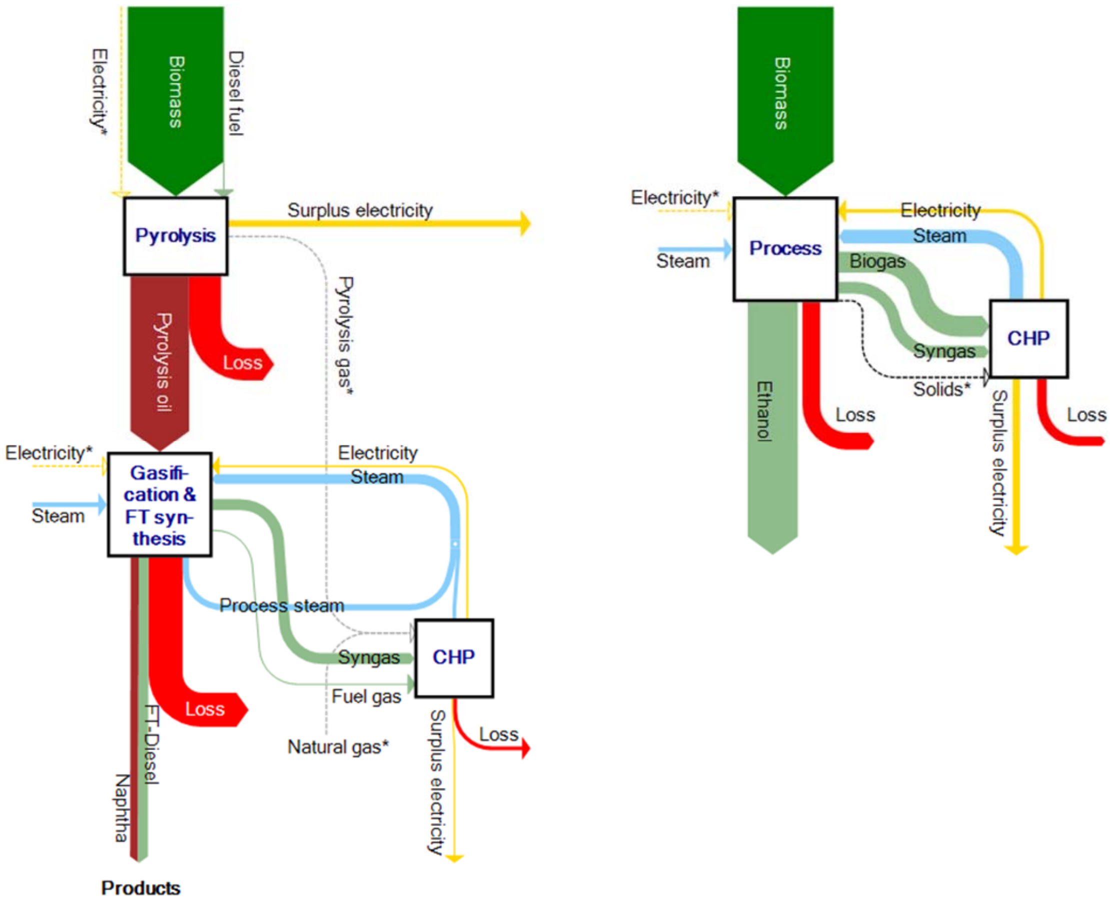


Fig. 4-25 Final energy flows within the biorefinery for the thermochemical route (left: scenario IV, "Straw to FT fuels (2025)") and biochemical route (right: scenario II, "Straw to Ethanol (2025)"), respectively. * Flows of input electricity, pyrolysis gas, natural gas and solids are zero in these scenarios (→dotted lines)

- A common pattern that can be found for most biofuels including 2nd generation ethanol is that they achieve overall advantages regarding climate change and depletion of non-renewable energy resources but cause disadvantages in other environmental impact categories. This does not apply to the assessed SUPRABIO scenario on FT fuels production from forest residues because the whole life cycle involves very little nitrogen-related chemistry (Fig. 4-26). Also with straw as feedstock, disadvantages are smaller than for biochemical ethanol production.
- Whether the production of biofuels from lignocellulosic biomass via the thermochemical or biochemical route saves more greenhouse gas emissions strongly depends on technical details of the implementation and properties of the feedstock. In this concrete example, a slight advantage can be seen for biochemical ethanol production compared to thermochemical FT fuels production (Fig. 4-26).

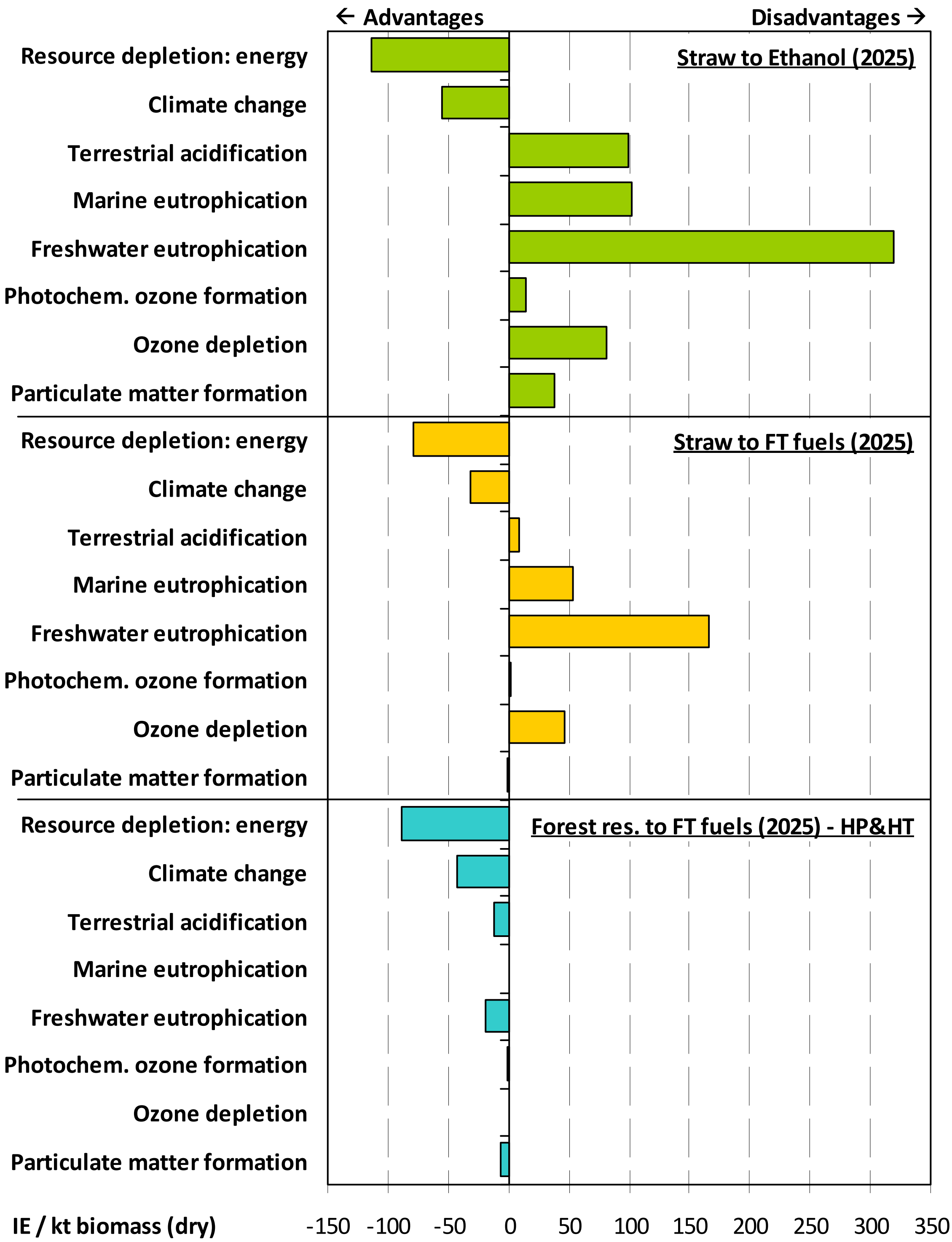


Fig. 4-26 Comparison of main biochemical and thermochemical scenarios that use straw as feedstock and an optimised thermochemical scenario that uses forest residues. Overall differences between SUPRABIO scenarios (biochemical scenario II and thermochemical scenarios IV and IX) and their reference products were normalised using inhabitant equivalents (IE).

4.3 Results: SUPRABIO vs. other biomass-based systems

In chapter 4.2, SUPRABIO systems are analysed in a first step based on the precondition that sufficient biomass and / or land are available for feedstock provision. This applies in reality only in few cases. Already today, there is competition for agricultural land, which leads to indirect land use changes and clearing of (semi-) natural ecosystems. For residues, underutilised resources still exist in many places but increased competition is expected for the future. This chapter therefore analyses in a second step, which of the competing biomass-based systems is the best choice from an environmental perspective.

4.3.1 Biomass use

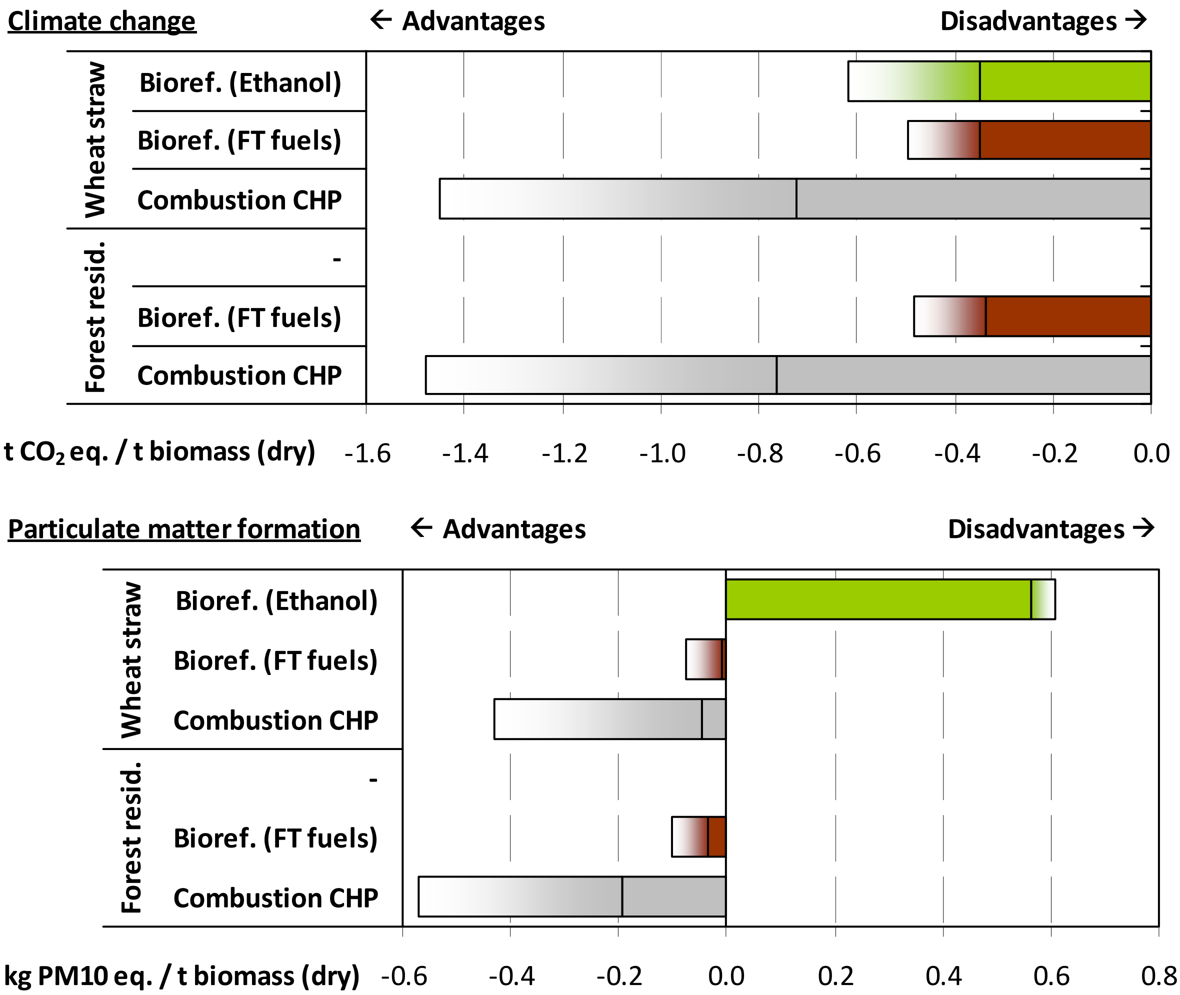


Fig. 4-27 Comparison of alternative biomass use options. Overall differences between environmental impacts of indicated biomass use option and reference product provision are shown for the categories climate change and particulate matter formation. Variability / optimisation potentials, which encompass all assessed scenarios for each shown pathway, are displayed as colour gradients. Optimisation potentials for the pathway wheat straw to FT fuels are extrapolated. For use options of poplar short rotation coppice please see Fig. 4-28.

Lignocellulosic biomass, especially wood and forest residues have a long tradition of use in energy generation. Such biomass is currently used in heat and power generation by direct combustion and various plans for future provision of renewable energy foresee an increased use. Thus, the use of all assessed kinds of lignocellulosic biomass in a biorefinery potentially competes with direct combustion either in existing or in envisioned plants even if currently underutilised residues are concerned. Fig. 4-27 shows that biorefineries according to the assessed SUPRABIO scenarios result in substantially smaller advantages in some environmental impact categories such as climate change compared to direct combustion. They can only reach the performance of direct combustion in some other categories such as particulate matter formation under certain conditions. Importantly, these results are based on the setting that European energy provision still requires fossil fuel combustion in 2025 but that a replacement of these fossil resources is ongoing. Energy from direct combustion as well as surplus electricity from biorefineries thus entirely replace energy from marginal fossil-powered plants, which would have to run longer or would have to be built additionally instead.

There are two principal reasons why fuel production from lignocellulosic biomass cannot compete with direct combustion of the same biomass under currently expectable conditions: First, there is always a loss in every conversion step (e.g. biomass to fuel, fuel to energy). Thus, avoiding conversion is better. Second, also in the near future a significant share of (marginal) energy demand is expected to be provided from coal, which causes higher CO_2 emissions per energy content than oil, which is replaced by transportation fuels. Nevertheless, if heat and power production would be dominated by alternative (non-bio) renewable resources in the future, biofuel production would outperform bioenergy production. Thus, to that extent to which coal and other fossil resources will redundant in the future as an important energy source, biofuels gain competitiveness from an environmental viewpoint.

4.3.2 Land use

If cultivated biomass such as poplar short rotation coppice is used for biofuel production, biorefineries do not only compete with other forms of biomass use but also with other use options for the land needed for biomass production. Established land use options for biofuel or bioenergy production were chosen for comparison. As for residue use, direct combustion of poplar short rotation coppice represents the best use option from an environmental standpoint (Fig. 4-28). As the comparison to triticale direct combustion shows, both feedstock and use option contribute to the advantages of poplar direct combustion. Regarding climate change mitigation or savings of non-renewable energy, SUPRABIO bioethanol and FT fuels are in a similar range of results as first generation bioethanol or biogas and perform better than first generation biodiesel (Fig. 4-28, for further categories see annex, chapter 9.3). In other categories such as acidification, results for SUPRABIO bioethanol are generally comparable to the worse end of the result spectrum of existing biofuels whereas SUPRABIO FT fuels mainly range at the better end. Thus, the global and local environmental impacts cause by the assessed 2nd generation biofuels ethanol and FT fuels are comparable to those of existing 1st generation biofuels but can hardly reach the advantages provided by direct biomass combustion under conditions expected for 2025. Mostly, production and use of FT fuels are connected with smaller disadvantages than 2nd generation ethanol in some environmental impacts such as acidification.

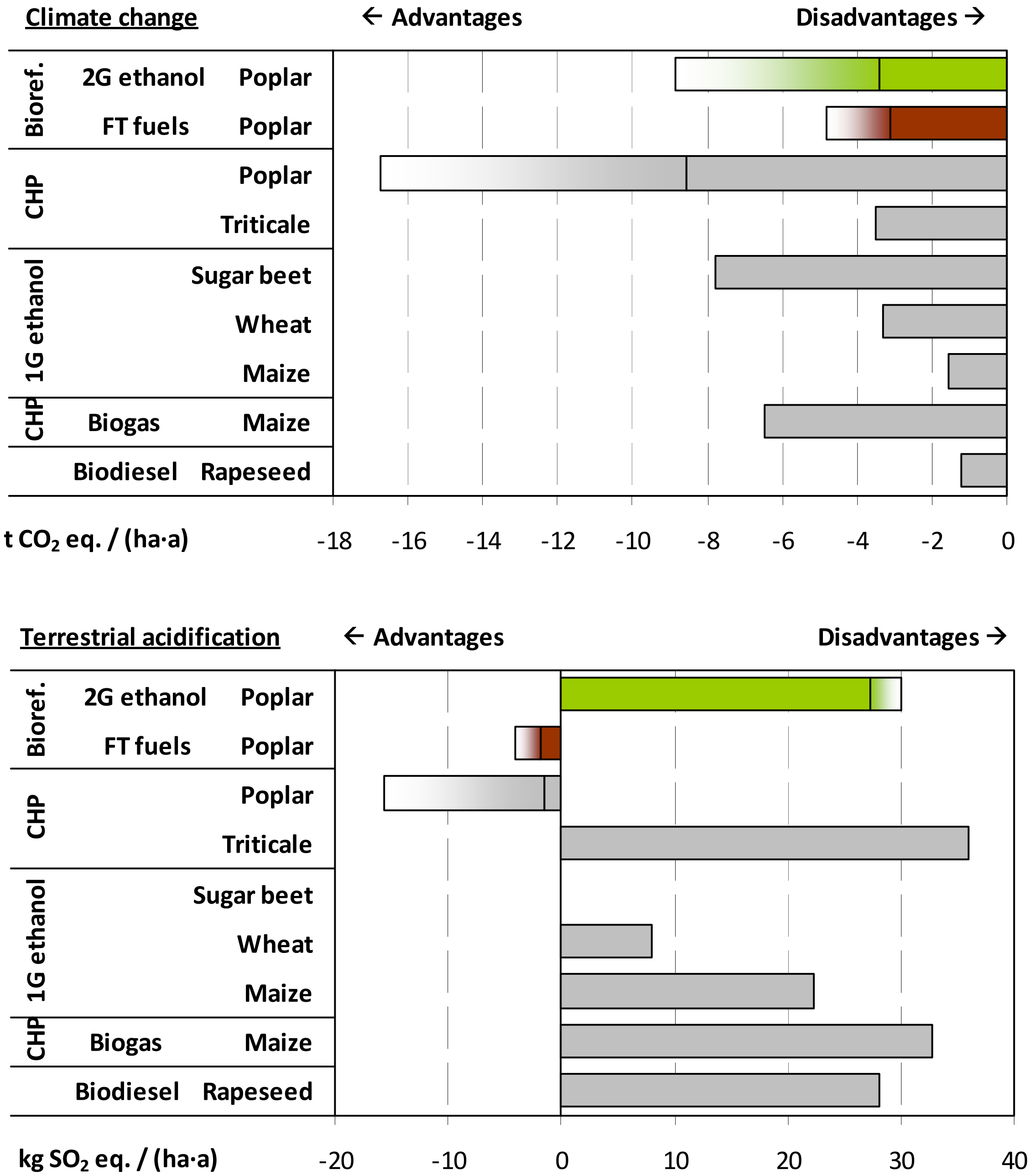


Fig. 4-28 Comparison of alternative land use options. Overall differences between environmental impacts of each indicated use option and its reference product(s) are shown for the categories climate change and terrestrial acidification per hectare and year of land use. Variability / optimisation potentials, which encompass all assessed scenarios for each shown pathway, are displayed as colour gradients if available. Optimisation potentials for the pathway poplar to FT fuels are extrapolated. 1G / 2G: 1st / 2nd generation, CHP: combined heat and power plant. Please note that the result for sugar beet acidification is about zero.

Another alternative, which was also studied in SUPRABIO, is the production of hydrogenated vegetable oils (HVO) from plant oils. As discussed in chapter 3.1.3.3, HVO production and use can only be assessed based on generic data in this study. Because of the identical feedstock, HVO mainly competes with biodiesel production. The environmental impacts are very similar but results for HVO in all impact categories are to a certain degree worse than those for biodiesel (Fig. 4-29). Whether this disadvantage can be overcome by HVO-specific improvements of the process that were studied within SUPRABIO cannot be judged based on available data.

Systematic problems associated with seed oil-based fuels are shared by biodiesel and HVO. In Europe, rapeseed is the dominating plant to produce seed oil for biofuels. Its productivity and thus greenhouse gas savings are comparatively low and disadvantages such as acidification caused by its fertiliser demand are comparatively high (see also Fig. 4-28). If imported seed oils are used, the environmental impacts are better for palm oil because of its high productivity and at least disadvantages are reduced for soybean oil because it does not require high fertilisation (Fig. 4-29). However, big areas of natural vegetation are being destroyed every year for their production. The effect of this direct land use change (dLUC) is illustrated for cleared rainforests. In many oil palm producing countries, even large areas of rainforests growing on peat soils are destroyed. In that case, greenhouse gases are additionally released by decomposition of the peat, in which much more carbon can be accumulated than in the above-ground vegetation. As Fig. 4-29 shows, LUC can be the by far dominating effect on climate change, which may cancel out any climate change mitigation achieved by the replacement of fossil fuels. Thus, neither biodiesel nor HVO should be produced from imported seed oils if dLUC cannot be certainly excluded.

Besides dLUC, indirect LUC (iLUC) can cause similar effects. This may happen via reallocation of resources on one market: For example, certified palm oil from existing plantations is sold to new biodiesel or HVO plants while existing customers receive palm oil from land, which was recently cleared due to increasing demand by new biofuel plants. Furthermore, iLUC can also happen via interdependent reallocations on several markets: For example, poplar short rotation coppice or rapeseed are planted on agricultural land in Europe instead of wheat. Wheat exports are thus reduced and food may be lacking elsewhere in less productive seasons. Subsequently, subsistence farmers may be forced to clear natural vegetation, partially also rainforests, elsewhere in the world.

Both versions of iLUC are hard to quantify because they involve indirect market effects on many actors. Nevertheless, iLUC due to imported seed oil, especially palm oil, seems more likely to be severe than iLUC due to poplar short rotation coppice or rapeseed because the more direct connection allows for less compensation and most land for potential new oil palm plantations is currently covered by rainforest. Thus, HVO and biodiesel production even from certified imported seed oil should not be expanded because of the risk of causing iLUC. As potential future advantages of HVO over biodiesel cannot overcome this principal risk, new HVO processes based on imported seed oil should not be developed. Furthermore, biofuels from residues should be preferred over biofuels from cultivated biomass because of the risk of iLUC.

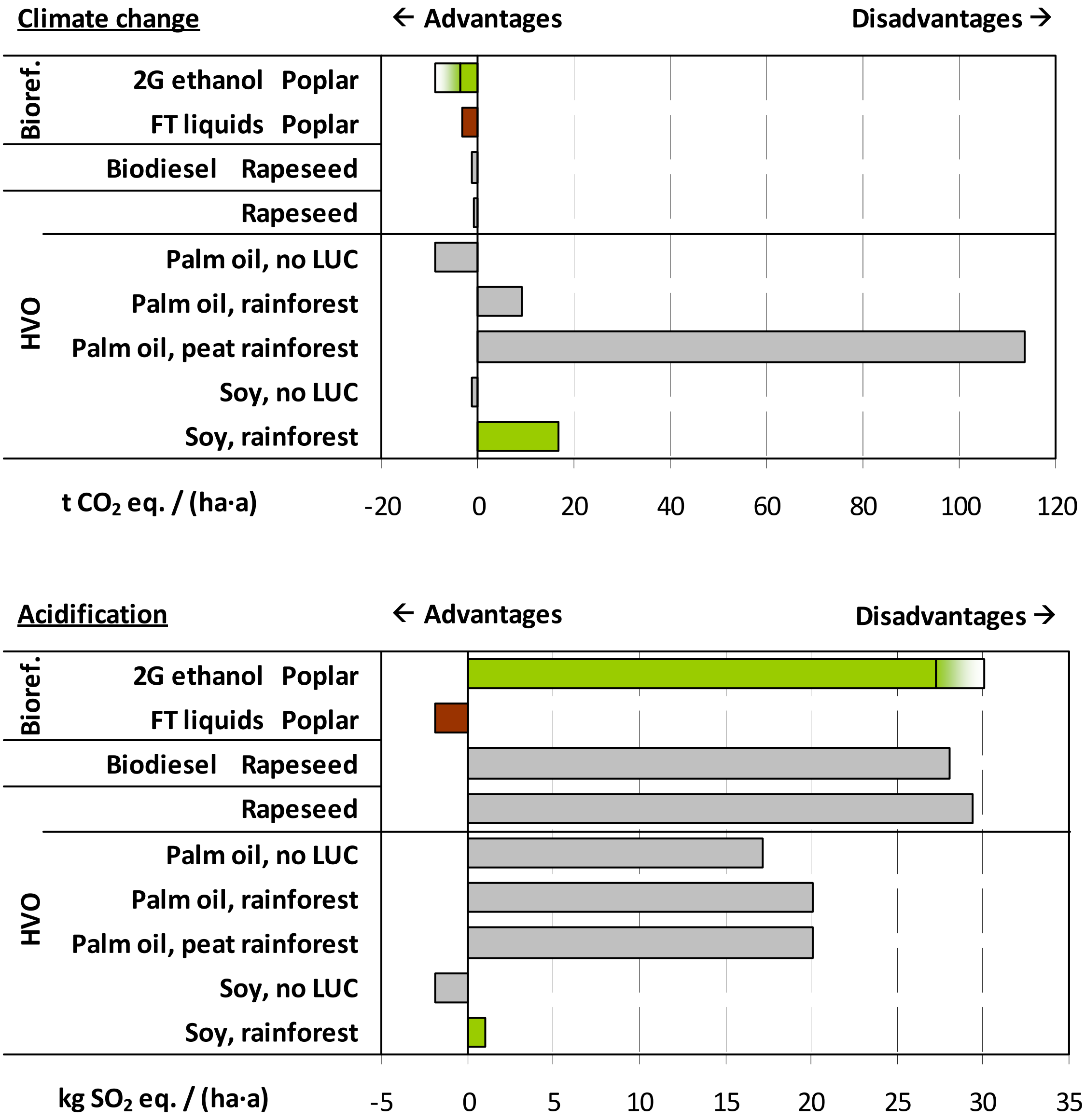


Fig. 4-29 Hydrogenated vegetable oils (HVO) as alternative to assessed SUPRABIO fuel products and effects of land use changes (LUC) on the results. Overall differences between environmental impacts of each indicated use option and its reference product(s) are exemplarily shown for the categories climate change and terrestrial acidification per hectare and year of land use. Palm oil and soybean are cultivated in different climatic zones with intrinsically different agricultural productivity (see separating line). Thus, this comparison is only indicative for discussed effects but not suitable for an overall comparison. One-time carbon emissions from clearing vegetation are evenly distributed over a time of 25 years (roughly one plantation period of oil palms).

4.4 Discussion and interpretation

General

- Lignocellulosic biomass can be provided with relatively low global / regional impacts. In contrast, its conversion into products (here mostly biofuels) requires intensive processing. Therefore, the main question regarding global / regional environmental impacts is whether the expenditures for biomass conversion can be reduced far enough so that the overall environmental footprint of the biofuel / bio-based product is substantially lower than the footprint of the conventional fuel / product. Thus, an optimisation of any SUPRABIO biorefinery is paramount.
- Regarding scenarios on bioethanol and Fischer-Tropsch fuel production, the optimisation targets gradual but nevertheless important improvements underlining the status of maturity that is already reached. For other scenarios such as mixed acid production, there is still the question which process steps need fundamental improvement in order to reach viability.

Biochemical routes

- Main scenario ethanol production:
  Most emissions along the life cycle are caused by the provision of enzymes and high amounts of nitrogen nutrients to the biorefinery. All required electricity and a big part of the required steam is produced internally from biomass residues which causes less emissions. As long as energy consumption is reduced as far as possible, a big amount of electricity is fed into the grid. Depending on the scenario, the saved non-renewable primary energy due to electricity export can compensate for more or less all non-renewable primary energy consumed throughout the whole life cycle (including e.g. enzyme and fertiliser production). Thus, the assessed 2nd generation ethanol process is particularly energy efficient. Additionally, only about three tonnes of biomass dry matter are required per tonne of ethanol, which is an important contribution to overall emission savings compared to gasoline.
- Main scenario mixed acids production:
  A more energy- and material-intensive reference product is replaced compared to ethanol production. However, the bigger expenditures in the biorefinery, mainly for very energy-intensive product separation, outweigh the expenditures for the reference product by far. This leads to overall disadvantages of mixed acids scenarios compared to the respective conventional product in all environmental impact categories. This process can only become environmentally beneficial if the energy demand is drastically reduced.
- Feedstock straw vs. poplar:
  Ethanol from straw and poplar short rotation coppice show the same pattern of advantages and disadvantages. Both feedstocks represent largely independent resources that do not compete with each other e.g. for agricultural land. However, the use of agricultural land for poplar cultivation comes along with a risk for indirect land use changes, which can severely affect the environment. Thus, underutilised residues should be preferred over agricultural biomass.
- Early implementation of ethanol production:
  In this scenario, the pre-treatment requires more inputs because hydrolysis of cellulose and hemicellulose and fermentation have to be done separately (SHF) whereas later

scenarios are based on a simultaneous saccharification and fermentation (SSF). This and a slightly lower efficiency lead to higher impacts in this scenario although patterns of advantages and disadvantages are the same as for the mature technology scenario. Thus, no specific measures or boundary conditions seem necessary in this respect for the implementation phase of this technology.

- Optimisation of ethanol production:
  One important aspect of biorefineries of the biochemical route is energy generation from unconverted biomass. From an environmental perspective, the main scenario Straw to Ethanol (2025), which uses a gas turbine, shows the best results regarding climate change under standard conditions. Several other options exist with only minor differences compared to the main scenario considering that results also depend on external influences such as the source of replaced power. Nevertheless, gasification of process residues has the potential to substantially improve the life cycle greenhouse gas balance of the process compared to a direct combustion in a boiler. Furthermore, improvements in external enzyme production and enzyme performance can reduce environmental impacts. Further reductions seem plausible if the input of nitrogen into the main process could be reduced.

Thermochemical routes

- Main scenario FT fuels:
  The process consumes big amounts of energy especially for the water gas shift reaction and acid gas removal. However, all required electricity and a big part of required steam can be produced internally from residues. The better these processes are optimised, the more surplus electricity can be fed into the grid and cause emission savings elsewhere. Depending on the scenario, the avoided environmental burdens due to electricity export can compensate for more or less all expenditures throughout the whole life cycle. As no major material inputs besides biomass are required, the whole life cycle of FT fuels production does not cause any big environmental disadvantages as long as the feedstock is provided with low expenditures.

- FTD vs. DME:
  The production of bio-based DME is more energy intensive than FT fuels production and less energy is produced from residues. This is not compensated for by the higher energy content of the fuel. Thus, DME production is disadvantageous compared to FT fuels production. The difference is not very big but robust.

- Feedstock:
  The best results are achieved by production of FT fuels from forest residues unless intensive residue extraction causes the need for compensatory fertilisation of forests. Yet, FT fuels from all feedstocks show rather similar advantages. Deviations mainly result from different fertiliser demands and different ratios of the co-products FT fuels and electricity (with lower fuel production leading to higher electricity production from process residues). Thus, all feedstocks should be used unless competition diverts these feedstocks from more advantageous use options or may cause undesired effects such as land use changes.

- The early implementation scenario does not perform much worse than the mature technology scenario.

- Optimisation of FT fuels production:
  All analysed alternative process design options lead to improvements of overall results. Pyrolysis should take place in one central plant instead of several distributed units because of more efficient energy provision from residues. Furthermore, all required steam should be produced internally via co-production instead of its acquisition from external heat plants. Finally, gasification units should be used that operate at higher pressures and release syngas at higher temperatures.

Comparison of routes and alternatives

- Whether the production of biofuels from lignocellulosic biomass is more environmentally friendly via the thermochemical or biochemical route depends on technical details of the implementation, properties of the feedstock and weighting of impacts. In this concrete example, slight advantage can be seen for biochemical ethanol production compared to optimised thermochemical FT fuels production regarding the impact categories like climate change. However, FT fuel production does not cause substantial overall additional environmental burdens as bioethanol production does e.g. regarding acidification. The main reason is that no additional process inputs like enzymes or nitrogen nutrients are required. The disadvantages are additionally reduced if forest residues can be used as feedstock, which were sustainably extracted without compensatory fertilisation. Thus, unless a strong preference is given to climate change mitigation and savings of non-renewable energy over other environmental impacts, optimised FT fuels production is likely to be the better choice because it largely avoids disadvantages.

- Results of greenhouse gas balances according to the RED do not provide a basis for such a differentiated comparison of ethanol versus FT fuels. They even suggest that FT fuels should be preferred over ethanol because of their lower GHG emissions per unit of fuel. However, since biomass availability limits overall achievable mitigation of greenhouse gas emissions, results should be compared relative to the amount of input biomass. Therefore, GHG balances according to the RED should not be taken as a basis for political decisions, but only for the regulation of economic operators.

- Alternative biomass use options:
  Under conditions expected for 2025, fuel production from lignocellulosic biomass cannot reach levels of climate change mitigation as is possible by direct combustion of the same biomass in a CHP plant. There are two principal reasons for it: First, there is always a loss in each conversion step (such as biomass to fuel). Thus, avoiding conversion is better. Second, in the near future a significant share of marginal power demand will be provided from coal, which causes higher CO_2 emissions per energy content than oil, which is replaced by transportation fuels. However, heat and power could also be mainly provided from alternative renewable resources other than biomass in the long run, which is not foreseeable for transportation fuels. Thus, to that extent to which coal and other fossil resources will be redundant in the future as important energy source, biofuels gain competitiveness from an environmental viewpoint.

- Alternative land use options:
  Also for poplar short rotation coppice, direct combustion for heat and power production is the best option from an environmental standpoint. At the same time, this is the best of all assessed land use options due to high agricultural productivity and efficient conversion.

SUPRABIO 2nd generation ethanol and FT fuels show results that are more or less within the range of results of established first generation biofuels and biogas.

- HVO production, which was studied within SUPRABIO but only analysed generically in this assessment, would need substantial improvement to perform similar to 1st generation biodiesel production, which is based on identical feedstocks. As feedstocks are shared between both processes, inherent problems regarding biomass production efficiency and land use changes are shared, too. From an environmental perspective, HVO and biodiesel production even from certified imported seed oil should not be expanded because of the risk of causing LUC. Since potential future advantages of HVO over biodiesel cannot overcome this principal risk, new HVO processes should not be developed if their implementation depends on seed oil imports.
- Generally, biofuels from underutilised and sustainably extracted residues should be preferred over biofuels from cultivated biomass because of the risk of causing iLUC. Although it seems less severe than for imported seed oils, it is not negligible.
- Which residues are truly underutilised in 2025 cannot be predicted as expansion is planned for many lignocellulose-based processes such as fuels, heat and power as well as bio-based materials. In many locations, competition and thus the risk of misallocation from an environmental perspective will be unavoidable. In the case of forest residues, an increased demand can for example lead to the use of chipped high quality timber instead of residues by CHP plants. This can already be observed in some locations today. This timber is then missing for more environmentally friendly use options such as furniture production or even construction of houses so that metal or concrete is used instead /Gärtner et al. 2013/. There are sawmills closing down partially also for this reason. In analogy to iLUC, this effect is termed iRUC (indirect residue use change). Its exact impact is similarly hard to quantify because of complex market interactions with competing users, feedstocks and products. Nevertheless, these effects do occur and have to be taken into account. Like for iLUC, iRUC can e.g. lead to additional overall greenhouse gas emissions although there are emission reductions due to the biorefinery in the first place.

5 Life cycle environmental impact assessment

5.1 Methodology

Task 7.3 addresses the local environmental effects using the elements of environmental impact assessment (EIA) and strategic environmental assessment (SEA). These elements are meant to supplement the life cycle assessments (LCA) in task 7.2 which are known to be less suitable for addressing local / site-specific environmental impacts.

5.1.1 Introduction to EIA methodology

The environmental impacts of a planned project depend on both the nature / specifications of the project (e.g. a biorefinery plant housing a specific production process and requiring specific raw materials which have to be transported there) and on the specific quality of the environment at a certain geographic location (e.g. occurrence of rare or endangered species, air and water quality etc.). With a standardised methodology proposed projects can be analysed regarding their potential to affect the environment, - the Environmental impact assessment (EIA).

It is based on the identification, description and estimation of the project’s environmental impacts and is usually applied at an early planning stage, i.e. before the project is carried out. EIA primarily serves as a decision support for project management and authorities which have to decide on approval. Moreover, it helps decision makers to identify more environmentally friendly alternatives as well as mitigation and compensation measures to minimize negative impacts on the environment.

The same project probably entails different environmental impacts at two different locations. EIA is therefore usually conducted at a site-specific / local level. These environmental impacts are compared to a situation without the project being implemented (“no-action alternative”).

5.1.1.1 Regulatory frameworks

Within the European Union, it is mandatory to carry out an environmental impact as-assessment (EIA) for projects according to the following Council Directive 85/337 EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment /CEC 1985/. This Directive has been amended several times, e.g.:

- Council Directive 97/11/EC of 3 March 1997 /CEU 1997/
- Directive 2003/35/EC of 26 May 2003 /EP & CEU 2003/
- Directive 2009/31/EC of 23 April 2009 /EP & CEU 2009a/.

An EIA covers direct and indirect effects of a project on the following environmental factors (according to Council Directive 85/337/EEC):

- human beings, fauna and flora; biodiversity;
- soil, water, air, climate and the landscape;
- material assets and the cultural heritage;
- interaction between these factors.

5.1.1.2 Steps of an EIA

Below the steps of an environmental impact assessment (EIA) are described in detail. The following steps are included:

- Screening
- Scoping
- EIA report
  - Project description and consideration of alternatives
  - Description of environmental factors
  - Prediction and evaluation of impacts
  - Mitigation measures
- Monitoring and auditing measures.

Screening

Usually an EIA starts with a screening process to find out whether a project requires an EIA or not. According to article 4 (1) and annex 1 (6) of the EIA Directive /CEC 1985/, an EIA is mandatory for “Integrated chemical installations, i.e. those installations for the manufacture on an industrial scale of substances using chemical conversion processes, in which several units are juxtaposed and functionally linked to one another and which are (i) “for the production of basic organic chemicals”. Referring to annex 1 (6) of the EIA Directive, an EIA would be required if SUPRABIO biorefineries were implemented.

Scoping

Scoping is to determine what should be the coverage or scope of the EIA study for a project as having potentially significant environmental impacts. It helps in developing and selecting alternatives to the proposed action and in identifying the issues to be considered in an EIA. The main objectives of the scoping are:

- Identify concerns and issues for consideration in an EIA
- Identify the environmental impacts that are relevant for decision-makers
- Enable those responsible for an EIA study to properly brief the study team on the alternatives and on impacts to be considered at different levels of analysis
- Determine the assessment methods to be used
- Provide an opportunity for public involvement in determining the factors to be assessed, and facilitate early agreement on contentious issues.

EIA report

An EIA report consists of a project description, a description of the status and trends of relevant environmental factors and a consideration of alternatives including against which predicted changes can be compared and evaluated in terms of importance.

- Impact prediction: a description of the likely significant effects of the proposed project on the environment resulting from:
  - The construction / installation of the project; temporary impacts expected, e.g. by noise from construction sites.
  - The existence of the project, i.e. project-related installations and buildings, durable impacts expected e.g. by loss of unsealed soil on the plant site.
  - The operation phase of the project; durable impacts expected, e.g. by emission of gases.

  Prediction should be based on the available environmental project data. Such predictions are described in quantitative or qualitative terms considering e.g.:
  - Quality of impact
  - Magnitude of impact
  - Extent of impact
  - Duration of impact.
- Mitigation measures are recommended actions to reduce, avoid or offset the potential adverse environmental consequences of development activities. The objective of mitigation measures is to maximise project benefits and minimise undesirable impacts.

Monitoring and auditing measures

Monitoring and auditing measures are post-EIA procedures aiming to proof the efficiency of potentially suggested mitigation measures. It can contribute to an improvement of the EIA procedure.

5.1.2 The approach for SUPRABIO

5.1.2.1 Objectives and approach

Within the SUPRABIO project, a set of different biorefinery concepts is analysed. Each biorefinery concept is defined by its inputs, the pre-treatment process, the downstream processes and the final products. This is also reflected in the objectives of the sustainability assessment in WP 7: the aim is to qualitatively assess the impacts associated with each of the (hypothetical) SUPRABIO biorefinery concepts (in the sense of technological concepts) at a generic level. The assessment is not meant to be performed for a specific SUPRABIO biorefinery plant at a specific geographic location.

Environmental impact assessment (EIA), however, is usually conducted at a site-specific / local level (see chapter 5.1.1) for a planned (actual) project. For the purpose of the SUPRABIO project which does not encompass the actual construction of a biorefinery plant, it is therefore not appropriate to perform a full-scale EIA according to the regulatory frameworks mentioned in chapter 5.1.1.1. Monitoring and auditing measures, for example, become redundant if a project is not implemented, as they are post-project procedures. Consequently, monitoring and auditing measures will be omitted within SUPRABIO. Nevertheless, elements of environmental impact assessment (EIA) are used to characterise the environmental impacts associated with the SUPRABIO biorefinery concepts at a generic level.

The elements of EIA used in SUPRABIO are shown in Fig. 5-1.

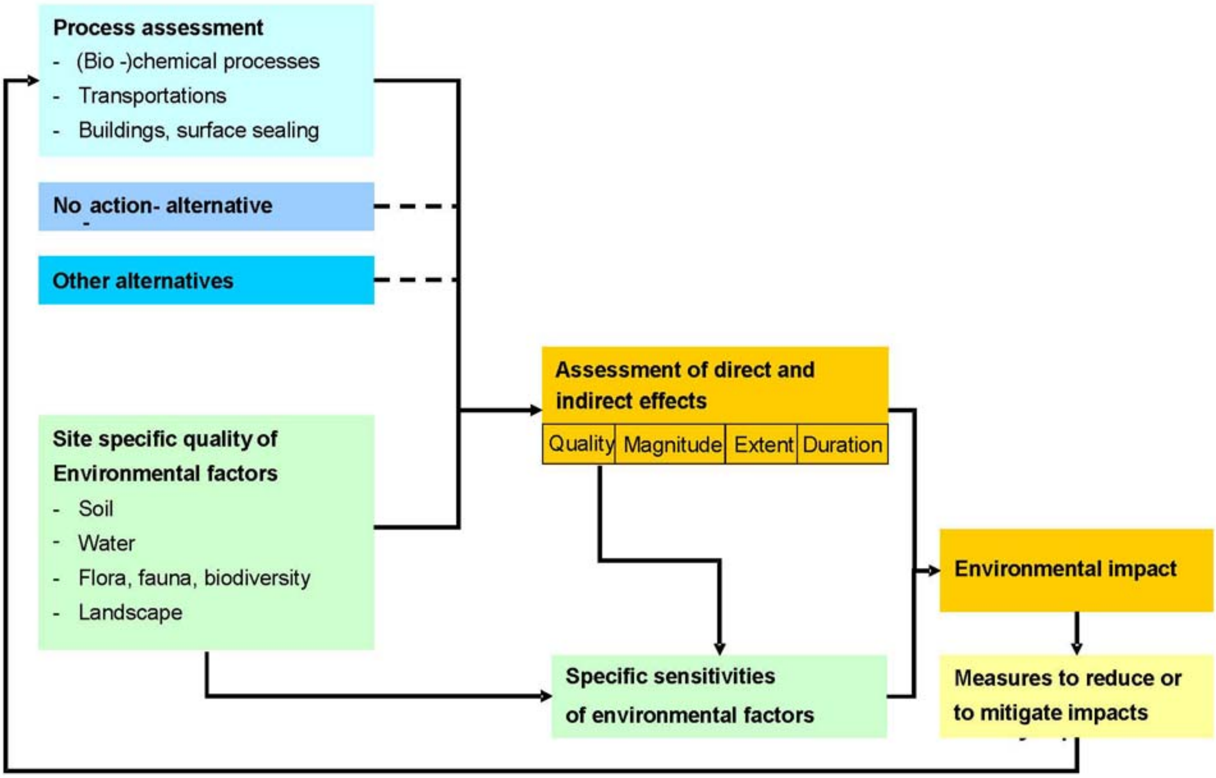


Fig. 5-1 Elements of EIA used in SUPRABIO

5.1.2.2 Reference systems

For SUPRABIO, the scope of the EIA was chosen to encompass all life cycle stages from biomass production through biomass conversion up to the use of the manufactured products. This assessment is restricted to one specific project or site such as a biorefinery. Biomass production sites and / or the impacts associated with the end use of the manufactured products are usually not considered. Generally, an EIA compares a planned project to a so-called no-action alternative (a situation without the project being implemented) in terms of environmental impacts. The environmental assessment used in SUPRABIO is comparing potential biorefinery scenarios with so-called reference systems, which is corresponding to a life-cycle perspective and goes beyond the regulatory frameworks for EIA.

Covering the impacts of biomass production is crucial for the environmental assessment because the land-use impact (including indirect impacts on fauna and flora, biodiversity, soil and water) of biomass production exceeds the land-use impact of biomass conversion by far. Therefore, the reference systems are divided into 1) reference systems for biomass production and 2) reference systems for biomass conversion and use. In details the reference systems are described in chapter 3.1.5.

5.1.2.3 Impact assessment

Following impact identification and prediction, impact evaluation is the formal stage at which the significance of an impact is determined. Impact significance depends on the joint consideration of its characteristics (quality, magnitude, extent, duration) and the importance (or value) that is attached to the resource losses, environmental deterioration or alternative uses. Significant negative impacts will be taken into further consideration for they could require mitigation measures. Impacts are likely to be significant if they

- lead to the total functional loss of an environmental factor
- have adverse effects of special or high relevance for environmental factors
- are extensive over space or time
- exceed environmental standards and thresholds
- do not comply with environmental policies / land use plans
- affect ecological sensitive areas
- affect community lifestyle, traditional land use and values

Non-significantly affected environmental factors are of minor importance in the further process. They do not require mitigation actions.

The assessment of environmental impacts resulting from biomass production, conversion and use is carried out as a benefit and risk assessment. This is useful if the project is considered as a theoretical concept with uncertainty regarding the possible future location of biomass cultivation sites and conversion facilities.

Impact assessment for biomass production

In the case of biomass production the following factors have been identified to assess the possible benefits and risks (see also Fig. 5-2).

- Soil
  - Soil erosion
  - Soil compaction
  - Soil chemistry
  - Soil organic matter
- Water
  - Nutrient leaching / eutrophication (water quality)
  - Use of water resources
- Flora, fauna & landscape:
  - Weed control / pesticides
  - Species diversity / habitat quality.

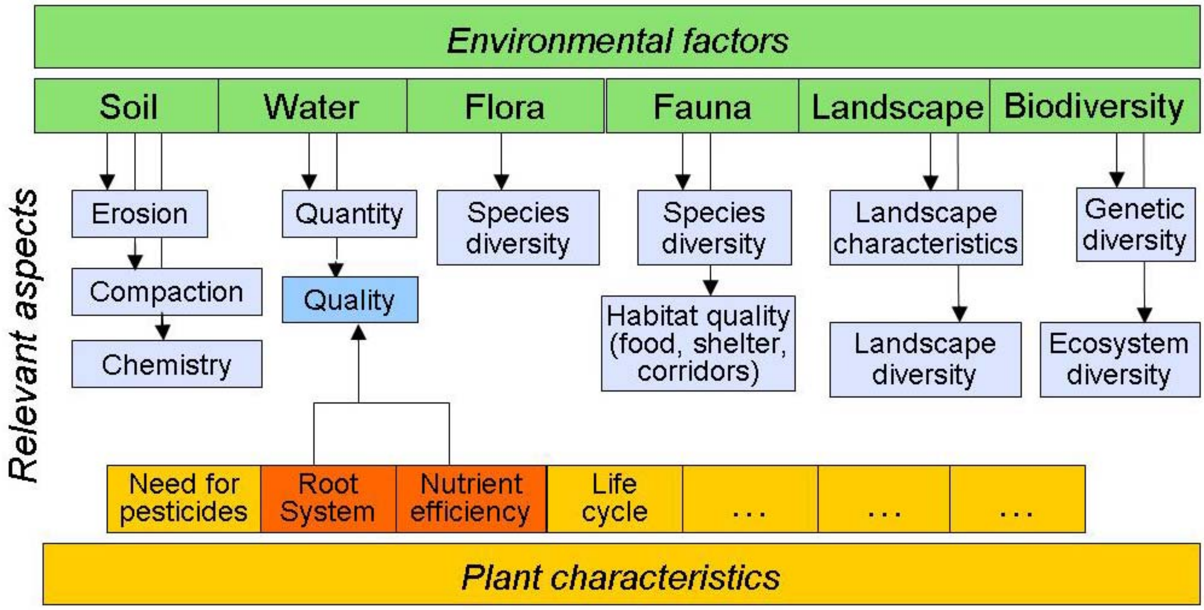


Fig. 5-2 Identification of environmental factors for the EIA of biomass production

Based on these factors, a biomass-specific assessment of the environmental impacts is done in this study. After that, an evaluation of different biomass feedstock relative to the respective reference systems is done by qualitative-descriptive classification in different classes.

Impact assessment for biomass conversion and use

A separate benefit and risk assessment is performed for biomass conversion and use. This assessment covers the impacts caused by the biorefinery, by the use of bio-based energy carriers and products as well as by transportation of biomass feedstock and intermediates. The benefits and risks assessment for conversion, use and transportation investigates potential effects of conversion and use units on the local environment. The environmental factors human health, soil, flora, fauna, biodiversity and landscape are studied. Effects beyond the local environment (e.g. climate change) are derived from results of LCA.

The potential environmental benefits and risks of the different conversion technologies are derived from the following factors:

1. emissions of noise and odour
2. waste water and waste water treatment
3. amount of traffic caused by potentially different logistics
4. size and height of conversion plants related to the different technologies.

The environmental issues potentially affected by these factors are shown in Table 5-1.

Table 5-1 Technology-related factors, environmental issues and potential environmental impacts of biomass conversion and use

Technology-related factor	Environmental issue	Potential environmental impact
Emission of noise and odours	Human health Fauna	Annoyance by an increase of environmental noise or gaseous emissions Disturbance of animals
Waste water and waste water treatment	Water Flora Fauna	Depletion of water resources Nutrient input into water bodies causing eutrophication habitat depletion for aquatic organisms (plants and animals)
Amount of traffic (noise and gaseous emissions)	Human health Fauna	Annoyance by an increase of environmental noise or gaseous emissions Disturbance of animals
Size and height of conversion plants	Soil Flora Fauna Biodiversity Landscape	Soil compaction or soil sealing Loss of vegetation Loss of habitat Negative effects on populations Landscape disturbance

5.1.2.4 Development of conflict matrices

Aggregated conflict matrices will be created based on the biomass-specific benefits and risks, which summarize the impacts of biomass production, conversion and use on the selected environmental factors. An example of a conflict matrix used for annual and perennial crops is given in Table 5-2. Theoretically, these crops could be compared to each other as indicated in Table 5-3, however, the focus of SUPRABIO is more on biomass residues than on dedicated crops. Moreover, it would be questionable to compare poplar and Jatropha, because they cannot be cultivated in the same agro-ecological zone. For the biomass residues like wheat straw and wood residues, the focus of the conflict matrices will be on changes in soil organic matter content, changes in nutrient balances or changes in the composition of the litter layer in forest soils.

The following qualitative indicators are used in the conflict matrices to compare the environmental impacts of biomass production and biomass conversion to the respective reference systems (relative evaluation):

- “positive”: compared to the reference systems, biomass production / biomass conversion is more favourable
- “neutral”: biomass production / biomass conversion show approximately the same impacts as the reference system
- “negative”: compared to the reference systems, biomass production / biomass conversion is less favourable.

Finally, mitigation measures could be deducted from these conflict matrices. As SUPRABIO is not aiming to a specific location mitigation measures are omitted.

Table 5-2 Risks associated with the cultivation a specific annual / perennial crop

Type of risk	Affected environmental factors								
	Ground water	Surface water	Soil	Plants / Biotopes	Animals	Climate / Air	Landscape	Human health / recreation	Biodiversity
Soil erosion									
Soil compaction									
Eutrophication									
Accumulation of pesticides									
Pollution of groundwater									
Pollution of surface water									
Loss of landscape elements									
Loss of habitat / biodiversity									

Categories: positive - neutral – negative

Table 5-3 Comparison of crops regarding the risks associated with their cultivation.

Type of risk	Crop				
	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5
Soil erosion					
Soil compaction					
Eutrophication					
Accumulation of pesticides					
Depletion of groundwater					
Pollution of groundwater					
Pollution of surface water					
Loss of landscape elements					
Loss of habitat / biodiversity					

Categories (A = low risk, E = high risk): A B C D E

5.2 Results: SUPRABIO vs. fossil systems

5.2.1 Local environmental impacts of the SUPRABIO system

For a number of scenarios it is defined that in case of implementing a biorefinery, sufficient land is available for feedstock provision as well as sufficient biomass (after subtracting both feed and food production). Direct competition for land or for different types of biomass is excluded in those scenarios. The idea is to concentrate on the impacts on the environmental factors arising from feedstock production and the implementation of a biorefinery.

Another set of scenarios is based on the precondition that in case of implementing a biorefinery, there is competition on biomass and land use. A biorefinery based on lignocellulosic biomass with a continuous request of feedstock will influence the market thus inducing shifts in land use and in crop cultivation.

To describe the potential range of local environmental impacts within the SUPRABIO system an approach of two contrarious hypotheses is used:

- Scenarios *without* land use or biomass competition: Case A

Result of this procedure is an evaluation of on-site effects caused by biomass provision and by application of the particular technology. Based on this precondition potential impacts on the environment will be discussed in chapter 5.2.1.1.

- Scenarios *including* land use or biomass competition: Case B

In this case, land or biomass is not sufficient to cover the non-food demand resulting in a competition for land or biomass. Consequently, this approach is an evaluation of on-site effects (biomass provision, application of a specific technology) as well as off-site effects due to land use change of the SUPRABIO concept as a whole. Potential off-site effects caused by land use changes due to competition, e.g. SUPRABIO vs. food production will be discussed on the end of the chapter 5.2.1.2.

5.2.1.1 Feedstock provision, case A: land or biomass is available

A potential biorefinery based on lignocellulosic biomass could be both driven by residues and / or cultivated biomass. In the case of SUPRABIO, residue feedstock can originate either from agriculture or forestry. Agricultural residues are biomass residues originating from production, harvesting and processing in farm areas, e.g. straw, hay or other harvest co-products. Forestry residues include logging residues, brushwood, bark and small-diameter trees removed during clearing and thinning operations not suitable for industrial use. Usually both agricultural and forestry residues remain on site and contribute to soil fertility and humus production.

Cultivated biomass is either based on energy or industrial crops from agriculture or wood from forestry and differs in types of land use. The biomass can be used both for bio-based materials (in the case of wood for example construction wood, furniture, particle board or paper) and for bioenergy. Agricultural biomass is even more flexible in terms of potential uses, but most of all because annual crops (the vast majority of crops cultivated in Europe is annual crops) allow the farmer to choose each year which crop to cultivate on the land.

Residues and their reference systems

The following scenarios will focus on the provision of feedstock from agricultural residues (annual crops) and residues from forestry:

- For agricultural residues the investigated scenario for a potential biorefinery is based on a sustainable use of approx. 33 % of wheat straw (i.e. once every three years) compared to the reference system of leaving the straw on the field, i.e. ploughing in the residues for SOC maintenance.
- For forest residues the investigated scenario for a potential biorefinery is based on the use of thinning wood and other residues with the reference system of leaving 100 % of the residues on site for SOC maintenance.

Provision of wheat straw - reference system: straw left on field

Wheat is grown on deep, heavy and nutrient-rich high quality soils and needs good drainage. Intensive agricultural use primarily leads to impacts on soil. Weed and pest control is obligatory, increasing the risk of soil compaction which is usually linked to negative aspects on the diversity of arable flora and epigeous fauna. Especially the young plants require application(s) of nitrogen fertiliser (app. 150 kg / ha) which increases the risk of nutrient leaching and eutrophication. Intensive cereal cultures are grown as monocultures and this generally leads to impacts on soil, water, plants / biotopes, animals and biodiversity. Especially in areas with water scarcity during the dry season the need of irrigation could cause long term impacts on the environment /Doublet et al 2012/.

Following the scenario of a potential biorefinery it is assumed that 100 % of the crop is harvested each year whereas 100 % of the straw is harvested once every three years. Thus, via crop rotation approx. 60-70 % of SOC debit is supplemented. Moreover, nutrients removed via straw are compensated for by mineral fertiliser. This results in a sustainable use of straw as /Panoutsou et al. 2012/ estimate that an export of 40 % of straw in case of wheat will maintain the carbon cycle.

In the reference system of conventional use it is assumed that 100 % of the straw is left on the field and ploughed in the soil to maintain the soil organic carbon stock. Since both systems are sustainable, differences in impacts on the environmental factors between a conventional system (100 % residues left on field) and the sustainable use of straw (approx. 33 %) in context with a biorefinery are low. In case of intensified use of straw for a biorefinery based on sustainable production conditions, the use of long-stalked cereal varieties might be increased thus leading to slightly positive effects for arable plants, since long-stalked varieties reduce the amount of pesticides necessary for weed control due to higher competitiveness. This might result in an increased number of animals linked to arable land (arthropods) and an increased biodiversity.

Table 5-4 Risks associated with the sustainable provision of straw from cereal (e.g. wheat, barley) compared to the reference system "of straw left on field" (ploughing in)

Type of risk	Affected environmental factors								
	Soil	**Ground water**	**Surface water**	**Plants / Biotopes**	**Animals**	**Climate / Air**	**Land-scape**	**Human health and recreation**	**Bio-diversity**
Soil erosion	neutral		neutral						
Soil compaction	neutral	neutral		neutral	neutral				neutral
Loss of soil organic matter	neutral			neutral	neutral				neutral
Soil chemistry / fertiliser	neutral	neutral							
Eutrophi-cation	neutral	neutral	neutral	neutral	neutral				neutral
Nutrient leaching		neutral							
Water demand		neutral		neutral	neutral				neutral
Weed control / pesticides		neutral	neutral	neutral	neutral				neutral
Loss of landscape elements				neutral	neutral	neutral	neutral	neutral	neutral
Loss of habitat types				**neutral / positive[1]**	**neutral / positive[1]**				**neutral / positive[1]**
Loss of species				**neutral / positive[1]**	**neutral / positive[1]**				**neutral / positive[1]**

1: Positive in case of long-stalked varieties since less weed control is necessary

Provision of wood residues (thinning wood) - reference system: material is left of site

Forest productivity depends on soil quality and the availability of water resulting in regionally specific production rates. Since any use of wood is correlated with a loss of the ecosystem's nutrients, the intensity of forestry therefore has an effect on the sustainability issues. The main objective of forestry in central Europe is to keep the balance between growth and use of the system. Examples from literature indicate that an intensified use of the biomass can result in considerable losses in growth rates /Meiwes 2009/.

Wood residues originate from harvesting (sawdust, break-of branches), the provision of stem wood (removal of brushwood) and thinning. Depending on the harvesting practice (use of harvester < motormanual felling), physical relief of the woodland (the higher the slope the bigger the amount of residues) and the processing procedure (on site processing > processing on a centralised processing site) the residues can vary quite a lot.

The usable volume of wood provided by a tree is considered as "Derbholz" (wood with a strength diameter > 7 cm and without bark or stump). In spruce this fraction is about 77 % of the tree whereas in beeches the percentage goes up to 83 % of the total above-ground biomass /Gauer et al. 2013/. The opposite would be wood with a strength diameter < 7 cm (small branches and brushwood, considered as "Nichtderbholz") which, according to /Gauer et al. 2013/, is about 15-16 % in spruce and 11-12 % in beeches. Depending on the tree species the non-harvestable fraction of "Derbholz" reaches up to 6 % in spruce and 25 % in beeches, whereas the percentage of losses in the small-wood fraction ("Nichtderbholz") is comparable (72 % in spruce, 77 % in beech) /Wilpert et al. 2011/.

Thinning is a process to remove especially younger trees allowing the remaining trees to maintain higher growth rates. Thinning material as well as wood residues usually is removed and sold, as there is a growing market (e.g. paper industry, firewood in case of the reference system). According to literature, the demand for wood residues is increasing /Mantau 2012/ resulting in increased competition and prices. E.g. the potential of wood residues for Germany was calculated between 12 million m³/a (low potential scenario) up to 42 million m³/a (high potential scenario) whereas the use of wood residues in 2010 with 8 million m³ was even below the calculated threshold of the low potential scenario /Mantau 2012/.

Intensified use of thinning material might lead to reduced rotation cycles and to a decrease in woody debris. As wood residues left on site (woody debris) are crucial for nature conservation and biodiversity an intensified use of wood residues is expected to affect the environmental factors of soil (decrease in soil organic matter) and biodiversity on the long term.

Therefore, a no action scenario for a maximum of sustainability in forestry is leaving 100 % of wood residues on site is positive for the environment. Compared to the reference system the use of wood residues is expected to have impacts on soil organic matter. In addition a lack of habitats especially for saproxylic animals (e.g. beetles) and other animals living on woody debris (e.g. wood bird like the Black woodpecker or bats) is expected on the long term.

Table 5-5 summarises the assessment of hardwood provision as biorefinery feedstock based on thinning stems compared to the reference scenario of leaving 100 % thinning wood on-site.

Table 5-5 Risks associated with the provision of **wood residues** (thinning material) compared to the reference system of leaving 100 % thinning wood on-site

Type of risk	Affected environmental factors								
	Soil	**Ground water**	**Surface water**	**Plants / Biotopes**	**Animals**	**Climate / Air**	**Land-scape**	**Human health and recreation**	**Bio-diversity**
Soil erosion	neutral		neutral						
Soil compaction	neutral	neutral		neutral	neutral				neutral
Loss of soil organic matter	negative			neutral	negative				negative
Soil chemistry / fertiliser	negative	neutral	neutral		neutral				neutral
Nutrient leaching	neutral	neutral							
Eutrophi-cation	neutral	neutral	neutral	neutral[1]	neutral				neutral
Water demand		neutral	neutral	neutral					neutral
Weed control / pesticides		neutral	neutral	neutral	neutral				neutral
Loss of land-scape elements				neutral	neutral	neutral	neutral	neutral	neutral
Loss of habitat types				negative	negative				negative
Loss of species				neutral	neutral				neutral

Table 5-6 summarises crop specific impacts from the provision of cereal straw and wood residues. Differences are relatively low. Regarding cereal straw there might be an increase in habitat diversity in case of a development towards the use of long-stalked varieties. Due to higher competition the amount of pesticides is expected to be less resulting in lower pressure on biodiversity. An issue could be the availability of water. Especially in areas with water scarcity during the dry season the need of irrigation could cause long term impacts on the environment /Doublet et al 2012/.

The use of wood residues on the long term is negative compared to the reference system of leaving residues in the woods. Due to export of biomass the availability of SOM and habitat diversity for saprophytic organisms is reduced.

Table 5-6 Impacts from biomass residues versus different reference system

Feedstock	Reference system	Soil erosion	Soil compaction	Soil organic matter	Soil chemistry / fertiliser	Nutrient leaching	Water demand	Weed control / pesticides	Loss of habitat / species diversity	Loss of landscape elements
Cereal straw	Straw left on field (ploughing in)	C	C	C	C	C	C	C	B	C
Wood residues	Wood left on site	C	C	D	D	C	C	C	D	C

Cultivated biomass and their reference systems

The following scenarios will focus on the provision of cultivated crops from agriculture:

- Cultivation of short rotation coppice (SRC) poplar versus fallow land (Europe)
- Cultivation of rapeseed versus fallow land (Europe)
- Cultivation of oil palms versus fallow land (Indonesia)
- Cultivation of soy versus fallow land (Brazil)
- Cultivation of Jatropha versus fallow land (India/Mozambique)

<u>Short Rotation Coppice (SRC) poplar – reference system: non-rotational fallow land</u>

Basically poplar or willow is used for the cultivation of short rotation coppice, both referring to a soil layer of at least 60 cm regarding the growth of the roots. In the beginning of the cultivation the soil coverage is quite low indicating a high risk of erosion compared to the reference system. Whole year coverage and particularly dense root systems reduce the risk of erosion in older plantations significantly. Decomposition of leafs reduces the use of fertiliser thus resulting in low risk of eutrophication and stimulating the soil quality. Due to low maintenance (low fertiliser, weed control only in the first 2 years) the impact on soil is positive compared to the reference system. Diversity of plants and animals can be positively affected as SRC can offer additional habitats to flora and fauna especially in regions with large areas of intensive agriculture and low landscape diversity. In wind prone areas, SRC may take the function of hedges and so minimise wind erosion. The effect as a filter for dust as well as higher transpiration rates might result in positive impacts on the local micro-climate.

The reference system “non-rotational fallow land” is arable land taken out of agricultural use for more than a year as e.g. practiced in the three-field crop rotation with potential positive effects on soil (no use), groundwater (no leaching effects), arable plants and animals (no damage of habitats) and biodiversity.

Table 5-7 summarises the risks associated with cultivation of SRC poplar on the environmental factors.

Table 5-7 Risks associated with the cultivation of **SRC** poplar compared to the reference system of non-rotational fallow land

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	neutral[1]		neutral[1]						
Soil compaction	positive[1]	neutral[1]		neutral / positive[1]	neutral / positive[1]				neutral / positive[1]
Loss of soil organic matter	positive[1]			neutral / positive[1]	neutral / positive[1]				neutral / positive[1]
Soil chemistry / fertiliser	positive[1]	neutral[1]	neutral[1]						
Nutrient leaching	neutral[1]	neutral[1]							
Eutrophi-cation	neutral	neutral	neutral	neutral[1]	neutral				neutral
Water demand		neutral	negative	neutral					neutral
Weed control / pesticides		neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Loss of landscape elements				neutral / positive[1]	neutral / positive[1]	positive[1]	neutral / positive[1]	positive[1]	neutral / positive[1]
Loss of habitat types				positive[2]	positive[2]				
Loss of species				positive[2]	positive[2]				positive[2]

1: Regarding the total cultivation period of the crop; slightly negative in the first year
2: No threatened/protected habitats considered in the reference system.

Rapeseed (ploughing of straw) - reference system: non-rotational fallow land

Rapeseed is generally grown on deep loamy grounds and requires adequate lime content and constant water supply. On heavy soils the production requires good nutrient supply with homogeneous precipitation. Both shallow and sandy soils lead to minor yields as rapeseed needs a high rooting depth. High efforts in weed / pest control is necessary as rapeseed is sensitive against diseases (e.g. fungi) and certain vermin beetles (e.g. cabbage stem flea beetle *Psylliodes chrysocephala* and cabbage stem weevil *Ceutorhynchus napi*). Furthermore rapeseed needs high doses of nitrogen (110-220 kg / ha) with an increased danger of nutrient leaching and eutrophication especially on groundwater. With a fruit : straw ratio of about 1 : 2,9 /Kaltschmitt et al. 2009/ ploughing of straw after harvesting e.g. in case of biodiesel production can contribute to soil balance although the residues provide high nitrogen doses in the soil thus enhancing the risk of nutrient leaching.

Potential impacts on soil fertility can be minimised with rotational cropping e.g. using rapeseed as a winter crop. Due to its intensive rooting and a dense coverage it is often used as a starter crop for early wheat seeds. Although rapeseed is cultivated in monocultures thus affecting the biodiversity of epigeous fauna the blossoms attract flower-visiting insects with a promoting effect on animals and biodiversity (Table 5-8).

Table 5-8 Risks associated with the cultivation of **rapeseed** compared to the reference system of rotational fallow land

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	neutral / negative[1]		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of SOM	neutral / negative[1,2]			neutral / negative[1,2]	neutral / negative[1,2]				neutral / negative[1]
Soil chem. / fertiliser	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Nutrient leaching		negative	negative						
Water demand		negative		negative	negative				neutral
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landsc. el.				neutral	neutral	neutral	neutral	neutral	neutral
Loss of hab. types				neutral / negative	negative / positive[2]				negative / positive[2]
Loss of species				neutral / negative	negative / positive[2]				negative / positive[2]

1: Negative impact can be minimised in case of double cropping, if used as a starter crop
2: Negative because of low biodiversity due to monoculture but increased number of blossom visiting insects during flowering period

Oil palms – reference system: non-rotational fallow land (Indonesia)

Oil palms require high temperature (24°C – 28°C) and humidity (1.500-1.800 mm/a) and are basically grown in Southeast Asia (Indonesia), additionally the production in West-Africa (Nigeria, Ivory Coast) and South America (Brazil, Columbia, Ecuador) is increasing. The plants prefer deep soils rich in humus although recent plantations are grown on bog soils in combination with use of fertilisers. In any case a sufficient supply of oil palm plantations with potassium, magnesium and nitrogen is crucial.

Mostly grown in monocultures oil palms are sensitive to pests which afford the use pesticides (insecticides, fungicides).

Table 5-9 summarises the risks associated with cultivation of oil palms on environmental factors.

Table 5-9 Risks associated with the cultivation of **oil palms** compared to the reference system of non-rotational fallow land

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	neutral / positive[1, 2]		negative'[2]						
Soil compaction	neutral / positive[1,2]	neutral / positive[1]		negative	negative				negative
Loss of SOM	neutral / negative[2]			neutral / negative[2]	neutral / negativ'[2]				neutral / negative[2]
Soil chem. / fertiliser	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Nutrient leaching		negative	negative						
Water demand		negative		neutral	neutral				neutral
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landsc. el.				neutral	neutral	neutral	neutral	neutral	neutral
Loss of hab. types				negative	negative				negative
Loss of species				negative	negative				negative

1 reduced number of maintenance cycles (perennial crop), manual harvesting
2 huge space between seedlings; negative in the first two years;

Soy – reference system: non-rotational fallow land (Brazil)

Based on the high content of oil and protein soy is one of the dominant plants in global agriculture. In 2010 about 260 million tons of soy was produced according to the Food and Agriculture Organisation of the United Nations (FAO, FOASTAT).

Soy is an annual crop usually grown on loose soils which are easily warmed up and provide a high water capacity. Due to high demands on temperature and climate it is basically grown in warmer regions/countries out of Europe such as USA, Brazil and Argentina.

Especially during the last year genetic modified soy seeds resistant against Glyphosate ("round up") were used allowing airborne application of fertiliser and pesticides on a large scale. As a consequence health problems in the vicinity of treated fields as well as the explosion of Glyphosate-resistant "superweeds" were observed /Antoniou et al. 2010/.

Table 5-10 summarises the risks associated with cultivation of soy on environmental factors.

Table 5-10 Risks associated with the cultivation of **soy beans** compared to the reference system of non-rotational fallow land

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	negative		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of soil organic matter	negative			negative	negative				negative
Soil chemistry / fertiliser	negative	negative	negative	negative	negative				neutral
Nutrient leaching	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Water demand		negative	negative	neutral	neutral				neutral
Weed control / pesticides		negative	negative	negative	negative			negative	negative
Loss of land-scape elements				neutral	neutral	neutral	neutral	neutral	neutral
Loss of habitat types				neutral	neutral				neutral
Loss of species				neutral	neutral				neutral

Jatropha (intensive culture) – reference system: non-rotational fallow land (India / Mozambique)

Jatropha or the so-called physic nut is a perennial shrub from the spurge family (Euphorbiaceae) found in subtropical and tropical habitats around the world. The crop shows good results in dry climates with rainfall of app. 400 mm/a. As the plants are growing on poor and degraded soils not suitable for food production Jatropha has the advantage of not competing against crops used for food and feed production.

In theory several advantages make Jatropha a preferred crop in dry regions. Plants are poisonous and therefore hardly consumed by herbivorous animals. Due to succulence they are able to withstand dry seasons. The dense and wide root system provides soil protection against erosion and can help to redevelop barren and desert areas not suitable anymore for agriculture. According to /WWF-GEXSI 2008/ most of the land worldwide used for Jatropha cultivation was not used for agriculture before, was even wasteland (49 %) or were former non-food production areas (45 %).

In practice Jatropha is cultivated intensively in huge plantations properly provided with water and fertilizer in order to improve yields. Due to monocultures pests and plant diseases are increasing thus affording the intensive use of pesticides and fertilizer /Ribeiro & Mantavel 2009/ with heavy impacts on soil, water, flora, fauna and biodiversity. The impact on landscape is dependent on the local conditions.

As Jatropha can grow under dry conditions and on poor soils marginal land seems to provide ideal growing conditions. In order to provide adequate yields the input of water and nutrients is expected to be quite high which might have impacts on water (both superficial and ground water), soil (compaction), flora and fauna. In comparison to other energy crops Jatropha plantations afford huge areas in order to provide equivalent yields /Shumba et al 2013/. As the plantations on poor soils are expected to exceed rich soil fields in order to provide appropriate yields, huge monocultures might impacts biodiversity by minimising habitat variety. In addition fertiliser and pesticides could cause heavy constraints in wildlife habitats. However, investigations on long-term effects of large scale plantations on soil fertility and biodiversity are outstanding.

Table 5-11 summarises the risks associated with intensive cultivation of Jatropha on the environmental factors.

Table 5-11 Risks associated with the cultivation of **Jatropha (intensive culture)** compared to the reference system of non-rotational fallow land

Type of risk	**Affected environmental factors**								
	Soil	**Ground water**	**Surface water**	**Plants / Biotopes**	**Animals**	**Climate / Air**	**Land-scape**	**Human health and recreation**	**Bio-diversity**
Soil erosion	negative		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of soil organic matter	neutral[1]			negative	negative				negative
Soil chemistry / fertiliser	negative	negative	negative						
Nutrient leaching	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	**neutral / negative[1]**				negative
Water demand		negative	negative	negative					negative
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landscape elements				**neutral / negative[1]**	**neutral / negative[1]**		**neutral / negative[1]**	neutral	**neutral / negative[1]**
Loss of habitat types				negative	negative				
Loss of species				negative	negative				negative

1: Regarding the total cultivation period of the crop; slightly negative in the first year

Sensitivity analysis

<u>Jatropha (extensive culture) – reference system: marginal land (India / Mozambique)</u>

Depending on the local climate extensive cultivations need less input of water, fertiliser and pesticides thus reducing maintenance cycles in a plantation. Impacts on soil, water, plants and animals are less heavy than in intensive cultures. Little differences expected compared to the reference system. Soil quality might even increase on the long term due to biomass input (leaves, roots).

Compared to the reference system the impacts on animals, plants, landscape and biodiversity might be neutral or even positive. As marginal land in arid areas is sparely covered with vegetation environment can benefit from an extensive cultivated Jatropha plantation.

Table 5-12 summarises the risks associated with cultivation of Jatropha on environmental factors compared to the reference system of marginal land.

Table 5-12 Risks associated with **extensive cultivation of Jatropha** compared to the reference system of marginal land

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	neutral - positive		neutral - positive						
Soil compaction	neutral - negative	neutral - negative		neutral - negative	neutral - negative				neutral - negative
Loss of soil organic matter	neutral – positive[1]			neutral - positive	neutral - positive				neutral - positive
Soil chemistry / fertiliser	neutral - negative [3]	neutral - negative [3]	neutral - negative [3]						
Nutrient leaching	neutral	neutral							
Eutrophi-cation	neutral - negative	neutral - negative	neutral - negative	neutral - negative	neutral - negative				neutral - negative
Water demand		negative	negative	negative					negative
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landscape elements				positive - negative[2]	positive / negative[2]		positive / negative[2]	neutral	positive / negative[2]
Loss of habitat types				positive - negative[2]	positive - negative[2]				
Loss of species				no risk assessment possible [3]	no risk assessment possible [3]				no risk assessment possible [3]

1: Regarding the total cultivation period of the crop; slightly negative in the first year
2: Depending on the landscape structure of the plantation site. Jatropha is in parts used as hedgerow around arable land.
3. So far, long term effects of large scale plantations on soil fertility and biodiversity are unknown

Table 5-13 compares impacts from the provision of different feedstock crops. SRC poplar is performing quite well in comparison to the reference system of non-rotational fallow land, basically due to reduced maintenance cycles as it is a perennial crop. Soil compaction is relatively low and due to leave fall SOC/SOM is expected to be quite high.

Other crops vary in the intensity of impacts on environmental factors. Perennials (oil palm) are slightly better than annual crops (rapeseed, soy) as maintenance cycles are lower. An option to be considered more closely is an extensive cultivation of Jatropha on marginal land (low application of fertiliser / pesticides) as it could help to improve depleted soils. For a clear recommendation site specific conditions need to be taken into account.

Table 5-13 Comparison of crop specific impacts versus different reference system

Feedstock	Reference system	Soil erosion	Soil com-paction	Soil organic matter	Soil chemistry / fertiliser	Nutrient leaching	Water demand	Weed control / pesticides	Loss of habitat / species diversity	Loss of landscape elements
SRC poplar	non-rotational fallow land	B	B	A	B	C	C	C	B	B
Rapeseed	rotational fallow land	D	D	C	D	D	D	E	D	C
Oil palm	non-rotational fallow land	C	B	B	D	D	C	D	E	C
Soy	rotational fallow land	D	D	C	D	E	D	D	E	E
Jatropha (intensive)	non-rotational fallow land	D	D	C	E	E	D	D	C	C
Jatropha (extensive)	marginal land	B	B	B	D	C	C	C	B	B

Impacts are ranked in five comparative categories; "A" is assigned to the best options concerning the factor, "E" is assigned to unfavourable options concerning the factor

5.2.1.2 Feedstock provision, case B: competition on land use and biomass

The results shown so far were achieved under the assumption that sufficient land for the production of biomass is available (scenario case A, see page 79). An increased request on lignocellulose biomass could be met by increasing the cultivated area at the expense of other crops e.g. wheat or maize in Europe or oil palms at the expense of rain forest in Indonesia (land use change). The feedstock types have similar requirements on growing conditions regarding soil quality, water supply and temperature. However, these crops are either used for feed & food production or are important for biodiversity and a loss due to reduced area has to be compensated. As all land available for agriculture is in process additional land is necessary to meet constant demand.

The contrarious assumption applies competition for area and biomass production which will be discussed in two examples:

- Cultivation of short rotation coppice (SRC) poplar at the expense of grass land (Europe)
- Cultivation of oil palms (extensive) on the expense of rain forest (Indonesia)

<u>Cultivation of SRC poplar at the expense of grassland (Europe)</u>

Extensive meadow grasslands in Europe in general are rich in species and represent important habitats for a wide variety of plants, insects and other wildlife. Whereas in a traditional fertile meadow about 20-30 plant species can be found, extensively used grasslands can have more than 40 species. Biodiversity and habitat diversity in these areas is high as wild flowers provide a food source for insects which in turn provide an important food source for birds.

A land use change from grassland to arable land in order to produce energy crops like SRC is unfavourable for the environment:

- Habitat types for rare and often endangered species as well as the species itself are destroyed thus impacting the environmental factors of plants / biotopes, animals and biodiversity
- Biodiversity is reduced by replacing an area with considerably high biodiversity by a few favourable common species; biodiversity is expected to increase over time as wood land species might immigrate over the years, but they'll lose habitats at the end of the cultivation period.
- The conversion of grassland to SRC cultures causes an increase of greenhouse gas emissions. Huge amounts of carbon are stored in the soil and will be set free by ploughing. The effect exceeds the plantation of SRC cultivation /Fritsche & Wiegmann 2008/.
- Changes in land use might be beneficial in areas with intensive used grassland where SRC could increase habitat variety and provide additional habitat types for wood related species

Planting SRC seedlings in grassland without ploughing is considered unfavourable from a biodiversity point of view as well /BfN 2010/, /FNR 2012/. It will cause a shift from a species-rich meadow community with habitats for rare species towards a degraded community of a common species dominated by generalists.

Table 5-14 summarises the risks associated with cultivation of SRC at the expense of grassland.

Table 5-14 Risks associated with the provision of SRC at the expense of grassland

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	neutral[1]		neutral[1]						
Soil compaction	neutral	neutral		neutral	neutral				neutral
Loss of soil organic matter	negative			negative	negative				negative
Soil chemistry / fertiliser	negative	negative							
Eutrophi-cation	neutral[1]	neutral[1]	neutral[1]	neutral[1]	neutral[1]				neutral[1]
Nutrient leaching		negative							
Water demand		neutral		neutral	neutral				neutral
Weed control / pesticides		neutral	neutral	neutral	neutral				neutral
Loss of landscape elements				negative / positive[2]	negative / positive[2]	negative / positive[2]	negative / positive[2]	negative / positive[2]	negative / postive[2]
Loss of habitat types				negative / positive[2]	negative / positive[2]				negative / postive[2]
Loss of species				negative	negative				negative

1: Slightly negative in the first year, neutral over the total cultivation period
2: Depending on the structure of the surrounding landscape positive or negative impacts are expected

<u>Cultivation of oil palms (extensive) on the expense of rain forest (Indonesia)</u>

Tropical rain forests are considered highly diverse ecosystems. They evolved over a long period of time largely uninfluenced by mankind. They provide an enormous richness in species as a result of constant diversification probably due to the continuing existence of this ecosystem since its formation.

Since agricultural land is becoming increasingly scarce, more and more forest land is transferred into arable land. Such changes in land cover not only have direct influence on the environmental factors plants, landscape and climate (greenhouse gas balance). Land use changes also affect regional soil functions, water quality and habitat quality and therefore have impacts on the environmental factors of water, fauna and biodiversity. In addition a change in land use has influence on the carbon stock of an area thus contributing to climate change (e.g. /Romjin 2011/). The application of fertiliser especially in areas with poor soils has implications on ground and superficial water (e.g. /Boveland 2010/).

An oil palm plantation on the expense of tropical rain forest definitely has impacts on the environment due to the complete and irreversible change of a highly diverse ecosystem into a quasi-monoculture of palms. From an ecological point of view this provides a reduction in biodiversity even if the oil palms are extensively cultivated.

- Highly diverse forests with a huge variety of habitats for highly specialised species are substituted by agricultural areas with low habitat variety suitable only for few generalists (plants and animals).
- Due to the provision of at least part time uncovered soil erosion and leaching of nutrients will increase. Efforts for a cost-efficient agriculture (e.g. fertiliser, pesticides) will rise leaving at the end depleted soils not suitable for agriculture.
- As the appearance of natural forests will slightly differ a lot from an established oil palm plantation impacts on landscape are very high immediately after the clearance of the forest but might decrease over time.
- The conversion of rainforest to oil palm plantations causes an increase of greenhouse gas emissions.

Table 5-15 summarises the risks associated with cultivation of oil palms at the expense of rain forest.

Table 5-15 Risks associated with the cultivation of **oil palms** compared to the reference system of rain forest

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	negative		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of soil organic matter	negative			negative	negative				negative
Soil chemistry / fertiliser	negative	negative	negative						
Nutrient leaching	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Water demand		negative	negative	negative					negative
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landscape elements				negative	negative	negative	negative	negative	negative
Loss of habitat types				negative	negative				
Loss of species				negative	negative				negative

In a nutshell from an EIA point of view, both the cultivation of SRC at the expense of grassland and the cultivation oil palms at the expense of a natural forest are unfavourable for the environment. Naturally diverse and species rich ecosystems are converted in monoculture crop land dominated by common species and generalists. Furthermore the EU Renewable Energy Directive /EP & CEU 2009b/ excludes highly bio-diverse grasslands from being used for the provision of a biorefinery feedstock in order to avoid impacts on biodiversity.

Sensitivity analysis

Soy - reference system: rain forest (Brazil)

As there is an increased demand for new agricultural areas soy production is a major driver for land-use changes especially in Brazil and Argentine, where often rain forest is changed to agricultural monocultures. One of the consequences is a heavy loss in biodiversity in combination with an increase in the use of pesticides and fertiliser in the areas of production, thus affecting the environmental factors of soil, water, plants, animals and biodiversity. Furthermore export of soy to Europe as a potential feedstock for biorefineries causes additional traffic with impacts on the environment.

As mentioned above an additional risk for environment of overseas soy production is the increasing use of genetically modified plants resistant to total herbicides. This can even have consequences for human health.

Table 5-16 summarises the risks associated with cultivation of soy on the environmental factors compared to the reference system of rain forest.

Table 5-16 Risks associated with the cultivation of **soy beans** compared to the reference system of rain forest

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	negative		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of soil organic matter	negative			negative	negative				negative
Soil chemistry / fertiliser	negative	negative	negative						
Nutrient leaching	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Water demand		negative	negative	negative					negative
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landscape elements				negative	negative		negative	negative	negative
Loss of habitat types				negative	negative				
Loss of species				negative	negative				negative

Jatropha (intensive culture) – reference system: rain forest (India / Mozambique)

Compared to the reference system of rain forest an intensive Jatropha plantation causes negative impacts on soil, water, animals, plants and biodiversity due to intensive maintenance cycles, the use of pesticides and fertiliser. Land use changes might even stimulate the climate change as the conversion of rain forest into agricultural land goes along with the disposal of carbon dioxide, thus on the long term affecting climate and human health. /Romijn 2011/ calculated emissions of more than 60 t/ha of carbon from converting virgin tropical dryland ecosystem in Africa (Miombo woodland) into a Jatropha plantation.

Table 5-17 summarises the risks associated with cultivation of Jatropha on the environmental factors compared to the reference system of rain forest.

Table 5-17 Risks associated with an in cultivation of **Jatropha** compared to the reference system of rain forest

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	negative		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of soil organic matter	negative			negative	negative				negative
Soil chemistry / fertiliser	negative	negative	negative						
Nutrient leaching	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Water demand		negative	negative	negative					negative
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landscape elements				negative	negative	negative	negative	negative	negative
Loss of habitat types				negative	negative				
Loss of species				negative	negative				negative

5.2.1.3 Transport and logistics

The provision of a biorefinery with feedstock goes along with impacts from transportation (e.g. exhaust fumes, noise, movements of vehicles) which will vary according to the agricultural productivity of a target region. In addition impacts depend on the efficiency of the fuel which in case of ethanol is lower than in case of petrol. Storage facilities are crucial to guarantee continuous operating of the refinery. Overall the impact dimension will vary with the size of the plant. Potential impacts of logistics are expected from:

- Plant size
- Transportation infrastructure
- Fuel efficiency
- Storage facilities

Potential impacts due to plant size

Within SUPRABIO both biochemical and thermochemical routes for a potential plant are assessed in two different time frames (2015, 2025) with diverging maturity levels and capacities, as mentioned in the report of definitions and settings /Rettenmaier et al. 2011/. The following estimations mainly are based on straw productivity in Germany.

<u>Cereal straw (2015)</u>

As a standard configuration for a plant in both routes an input of 40 kt of dry matter per year is assumed. In Germany for instance the estimated amount of straw available for sustainable use is about 8-13 million t of fresh matter (FM) per year /Zeller et al. 2012/, with huge variations in regional availability. Maximum ranges in straw potential were calculated for Schleswig-Holstein (2-3 t FM/(ha·a)) and Mecklenburg-Vorpommern (0,9-2,5 t FM/(ha·a)), depending on the method of calculation (minimum-maximum scenario). Fresh matter usually contains a surplus of 15 % of water in comparison to dry matter. /Doublet et al 2012/ calculated for the Beauce region, the most important area for wheat production in France with an agricultural area for wheat cultivation of app. 427.000 ha, a straw potential of about 435.000 t DM/a. This was done in a case study approach within the BIOCORE-project. The results show a yield of about 1.02 t DM/(ha·a) of potentially available straw for a biorefinery which corresponds to the range mentioned above.

Taking into account different types of storage a loss between 2 % (depot) and 11 % (stack piles) are expected /Zeller et al. 2012/. In the following estimation an average loss of about 6 % is assumed.

For the provision of a 40 kt DM/a SUPRABIO plant therefore an amount of roughly 42,4 kt DM/a is necessary (6 % loss included), which corresponds to approximately 48,8 kt FM of straw biomass per year. Producing this amount e.g. in optimal straw regions in Germany (e.g. Schleswig-Holstein) it affords an agricultural area of 160-240 km². As a consequence the fresh matter straw biomass for a 200 kt DM/a SUPRABIO plant for the gasification scenario would need an input of 244 kt FM of straw per year. The agricultural area necessary for the production of this amount of straw is somewhat between 800 km² and 1.200 km².

As only part of the area is used for agriculture respectively for cereal production the range of a potential plant based on straw as feedstock is even wider. As an example from reality the BEKW Emsland, a CHP based on straw with a capacity of 75 kt/a in the north of Germany, made contracts with over hundred farmers within a range of 60 km to provide sufficient feedstock /Knieper 2012/. This covers an area of about 11.300 km² in a region with a high straw potential of about 1,1-2,2 t FM/ha /Zeller et al. 2012/. The big amount of area indicates that the potential straw yields in the vicinity are not used in total for the BEKW plant.

Cereal straw (2025)

The mature configuration of a SUPRABIO biorefinery is aiming at 400 kt DM/a gasification plant. Storage losses for a plant in that dimension are calculated with about 12 % /Zeller et al. 2012/. According to the figures mentioned above the agricultural area necessary to provide a straw capacity of app. 450 kt DM/a is somewhat between 1.600-2.400 km².

An estimation closer to reality is based on scenarios given in /Zeller et al. 2012/. According to this figures a mature SUPRABIO refinery based on straw with an input of about 400 kt DM/a of feedstock (provision of 450 kt DM/a due to storage losses) would afford feedstock from an area of about 16.640 km².

Forest residues (2015)

According to /FNR 2013/ typical yields of wood residues in Germany would be around one ton per hectare per year. Applying this figure on a SUPRABIO plant based on wood residues and taking into account storage losses of 10 % the provision of feedstock for a biorefiney with a capacity of 40 kt/a would afford about 44.000 ha respectively 440 km². The feedstock could be provided theoretically within a range of 12 km around a potential plant.

Forest residues (2025) scenario

In a mature configuration a potential plant with a capacity of 400 kt DM/a (450 kt DM/a due to storage losses) would need an area ten times as big for the provision of feedstock. Based on the figures mentioned in /FNR 2013/ this would result in an area of approximately 450.000 ha respectively 4.500 km², which means, the necessary amount of wood residues to run a mature SUPRABIO gasification plant could theoretically be provided within a range of 38 km around a potential biorefinery.

Potential impacts due to transportation

Transportation and distribution of feedstock will mainly be based on trucks and railway / ships with need of roads and tracks / channels. Depending on the location of a potential biorefinery there might be impacts resulting from the implementation of additional transportation infrastructure. In order to minimise transportation it would make sense from an economic point of view to build a plant close to feedstock production. As far as it is necessary to build additional roads environmental impacts are expected on soil (due to sealing effects), water (reduced infiltration), plants, animals and biodiversity (loss of habitats, individuals and species, disturbance by moving vehicles). The following estimation is focussing on the transportation of straw.

Standard configuration (2015)

/Zeller et al. 2012/ calculated the annual demand of straw for a bio-SNG plant with a capacity of 48,4 kt DM/a for about 54,3 kt DM/a due to losses in storage. To provide this amount of feedstock an area of about 2.000 km² is necessary with an average transport distance of 44 km from field to plant (50 % empty drives included). Assuming a straw transporter with a capacity of 12 t/vehicle it needs about 4.500 trips/a covering a total annual transport distance of about 200.000 km. With an average consumption of 20 L/100 km this affords about 40.000 L/a of conventional diesel due to feedstock transportation to the plant.

Mature configuration (2025)

In a mature scenario a feedstock capacity of 400 kt DM/a for a gasification plant is assumed. Based on the figures in /Zeller et al. 2012/ a mature SUPRABIO refinery based on straw would need about 450 kt DM/a of feedstock (due to storage losses) from an area of about 16.640 km². This would result in an average distance from field to plant of about 130 km. Assuming a transportation capacity of 12 t/vehicle this would result in 37.500 trips covering a total distance of 4,9 million kilometres per year. Assuming a fuel consumption of 20 l/100 km this affords about 980.000 l of conventional fuel per year for feedstock transportation.

In order to minimise transport efforts it would make sense for a mature gasification plant with a capacity of 400 kt DM/a to decentralise the system by implementing 5 times an 80 kt-plant. Based on the scenario of the standard configuration this would result in lower range of area (10.000 km²), a 20 % higher number of trips (45.000), lower kilometres (2.000.000 km) and lower fuel consumption (400.000 l) per year.

Potential impacts due to fuel efficiency

Impacts on the environment are expected to result from the lower energy content of ethanol compared to conventional fossil fuels resulting in an increased need of refilling the tank. This might increase emissions of noise and exhaust fumes affecting soil, animals, plants, air and human health. In addition the traffic due to delivery of feedstock, transportation of products and maintenance might slightly be increased. Depending on the surroundings and the already existing impacts the significance of additional emissions and traffic can be diverging. The risk of emissions in comparison with large-scale emissions and high traffic loads of industrial areas (Brownfield scenario) will be below detection limits. In more sensitive areas (Greenfield scenario) mitigation measures might be necessary (e.g. reduced speed for transportation traffic).

Potential impacts due to storage facilities

A prospected biorefinery with a capacity of 40 kt DM/a (standard configuration of the biochemical and thermochemical route) or 400 kt DM/a (mature configuration) needs a guaranteed feedstock supply, provided either by on-site storages (e.g. stack piles for straw) or storage facilities in the refinery, to facilitate short-term feedstock supply and protection against weather impacts. Especially in case of straw a huge storage capacity is necessary due to the low specific weight density. As straw can only be harvested once a year it has to be either stored on-site in foil-covered piles or in roofed buildings to minimise damage due to humidity (mould) or vermin. Losses due to storage reach from up 11 % in uncovered piles to 2 % in light depot buildings. According to /Zeller et al. 2012/ plants with a capacity of more than 2000 t/a of straw use a two-step storage system i.e. decentralised storages on the fields (stack piles) and a centralised depot in the plant. In any way additional buildings cause sealing and compaction of soil, loss of habitats (plants, animals) and biodiversity as well as reduced groundwater infiltration.

Wood residues can be stored on central storage places on site for a while for a just in time delivery as the feedstock is available throughout the year. Nevertheless short time storage in the plant would be necessary causing additional impacts to the local environment.

5.2.1.4 Raw material conversion

Feedstock processing and provision of the product portfolio is done in a biorefinery. The local environmental impacts associated with the implementation of a biomass conversion unit will be considered in the following chapter. It will be done as a benefit and risk assessment, based on the investigation of potential effects on the environmental factors compared to reference scenarios.

Following impact identification and prediction, impact evaluation is the formal stage at which the significance is determined. Impact significance depends on the joint consideration of its characteristics (quality, magnitude, extent, duration) and the importance (or value) that is attached to the resource losses, environmental deterioration or alternative uses (see chapter 5.1.2.3).

Impacts are related to the

1. Construction phase
2. Project itself: buildings, infrastructure and installations
3. Operation phase

Following the LCA approach the expected impacts will be compared to reference systems. In order to pre-estimate the range of potential impacts two contrarious scenarios for the location of a potential biorefinery were chosen:

- Greenfield scenario (Table 5-18): since new space for new industrial sites is generally restricted it is assumed as a worst case-scenario that the biorefinery will be constructed in the open landscape e.g. on fallow land
- Brownfield scenario (Table 5-19): less and / or lower impacts are expected on former industrial zones where most of the area is already sealed and at least parts of traffic infrastructure might be available
- Furthermore potential impacts from an additional implementation of a biorefinery running with algae are taken into account.

Table 5-18 Technology related impacts expected from a SUPRABIO biorefinery in a Greenfield scenario

Technology related factor	Environmental factors							
	Water W	Soil S	Flora (plants) P	Fauna (animals) A	Climate / air quality C	Land-scape L	Human health H	Bio-diversity B
1 Construction phase								
1.1 additional temporary land use for construction sites	W1.1	S1.1	P1.1	A1.1	C1.1	L1.1		B1.1 (→ A1.1)
1.2 risk of collisions and road kills during construction				A1.2			H1.2	B1.2 (→ A1.2)
1.3 emission of noise				A1.3			H1.3	B1.3 (→ A1.3)
1.4 visual disturbance during construction				A1.4		L1.4	H1.4	B1.4 (→ A1.4)
1.5 emission of substances and odour	W1.5	S1.5			C1.5		H1.5	B1.5
2 Project related: buildings, infrastructure and installations								
2.1 drain of land resources for project related buildings and installations	W2.1	S2.1	P2.1	A2.1	C2.1 (→ P2.1)	L2.1 (→P2.1)		B2.1 (→ P2.1, A2.1)
3 Operation phase								
3.1 emission of noise (biorefinery)				A3.1		L3.1	H3.1	B3.1 (→ A3.1)
3.2 emission of gases and fine dust (biorefinery)		S3.2	P3.2	A3.2	C3.2		H3.2	B3.2 (→ A3.2)
3.3 emission of light (biorefinery)				A3.3		L3.3	H3.3	B3.3 (→ A3.3)
3.4 drain of water resources for production (biorefinery)	W3.4		P3.4	A3.4			H3.4	
3.5 waste water production and treatment (biorefinery)	W3.5		P3.5	A3.5				
3.6 traffic (collision risk, emissions)	W3.6	S3.6		A3.6		L3.6	H3.6	B3.6 (→ A3.6)
3.7 electromagnetic emissions from high-voltage transmission lines				A3.7			H3.7	
3.8 risk of accidents, explosion, fire in the plant or storage areas, GMO release	W3.8	S3.8	P3.8	A3.8	C3.8		H3.8	B3.8

Potential impacts

Likely significant impacts

Potentially significant impacts dependent on the local surroundings of the plant

→ **Impacts due to the interaction of environmental factors**

Table 5-19 Technology related impacts expected from a SUPRABIO biorefinery in a Brownfield scenario

Technology related factor	Environmental factors							
	Water W	Soil S	Flora (plants) P	Fauna (animals) A	Climate / air quality C	Land-scape L	Human health H	Bio-diversity B
Construction phase								
additional temporary land use for construction sites	W1.1	S1.1	P1.1	A1.1	C1.1	L1.1		B1.1 (→ A1.1)
risk of collisions and road kills during construction				A1.2			H1.2	B1.2 (→ A1.2)
emission of noise				A1.3			H1.3	B1.3 (→ A1.3)
visual disturbance during construction				A1.4		L1.4	H1.4	B1.4 (→ A1.4)
emission of substances and odour	W1.5	S1.5			C1.5		H1.5	B1.5
Project related: buildings, infrastructure and installations								
drain of land resources for project related buildings and installations			P2.1	A2.1				B2.1 (→ P2.1, A2.1)
Operation phase								
emission of noise (biorefinery)				A3.1		L3.1	H3.1	B3.1 (→ A3.1)
emission of gases and fine dust (biorefinery)		S3.2	P3.2	A3.2	C3.2		H3.2	B3.2 (→ A3.2)
emission of light (biorefinery)				A3.3		L3.3	H3.3	B3.3 (→ A3.3)
drain of water resources for production (biorefinery)	W3.4		P3.4	A3.4			H3.4	
waste water production and treatment (biorefinery)	W3.5		P3.5	A3.5				
traffic (collision risk, emissions)	W3.6	S3.6		A3.6		L3.6	H3.6	B3.6 (→ A3.6)
electromagnetic emissions from high-voltage transmission lines				A3.7			H3.7	
risk of accidents, explosion, fire in the plant or storage areas, GMO release	W3.8	S3.8	P3.8	A3.8	C3.8		H3.8	B3.8

Potential impacts
Likely significant impacts
Potentially significant impacts dependent on the local surroundings of the plant
→ **Impacts due to the interaction of environmental factors**

Referring to the different impact categories associated with the implementation of a project it becomes obvious, that differences between the two scenarios are not to be expected during construction phase and the operation phase. Impacts expected during the project-related phase due to implemented buildings infrastructure and installations differ from the location of a potential plant. In case of a Brownfield scenario less impacts are expected than in a Greenfield scenario, where additional land has to be sealed.

Biorefinery based on algae feedstock

Algae respectively micro-algae form another feedstock to be taken into account within SUPRABIO. Any scenarios dealing with a biorefinery based on algae first of all need input of CO_2 and light. In SUPRABIO algae production is addressed as an integrated part of an advanced lignocellulose biorefinery which would guarantee a provision with CO_2 (e.g. from fermentation processes or exhaust fumes from a CHP-plant). For biomass production there are two general options:

- Algae cultivation on the flat land using open ponds
- Algae cultivation in a closed system (photo bioreactor, PBR)

Pond systems are constructed in open areas in form of raceways or use natural water bodies (lake, sea) in order to receive a maximum input of solar light, preferable associated with a CO_2-producing plant in order to guaranty the major feedstock. A disadvantage is the huge amount of area necessary which normally is calculated in tens of hectares. Assuming that a raceway is constructed on arable land similar impacts are expected as in the Greenfield scenario shown in Table 5-18. Significant impacts would basically result from sealing of soil and the loss of habitats (impacts on environmental factors of soil, water, flora, fauna, landscape and biodiversity) as well as from drain of water, in particular in areas suffering from water shortage or the production of waste water.

A cultivation system with less demand for land is a photo bioreactor (PBR) where the algae are cultivated in tubes with the opportunity of implementing an artificial lighting. A PBR could be added on the site of a plant as a supplement e.g. to a pyrolysis plant. Assuming the PBR is built on-site, similar impacts are expected as in the brownfield scenario demonstrated in Table 5-19. Significant impacts are expected to be lower as additional sealing of soil would not be necessary. Significant impacts might occur from drain of water in areas suffering from water shortage or the production of waste water.

5.2.2 Local environmental impacts of SUPRABIO's reference systems

Following a life cycle-oriented approach, the objective of the environmental assessment in task 7.3 is to compare potential impacts of a SUPRABIO biorefinery with other conventional (fossil-driven) reference systems. Reference technologies for provision of base products which are compared to SUPRABIO include:

- Crude oil refinery (production of fuels and chemicals)

For the later comparison of competing biomass-based systems with their conventional (fossil-driven) reference systems, the following energy-providing systems (including value chains) are evaluated:

- Gas-fired power plant (heat and power generation)
- Coal-fired power plant (heat and power generation)
- Nuclear power plant (heat and power generation)

Crude oil refinery (production of fuels and chemicals)

Oil refineries process crude oils into useful products e.g. naphtha, diesel or kerosene. The crude oil comes from oil production platforms (via pipelines or tankers) and is separated into fractions by fractional distillation. The fractions at the top of the fractionating column have lower boiling points than the fractions at the bottom. The heavy bottom fractions are often cracked into lighter, more useful products. All of the fractions are processed further in other refining units. The majority of the products are used for energy purposes.

Gas-fired power plant (provision of heat & power)

Gas processing is usually done on-site and goes along with the exploitation, either on land (on shore) or off-shore. Depending on the quality of the natural gas it is necessary to separate ingredients like water, nitrogen, carbon dioxide and higher-valence hydrocarbons. The processing of acidic gas integrates a removal of hydrogen sulphide (H_2S) in a gas scrubbing process. The international transportation is done via pipelines or special cargo vessels.

Natural gas is to a large extent used for energy production. It can either be burnt in a boiler to produce steam and to drive a steam turbine or in a combustion turbine to create electricity. A modern approach is to use both combustion turbine and use the heat to drive a steam turbine (CHP-plant).

Coal fired power plant (provision of heat and power)

Coal is burnt to produce heat in order to generate electric power. In general this is done via an electric generator driven by steam. Modern coal plants can act as CHP-plants if in addition to power generation a community heating system is attached.

Nuclear power plant (provision of heat and power)

Nuclear fission produces energy which is used to generate electric power via a generator. Heat is usually left over as dead energy as distances towards settlements are too long to establish a cost-effective transportation.

5.2.2.1 Feedstock provision

According to the LCA approach an assessment of feedstock provision i.e. value chains in conventional reference systems will be applied, which in case of SUPRABIO are crude oil and gas provision as well as the provision of coal and uranium ore. Each is related with different types of risks causing potential impacts on the environment. Impacts of transportation are taken into consideration as well.

Crude oil provision

Impacts of crude oil provision are expected to affect all environmental factors. The impacts are classified as unfavourable for the environment. Drilling processes especially in combination with the production of oil and water based mud and the huge demand of water /Ziegler 2011/ bear significant risks for the environment. Further significant impacts are expected from transportation especially the implementation of pipelines.

The value chain includes high risks of environmental impacts due to accidental and operational discharges from provision, transport and use /GPA/. Basically the environmental factors soil, water, plants / biotopes, animals and biodiversity are affected. Table 5-20 summarises potential impacts on environmental factors on the value chains for both crude oil provision and gas provision as exploitation and refining are very often done simultaneously.

Table 5-20 Impacts on environmental factors related with the value chain of crude provision; potentially significant impacts are marked with thick frames; reference scenario: no use

Technological factor	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Prospection	negative			negative	negative				negative
Drilling / mining	negative	negative	negative	negative	negative		negative		negative
Waste (oil based and water based mud)	negative	negative	negative	negative	negative				negative
Demand of water (process water)		negative	negative	negative	negative		negative		negative
Emissions (exhaust fumes, water, metal)		negative	negative	negative	negative	negative		negative	
Land requirements	negative	negative	negative	negative	negative	negative	negative		negative
Demands of steel (tubes, equipment)	negative			negative	negative		negative		
Transportation (carriers, pipelines)	negative	negative	negative	negative	negative	negative	negative	negative	negative
Refining / processing	negative	negative	negative	negative	negative		negative	negative	negative
Accidents (traffic, pipeline leakage)	negative	negative	negative	negative	negative		negative	negative	negative

Likely significant impacts

Coal provision

Coal is a soil resource and available in two main types:

- Hard coal is provided with deep mining; major sources are found in the United States, China and Russia.
- Lignite is usually exploited in surface mining; the largest deposits are found in the United States and in Russia.

The intensity of impacts summarised in Table 5-21 is varying with the type of mining, both causing severe impacts on the environment:

- Impact on ground water: deposits beneath the groundwater level require huge draining efforts with further consequences for the groundwater table on a regional scale; in addition huge amounts of water are needed for dust prevention in open pits
- Burden piles: inert material might cause environmental problems due to pollution of surface water and ground water
- Air pollution: surface mining causes fine dust and can release radioactive substances (e.g. radon) associated with coal deposits
- Since lignite is dug in open pits (surface mining) the major impact is the loss of land. Huge areas with habitats and wildlife including human settlements are dug away affecting soil, water, plants / biotopes, animals, landscape, human beings and biodiversity.

Table 5-21 Impacts on environmental factors related with the value chains of coal provision; potentially significant impacts are marked with thick frames; reference scenario: no use

Technological factor	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Prospection				negative	negative				negative
Mining	negative	negative	negative	negative	negative		negative		negative
Waste (excavated material)	negative			negative	negative				negative
Demand of water (process water)		negative	negative	negative	negative				negative
Emissions (exhaust fumes, water, metal)		negative	negative	negative	negative	negative		negative	
Land requirements	negative	negative	negative	negative	negative		negative	negative	negative
Demands of steel (tubes, equipment)				negative	negative		negative		
Transportation (carriers)	negative		negative	negative	negative	negative	negative	negative	negative
Refining / processing							negative	negative	
Accidents (traffic)	negative	negative	negative	negative	negative		negative	negative	

Likely significant impacts

Provision of uranium ore

Uranium as the main driver of nuclear power plants is a widely spread soil resource but generally low concentrated. As a heavy metal it is toxic and it is radioactive. Most of the uranium ore is found in Australia, Canada, Kazakhstan and Africa.

Uranium mining goes along with heavy impacts on the environment (e.g. /Kaspar 2012/), basically related with mining, production of waste, water depletion, emissions and land requirements.

- Mining: as the concentration of uranium in the ore is relatively low (0,02-12,9 %) huge amounts of rocks have to be moved causing major land consumption with severe impacts on soil, water, wildlife and landscape
- Uranium is chemically extracted leaving huge amounts of waste (tailings) contaminated with heavy metals (associated with uranium ore) and other radio nuclides, basically impacting water and wildlife
- Dried tailings cause toxic and radioactive dusts impacting huge areas used for stock breeding or agriculture thus causing negative impacts on soil, wildlife, and human beings /Schramm 2012/.
- An important impact on local societies arises from massive expropriations and displacements.

Table 5-22 summarises major impacts of uranium mining on the environment.

Table 5-22 Impacts on environmental factors related with the value chains of provision of uranium ore; potentially significant impacts are marked with thick frames; reference scenario: no use

Technological factor	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Prospection				negative	negative				negative
Mining	negative	negative	negative	negative	negative		negative		negative
Waste (excavated material)	negative	negative	negative	negative	negative		negative		negative
Demand of water (process water)		negative	negative	negative	negative				negative
Emissions (exhaust fumes, dust, metal)	negative	negative	negative	negative	negative	negative		negative	
Land requirements	negative			negative	negative		negative		negative
Demands of steel (tubes, equipment)				negative	negative		negative		
Transportation (carriers)	negative			negative	negative				
Enrichment	negative						negative	negative	
Accidents (traffic)	negative			negative	negative				

Likely significant impacts

Comparison of conventional value chains

Although impacts might vary in details the provision of different fossil energy carriers shows similar impacts on the environment on a generic level. Major impacts are caused by land requirements which might in case of mining (provision of coal especially lignite and uranium ore) exceed land consumption in context with crude oil provision or the provision of natural gas, even if the land necessary for the construction of pipelines is taken into account. The considered value chains have heavy impacts on water, either by draining (coal), washing (uranium) or the use of process water (crude oil). Heavy impacts are expected from dusts in case of coal and uranium provision showing high intensities in open pit mining and because of toxic and radioactive dusts in uranium mining as well. The risk combined with accidents might be highest in crude oil and gas provision as these value chains are dealing with hazardous substances. Table 5-23 summarises major implications of the considered value chains in comparison with the no-action alternative.

Table 5-23 Potential impacts on the environment related to different value chains regarding the provision of heat and power in conventional systems; reference system: no use

Technological factor	Crude oil provision	Coal provision	Uranium provision
Prospection	C	C	C
Drilling / Mining	E	E	E
Waste	D	D	E
Demand of water (process water)	C / D[3]	D / E[2]	D
Emissions (exhaust fumes, dust, water, metal)	C / D[3]	C / E[2]	E
Land requirements	C / D[1]	C / E[2]	E
Demands of steel (tubes, equipment)	D	C	C
Transportation (carriers, pipelines)	D	D	D
Refining / processing / enrichment	D	D	D
Accidents (traffic, pipeline leakage)	E	C	C

Impacts are ranked in comparative categories; “A” and “B“ are assigned to the best options concerning the factor, but are not used in this case; “E” is assigned to unfavourable options concerning the factor; ; reference scenario: “no action”-alternative

1: Increased land requirements in on-shore production

2: Increased impacts with open pit mining

3: Increased impact in crude oil provision

5.2.2.2 Raw material conversion

Impacts from implementing a refinery for conversion and use of conventional (fossil) feedstock are expected from

- the construction of the plant
- buildings, infrastructure and installations on-site as well as to the
- operation of a prospective plant

Construction phase

Impacts related with the construction of a plant are temporary and not considered to be significant.

Buildings, infrastructure and installations (size and height of the plant)

Refineries need processing facilities, energy generation, administration buildings, waste water treatment etc., which usually goes along with sealing of soil. Differences are expected regarding the location of a plant as shown in a worst case approach with Greenfield scenario and Brownfield scenario (see chapter 5.2.1.4).

Other impacts might vary in quantity but not in quality, which in case of a generic approach on potential environmental impacts of technologies is negligible. Scaling up plants from different technologies to comparable outputs and yields might further minimise the differences in land consumption. Significant impacts are expected on water, soil, plants, animals and landscape and are highly dependent on local conditions.

Operation phase

Impacts from operating a conversion plant are expected from:

- emission of noise (refinery)
- emissions of gases and fine dust
- emission of light (refinery)
- drain of water resources for production (refinery)
- waste water production and treatment (refinery)
- traffic (collision risks, emissions)
- electromagnetic emissions
- risk of accidents, explosion, fire in the plant or storage areas

Significance of impacts might vary with the type of technology and the location of a potential plant. A decision on a case-by-case-basis is necessary anyway.

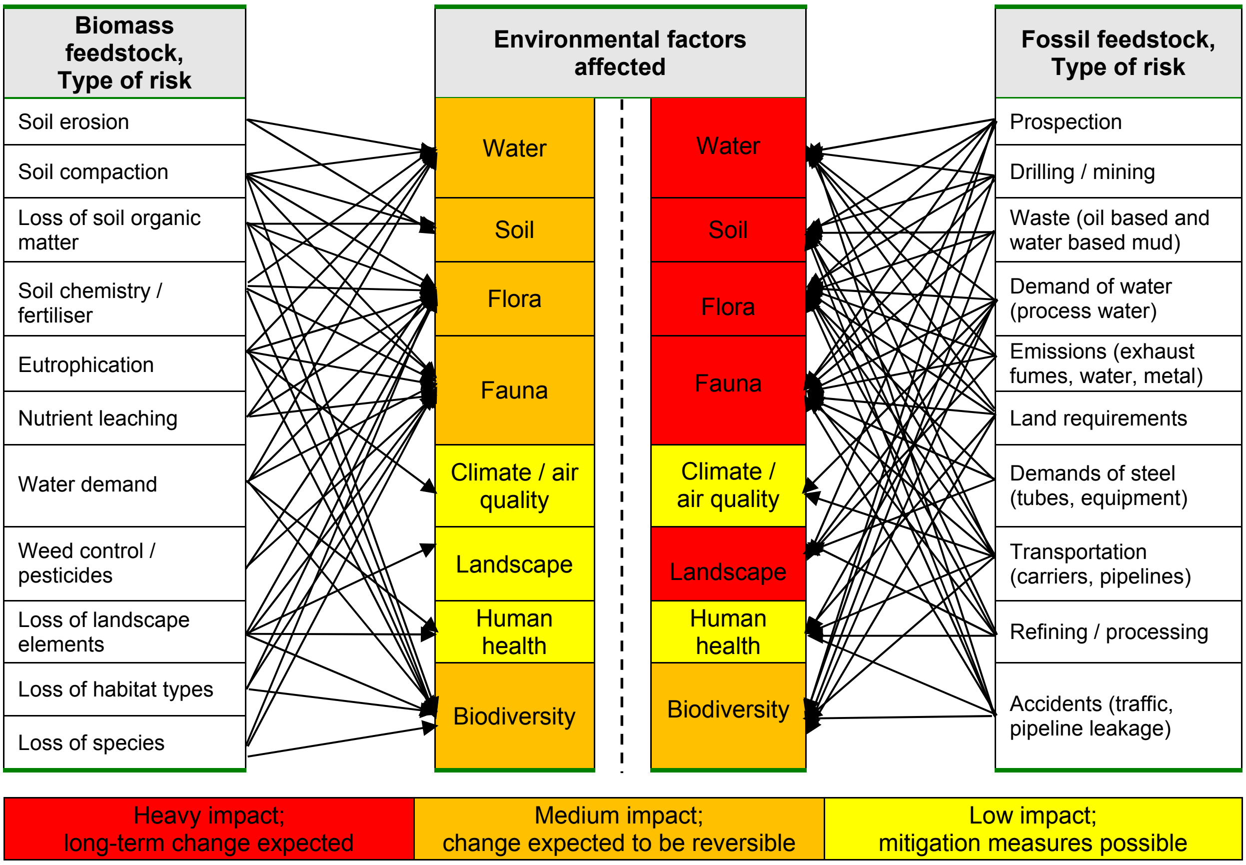
5.2.3 Comparison: SUPRABIO vs. fossil systems

5.2.3.1 Feedstock provision

The provision of feedstock is linked to local environmental impacts varying according to the type of feedstock and the technology. Both types of feedstock (renewable / conventional) can be used for energy production as well as sources for further processing (e.g. chemical industry). However, there are fundamental differences in provision technologies which in case of renewable bio-based feedstock are linked with different management types for soil and cultivation (agriculture).

The types of risks expected from provision of fossil, non-renewable feedstock in general are based on extraction technologies focussing on components below the surface. Regeneration normally is not possible. As type of risks associated with these technologies are completely different in quality and quantity a direct comparison is not possible. Nevertheless Table 5-24 shows a comparison of impacts on local environmental factors assuming a reference system of no use on a sustainability level, choosing three different impact categories: heavy, medium and low.

Table 5-24 Comparison of impact on environmental factors due to provision of bio-based and conventional feedstock regarding impact sustainability in three different categories; reference system: no use



From a sustainability point of view impacts related to the provision of bio-based feedstock are expected to be mostly reversible. For instance soil erosion due to agricultural cultivation or management, depletion of water due to use of fertiliser and pesticides or loss of habitats and species due to changes in land use can be compensated over a certain period of time, if risk factor responsible for the impact will be abandoned. However, most of the impacts from conventional fossil feedstock provision especially on water, soil, flora, fauna and landscape are expected to be long-term changes and non-reversible e.g. in open pit mining for coal provision everything above the coal layer is destroyed.

5.2.3.2 Raw material conversion

Implementing a reference technology faces similar challenges as the implementation of a bioenergy plant working with SUPRABIO technology. According to the applied methodology there are impacts related to

- the construction of the plant
- buildings, infrastructure and installations on-site as well as to the
- operation of a prospective plant

Construction phase

Compared to a SUPRABIO biorefinery no significant differences from impacts related with the construction of a conventional refinery are expected.

Buildings, infrastructure and installations (size and height of the plant)

Compared to a SUPRABIO biorefinery no differences are expected from impacts related to buildings, infrastructure and installations. All technologies considered need processing facilities, energy generation, administration buildings, waste water treatment etc. Significant impacts are expected from buildings, infrastructure and installations due to sealing and compaction, if the plant is built on unsealed areas (Greenfield scenario). Regarding former industrial zones the impacts related to buildings, infrastructure and installations are not expected to be significant (Brownfield scenario).

Impacts might vary in quantity but not in quality, which in case of a generic approach on potential environmental impacts of technologies is negligible.

Operation phase

Compared to a SUPRABIO biorefinery no differences are expected from

- emission of noise (refinery)
- emission of light (refinery)
- electromagnetic emissions

Each type of refinery / heat and power plant emits noise and light. These impacts on the environment are comparable on a generic level. As long as legal thresholds and state of the art technologies are met qualitative differences are not expected. The situation is different for the following impacts:

Drain of water resources for production and waste water production (refinery)

However, additional significant impacts are expected during operation of the plant, due to risks of explosions and fire in the plant or the storage areas, accidents and production / treatment of waste. Depending on the specific location of the plant additional impacts might become relevant due to

- drain of water resources for production (environmental factor: water)
- waste water production / treatment and release to the environment (environmental factors: water, plants, animals, biodiversity)

which might be lower in case of conventional refineries as they are usually associated with water reservoirs (sea, big rivers) to facilitate cooling and transportation.

The need for water especially in conventional refineries (very often situated along navigable rivers in order to benefit from lower transportation costs) might be of less concern. According to /Jungbluth 2007/ the average demand for process water in a conventional oil refinery is projected at 0,6 m³ of water / t of crude oil plus 4 m³ of water / t crude oil of cooling water. This has impacts on environmental factors water (superficial water) and the life associated with it (e.g. aquatic animals, plants).

Biorefineries would be situated close to areas with feedstock production, due to the minimisation of transportation routes and costs. The water demand in a biochemical biorefinery can even be higher than in a conventional refinery. In the scenarios as defined in chapter 3, the water consumption for the production of ethanol is approx. 1,1-2,4 m³ of fresh water per t DM of biomass (=4,2-7,8 m³ of fresh water per t of ethanol) plus 25-37 m³ of cooling water per t DM of biomass. In case of water scarcity especially in southern regions during summer this might lead to enormous risks, affecting environmental factors like water, animals, plants landscape and human beings.

Emission of gases and fine dust (refinery)

Gases (e.g. odours) in most of the considered technologies are expected to be equal, whereas unfavourable gases are often linked to crude oil refineries in combination with chemical refineries

In nuclear power plants emissions of radioactive substances is verifiable. The effect of low radiation doses on the environment are still under investigation and not yet completely clear. For instance a study done by the Federal office of radiation protection /BfS 2007/ in Germany confirms a significant correlation between the distance of residence from the nearest nuclear power plant at the time of the diagnosis and the risk of developing cancer (leukaemia) before the 5th birthday was registered /BfS 2007/.

Traffic (emissions, collision risk)

Differences are expected from traffic related with feedstock provision. Emissions from the provision of a biorefinery will concentrate around the plant, resulting basically in an increase of vehicle movements (delivery of feedstock and products) in combination with an increase in emissions and the risk of accidents. Impacts are expected to be local and especially in case of a Brownfield scenario in urban areas with high traffic density will hardly be verifiable. In rural areas local traffic due to the delivery of feedstock and products will increase. In case of a Greenfield scenario significant impacts on animals (vehicle movements, noise) and human health (emissions, noise) are expected especially with the implementation of a centralised thermochemical biorefinery which is expected to exceed summarised impacts from several decentralised plants with the same total capacity. If additional traffic infrastructure is needed further impacts are expected on soil, animals, plants and landscape. However, the amount of local traffic induced by the refinery is higher in case of a biorefinery, as the energy density of fossil feedstock exceeds biological feedstock.

The provision of fossil driven refineries goes along with long distance transportation by ship / railway and / or pipelines with little impacts on local traffic. From a LCA point of view differences in impacts might be lower especially if risks of accidents (e.g. oil spills) are taken into account but this goes beyond the scope of the applied methodology.

Crude oil as well as coal or “yellow cake” is usually shipped to Europe. Long-distance transportation increases exhaust fumes (cargo ship, lorries) with potential impacts on water (ocean), related organisms (plants, animals, biodiversity), air quality and landscape. Natural gas is provided in pipelines with additional impacts on the environment. The distribution in Central Europe basically runs over pipelines and vessels. As the range of impact is expanded to intercontinental scale there is, with means of EIA methodology designed for site-specific impacts, hardly any affection detectable due to dilution. Enlarged ranges of impact reduce its local significance. The effect might be clearer from an LCA point of view. In general transportation impacts of feedstock imports resulting from long travel distances are expected to be lower on a local level, whereas impacts from biorefineries with local feedstock production might increase local traffic density.

Nuclear power plants provide a special risk due to transportation of high-level radioactive waste such as sending nuclear fuel to reprocessing plants in special CASTOR-containers (CASTOR = **ca**sk for **s**torage and **t**ransport **o**f **r**adioactive material). The substances are radioactive and radiation is detectable outside the castor-containers. In addition some of transported radionuclides are highly poisonous (e.g. Plutonium) and potentially dangerous to the environment.

<u>Disposal of waste materials / residues</u>

All types of refinery / heat and power plants produce solid waste during operation, whereas the residues from biorefineries are biodegradable (potential use of fertiliser) or combustible (potential use in CHP) with potentially lower impacts on the environment. Taking into account statutory frameworks for the operation of plants non-biodegradable solid waste should be collected and provided for correct disposal. Considerable risks are expected in crude oil refineries especially when combined with chemical refineries as a number of dangerous substances are produced.

A potentially high risk for the environment are nuclear wastes from nuclear power plants, as an ultimate waste disposal is still pending, causing a long-term threat for environment and society including human health.

<u>Risk of accidents and explosion, fires in plant and storage areas, release of GMO</u>

Biotechnical production plants have advantages regarding the quality of the processes and the substances used as they generally operate under relatively soft conditions such as lower temperature, relatively low pressure and very often in aquatic ambience (at least in biochemical refineries). Chemical-technical production processes are often related with high temperatures, high pressure, use of organic solvents as well as the existence of pollutants. Otherwise the biotechnical production can have a specific risk due to possible releases of organisms being ecologically (genetically modified) and hygienically relevant, although the "related hazardous potential is classified at the most as 'low' and probably as 'negligible'" /Hoppenheidt et al. 2004/.

Dealing with a higher hazardous potential on substances and processing techniques both the risk of accidents and the potential consequences for the environment from chemical technical processes exceed biorefineries by far as historical and latest news could demonstrate (e.g. Switzerland, fire in the Sandoz plant in November 1986; Venezuela, fire in the Amuay refinery, in August 2012).

Nuclear technology bears an enormous risk as consequences from the core meltings of Chernobyl (26.04.1986) and Fukushima (11.03.2011) could proof. Radioactive releases and the toxicity of radionuclides have severe and enduring impacts on the environment as well as the total biosphere. Consequences of these disastrous accidents are still under investigation.

Comparison of conversion technologies

The comparison of the conversion technologies in different SUPRABIO scenarios and fossil driven reference systems on technological related factors is summarised in the following table.

Table 5-25 Potential impacts on the environment related to different technologies regarding feedstock conversion and transport

Technology / Product — Technology related factor	SUPRABIO systems				Reference systems			
Technology	Thermo-chemical standard config.	Thermo-chemical central config.	Bio-chemical config.	Hydro-genation plant	Crude oil refinery	Gas-fired power plant	Coal-fired power plant	Nuclear power plant
Product	FT diesel, DME		Ethanol, acids	HVO	Fuels; chemicals	Heat and power	Heat and power	Heat and power
Impacts resulting from construction phase								
Construction works	C	C	C	C	C	C	C	C
Impacts related to buildings, infrastructure and installations								
Buildings, infrastructure and installations (size and height)	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]
Impacts resulting from operation phase								
Emission of noise (refinery)	D	D	D	D	D	D	D	D
Emission of gases and fine dust (refinery)	C	C	C	C	D	C	D	C[5]
Emission of light (refinery)	C	C	C	C	C	C	C	C
Drain of water resources for production (refinery)	D	D	D	D	D	C	D	D
Waste water production and treatment (refinery)	D	D	D	D	D	C	D	D
Traffic (collision risk, emissions)	C	D[8]	C	C[3]	C[3]	C[3]	C[3]	E[6,7]
Electromagnetic emissions from high-voltage transmission lines	C	C	C	C	C	C	C	C
Disposal of wastes/residues	C	C	C	C	D[6]	C	C	E[6,7]
Risk of accidents explosion fire in the plant fire in the storage areas release of GMO	C / D[5]	C / D[5]	C / D[4]	C / D[5]	E[3,5,6]	E[3,5,6]	E[3,5,6]	E[3,5,6,7]

Impacts are ranked in five comparative categories; “A” is assigned to the best options concerning the factor (does not occur in a Greenfield scenario), “E” is assigned to unfavourable options concerning the factor; reference scenarios: “no action”-alternative

1: No significant impacts expected in a Brownfield scenario
2: Significant impacts expected in a Greenfield scenario
3: Less local impact due to transportation by import of feedstock from overseas
4: Increased impact potential expected due to operating with GMO (risk of release)
5: Increased potential of accidents due to potentially hazardous production conditions
6: Increased impact potential expected due to potentially hazardous substances
7: Increased impact potential expected due to radioactive substances; although the emission level during normal operation is low, the toxicity can be quite high.
8: Increased emissions and traffic load in centralised plant

5.3 Results: SUPRABIO vs. other biomass-based systems

In chapter 5.2 feedstock provision and technology in the SUPRABIO system were compared to conventional systems assuming that a) there is no competition on land use and biomass provision (scenario case A chapter 5.2.1.1) and b) there is a constant request for feed and food crops (scenario case B, chapter 5.2.1.2). The idea is to showcase potential impacts from feedstock production as well as impacts from the change of land use.

As a fact the availability of land for feedstock provision is limited indicating that there is competition in the use of land and in the use of lignocellulose feedstock. Taking this into account the following chapter raises crucial questions and tries to provide answers:

1. What is the best use for biomass residues? Are there alternative uses in comparison to a biorefinery?
2. What is the best use of cultivated biomass? Are there alternative uses in comparison to a biorefinery?
3. What is the best use of one hectare of land in comparison with other crops?

5.3.1 Alternative use of biomass residues

Differences in the **provision of feedstock** from residues are relatively low (see Table 5-6). Regarding cereal straw there might be a development towards the use of long-stalked varieties going along with a slight increase in habitat diversity. Due to higher competition the amount of pesticides is expected to be less resulting in lower pressure on flora and fauna. The use of wood residues on the long term is negative compared to the reference system of leaving residues in the woods, due to export of biomass as the availability of SOM and habitat diversity for saprophytic organisms is reduced. An **alternative use for biomass** instead of producing biochemical would be direct combustion in a combined heat and power plant (CHP). From an LC-EIA point of view differences between a biorefinery according to SUPRABIO systems and direct combustion is relatively low as shown in Table 5-26. Local environmental impacts due to construction works of a plant as well as due to buildings, infrastructure and installations are comparable and are basically related to the size of the plant. In both options (conventional / bio-based) impacts are expected during the operation phase due to noise and the risk of accidents as both types of technologies are operating under potentially hazardous production conditions. Emissions during the operation phase might differ slightly. In a biomass driven CHP the total biomass is burnt and emissions might exceed that of a SUPRABIO biorefinery based on lignocellulose residues. Higher impacts due to traffic (noise and movement of vehicles, exhaust fumes) are expected in the mature scenario of a centralised thermochemical plant as transport distance for feedstock provision is higher than the sum of distances in decentralised plants with the same capacity. But this might get clearer from an LCA point of view.

Answer to question 1: From an LC-EIA point of view the provision of wheat (cereal) straw as feedstock for a SUPRABIO biorefinery is a slightly better option than wood residues in comparison to the particular reference systems. Nevertheless, site specific conditions need to be taken into account indicating variability in the implication of local environmental impacts. Regarding the use of feedstock, differences between conversion technologies e.g. a biorefinery and a CHP are very low.

Table 5-26 Potential impacts on the environment related to different technologies regarding feedstock conversion and transport

Technology / Product Technology related factor	SUPRABIO systems				Reference system
	Thermochemical standard configuration	Thermochemical central configuration	Biochemical configuration	Hydrogenated vegetable oils (HVO)	CHP plant
	FT diesel, DME		Ethanol, acids	HVO diesel	Heat and power
Impacts resulting from construction phase					
Construction works	C	C	C	C	C
Impacts related to buildings, infrastructure and installations					
Buildings, infrastructure and installations (size and height)	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]	A[1] / E[2]
Impacts resulting from operation phase					
Emission of noise (refinery)	D	D	D	D	D
Emission of gases and fine dust (refinery)	C	C	C	C	D
Emission of light (refinery)	C	C	C	C	C
Drain of water resources for production (refinery)	D	D	D	D	D
Waste water production and treatment (refinery)	D	D	D	D	D
Traffic (collision risk, emissions)	C	D[7]	C	C	C / D[3]
Electromagnetic emissions from high-voltage transmission lines	C	C	C	C	C
Disposal of wastes/residues	C	C	C	C	C
Risk of accidents explosion fire in the plant fire in the storage areas release of GMO	D[5,6]	D[5,6]	D[4]	D[5,6]	D[5]

Impacts are ranked in five comparative categories; “A” is assigned to the best options concerning the factor (does not occur in Greenfield scenario), “E” is assigned to unfavourable options concerning the factor; reference scenarios: “no action”-alternative

1: No significant impacts expected in a Brownfield scenario
2: Significant impacts expected in a Greenfield scenario
3: Increase of local impacts due to transportation from local feedstock provision
4: Increased impact potential expected due to operating with GMO (risk of release)
5: Increased potential of accidents due to potentially hazardous production conditions
6: Increased impact potential expected due to potentially hazardous substances
7: Increased traffic in a centralised plant due to feedstock provision

5.3.2 Alternative use of land

Arable land is limited and competition as well as the demand for additional area is increasing due to constantly high prices for agricultural commodities. As lignocellulose feedstock for a biorefinery is facing competition from other potential users (e.g. CHP, gasification, 1st generation ethanol production, etc.) the question for the most efficient use of arable land is suggesting itself. Nevertheless, looking at potential impacts form different feedstock scenarios as summarised in Table 5-27 a specific answer is not possible as differences from the use of the same feedstock for different purposes are mainly qualitative (detailed information and impact matrices on the alternative feedstock crops are provided in Annex 9.4). E.g. the use of maize grain or wheat grain for 1st generation ethanol production implies the ploughing in of straw. As this usually is not enough to keep up SOM and nutrient balance the use of fertiliser is still necessary, although the amount is less than in case of harvesting the total plant e.g. for combustion (CHP) or for gasification. The following key messages can be derived:

- Least impacts are expected from the cultivation of SRC poplar (SUPRABIO feedstock) compared to the reference system of non-rotational fallow land, basically due to reduced maintenance cycles as it is a perennial crop. Soil compaction is relatively low and due to leave fall SOC/SOM is expected to be quite high.
- Heaviest impacts are expected from the cultivation of sugar beet and maize especially due to intensive maintenance cycles and in case of sugar beet the heavy machineries used for harvest (soil compaction), intensive use of fertiliser and pesticides (loss of habitat/species diversity) and nutrient leaching (water).
- Other crops including the SUPRABIO feedstock rapeseed do not differentiate enough on a qualitative level to provide differences on potential impacts from feedstock provision. A recommendation without taking into account site-specific conditions is not possible.
- Impacts from imported feedstock cultivated in oversea like soy, oil palms or Jatropha depend on the particular reference system. In general impacts due to land use change are to be expected. Irreversible impacts on the environment arise from the cultivation on the expense of natural ecosystems like rain forest. An option to be considered is an extensive cultivation of Jatropha on marginal land due to low application of fertiliser and pesticides as it could help to improve depleted soils. For a clear recommendation site specific conditions need to be taken into account.

Table 5-27 Comparison of crop specific impacts versus different reference system

Feedstock	Reference system	Soil erosion	Soil compact-ion	Soil organic matter	Soil chemistry/ fertiliser	Nutrient leaching	Water demand	Weed control / pesticides	Loss of habitat / species diversity	Loss of landscape elements
SRC poplar	non-rotational fallow land	B	B	A	B	C	C	C	B	B
Rapeseed (ploughing in of straw)	rotational fallow land	D	D	C	D	D	D	E	D	C
Sugar beet (ploughing in of leaves)	rotational fallow land	E	E	E	E	D	E	E	D	C
Wheat grain (ploughing in of straw)	rotational fallow land	C	C	D	D	D	C	E	D	C
Maize grain (ploughing in of straw)	rotational fallow land	D	C	D	D	D	C	E	D	C
Maize total plant	rotational fallow land	D	D	E	D	E	C	E	D	C
Triticale total plant	rotational fallow land	C	C	D	D	D	C	E	D	C

For the use of biomass clear differences in impacts are not to be expected on a qualitative level as shown in Table 5-26. An alternative use of SRC poplar in a SUPRABIO biorefinery could e.g. be combustion and energy provision in a CHP or gasification and the production of FT diesel. As impacts on the environment are similar no clear preference on technology is possible.

Answer to question 2: A clear answer to the question from an LC-EIA point of view is not possible. Regarding feedstock provision perennial crops seem to provide fewer impacts on environmental factors than annuals. However, impact intensity varies due to site specific conditions (e.g. soil quality, climate, availability of water, etc.). Regarding conversion technologies site specific impacts exceed technology based impacts. A technology based ranking is not feasible.

Answer to question 3: A clear answer regarding the best use of one hectare of land is not possible from an LC-EIA point of view. Regarding feedstock provision from perennial crops impact intensity varies due to site specific conditions (e.g. soil quality, climate, availability of water, etc.) and can locally be compensated or superimposed. In any case sugar beet cultivation is covered with more risks than other annual crops. Regarding conversion technologies site specific impacts exceed technology based impacts. A technology based ranking is not feasible.

5.4 Discussion and interpretation

Limited energy resources afford a sustainable use of energy as well as valorisation of alternative energy sources. The EU is favouring the production of liquid biofuels. By the year 2020 at least 10 % of the fuel used for transport and mobility should come from liquid biofuels including savings of GHG up to minus 50 % from 2017 onward (Renewable Energy Directive, /EP & CEU 2009b/). To reach this goal various strategies for biomass conversion and provision have to be taken into account. In case of biomass conversion the focus on lignocellulose feedstock is promising as in comparison to 1st generation biorefineries the rate of yield is higher. In addition the provision of valuable added products offers additional possibilities to produce and to substitute chemicals for special applications.

SUPRABIO is contributing to a successful implementation of the EU energy directive by providing a coherent concept for biorefinery based on lignocellulose feedstock.

5.4.1 Feedstock provision

Feedstock production for a biorefinery is linked to land and land is limited, especially in the EC. In 2000 the EC25 had a total area of 3.290.000 km² with an almost equal distribution on arable land (29 %), grassland (27 %) and woodland (36 %). Infrastructure was calculated with about 6 % and unproductive area including wilderness with about 1 % with highest amounts in Finland and Sweden (5 % of the national territory) /Schulze & Körner 2012/. This indicates that additional area for feedstock production is rare.

Nevertheless, a potential increase in area used for provision on energy crops is possible especially by intensifying the use of grasslands and providing the released area for agriculture /Schulze & Körner 2012/. An area of about 193.000-627.000 km² is predicted to be available for the provision of energy crops in 2050 representing 5-16 % of the arable land in the EC25. Fig. 5-3 shows a trend scenario of potential development in arable areas used in the EC25 in 2050 for energy crop provision in form of land balance and energy yields.

An increase in arable land on the expense of grassland has impacts on some environmental factors. An environmental impact assessment of this scenario is not possible in the range of this study. Nevertheless, the intensified use of grassland and arable land has lead in the past to several partly severe environmental impacts. Among these known impacts are:

- loss of biodiversity in cultural landscapes due to intensified use and loss of landscape elements.
- loss of grassland with high nature conservation value especially in marginal lands, e.g. for migrating and nesting birds, plants and insects.
- increase of the eutrophication of surface water bodies and groundwater bodies due to intensified use, especially of river margins.
- further compaction and erosion of soils due to intensified use.
- further pressure on conservation areas by intensified use of transition areas between core zones and neighbouring agricultural land.

Increased use of fertiliser and pesticides might increase negative impacts on superficial water and groundwater (eutrophication, leaching) thus affecting flora, fauna and biodiversity. /Geiger et al. 2010/ found negative effects of agricultural intensification on wild plant, ground beetle (Carabidae) and bird species diversity due to intensified use of pesticides.

Although the SUPRABIO approach seems to be promising by focussing on lignocellulose feedstock both from residues and cultivated biomass, further investigations are necessary especially to quantify potential impacts on biodiversity.

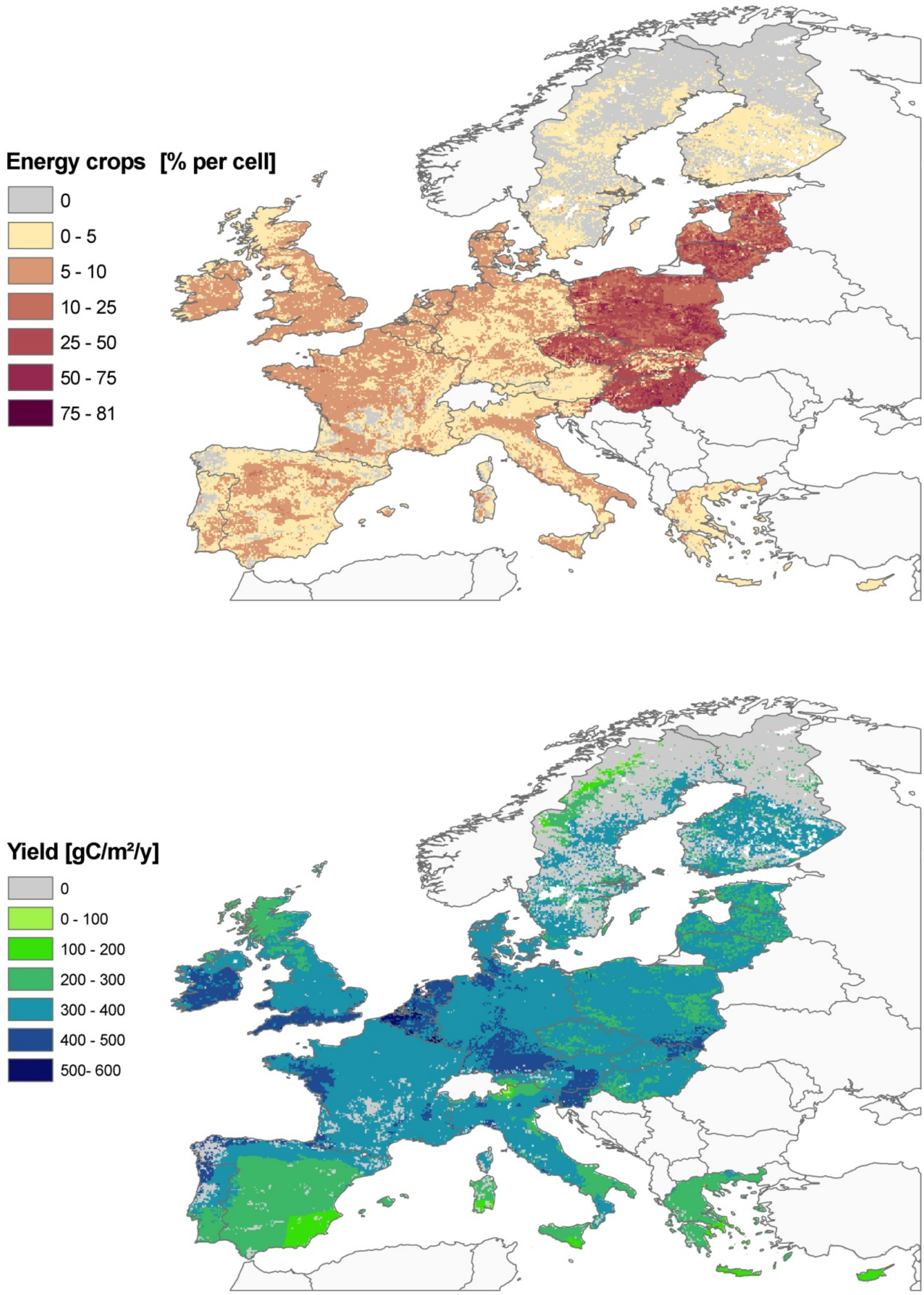


Fig. 5-3 Trend scenario on potential areas for energy crops (above) and energy yields in Europe (EC 25) in 2050 /Haberl et al. 2012b/

Residues

Cereal straw

From an EIA point of view the provision of both lignocellulose feedstock types investigated, i.e. cereal straw and wood residues, cause comparably little impacts on the environmental factors in comparison to the reference system. Straw has been used as feedstock ever since (fodder, litter)and the example of the BEKW Emsland (CHP) shows that there is feedstock available to drive a plant with 75 kt of straw per year /Knieper 2012/.

Potential impacts for the environment arise from the intensification of land use. Assuming a scenario of a straw-driven SUPRABIO biorefinery, a development towards intensified use (efficient harvesting machineries, long stalked cereal varieties) is expected, as straw will be allocated an additional value. Intensified agriculture means an increased consumption of nutrients from the soil that has to be supplemented either by cover crops or by fertiliser or both. Even if impacts from straw production are comparable to a reference system of conventional use (ploughing in of straw) a risk of decreasing biodiversity is expected on the long term.

Forest residues

The use of wood residues is bearing long-term risks compared to the reference system of traditional forestry where wood residues and thinning material usually are left onsite. The residues basically contribute to SOM balance and carbon sequestration.

Actual developments in forestry are opting for shorter rotation cycles and the valorisation of thinning wood and wood residues /Serup et al 1999/. The demand for wood chips and pellets increased yields as well as wood prices. In the long term this means a net export of nutrients and of carbon from forest soils. However, forestry in Germany is achieving to shorten rotation periods from 125 years (average) down to 60 years with the consequence of reducing the wood stock and the carbon stock by approximately 1.000 million of m³ within 10 years thus counteracting the efforts of protecting the atmosphere by reduction of fossil fuels /Schulze & Körner 2012/.

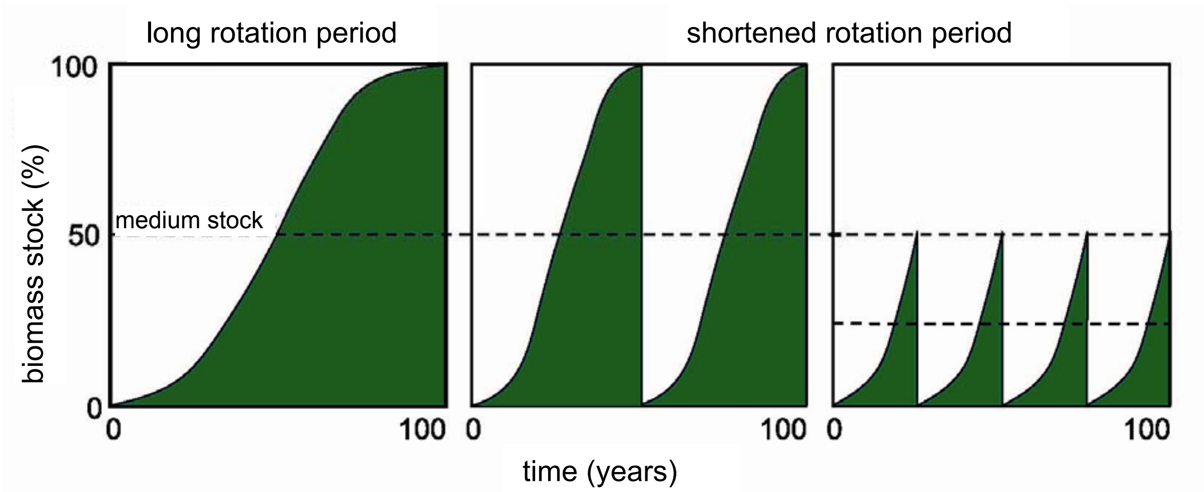


Fig. 5-4 Reduction of carbon stock in trees by shortening of rotation cycles /Schulze & Körner 2012/, modified

Cultivated biomass

Within the SUPRABIO project different types of cultivated biomass were investigated i.e. perennial crops, annual crops and the use of algae as add-on technology.

Perennials

Compared to the reference system of non-rotational fallow land, SRC poplar plantations on arable land perform better in respect to many environmental factors. Soil compaction and erosion is lower due to longer growing periods (SRC poplar: 5-7 years) and reduced maintenance cycles. Low need of fertiliser supports this valuation and results in low eutrophication rates with less negative impacts on soil and groundwater.

The variety of habitat types can be increased in agricultural areas. Species and habitat diversity would benefit from perennial crops like SRC poplar offering additional habitat types for plants, invertebrates (insects and other arthropods) and vertebrates (e.g. deer and birds). Due to the low light intensity within the plantation the species community tends to support species from woodlands.

Similar effects are expected from low-input Jatropha plantations compared to the reference system of marginal land. This effect is reversed when considering the cultivation of Jatropha or oil palms on the expense of tropical rain forest. Irreversible impacts on soil, water, biodiversity and landscape are expected. Risks are lower in case of cultivating perennial crops such as Jatropha or oil palms on non-rotational fallow land. Nevertheless, for a final assessment local conditions have to be taken into account. This is especially valid for the assessment of effects on biodiversity.

Annuals

The cultivation of annual crops in general results in higher impacts on the environment especially due to intensified conditioning of the plantations. Independently from annual crop investigated risks on soil compaction and erosion are higher than in the reference system of rotational fallow land. Crop specific differences are comparably small and only evident as on-site effects on the field. They mainly result from crop specific differences on soil erosion.

The higher risk of erosion in annual crop systems results from the part time coverage of the soil in crop rotation. Crop specific differences result from plant density and soil coverage during growing period. In case of sugar beet, the relatively wide distance between the rows increases the risk of soil erosion compared to cereals. The impact risk on groundwater and superficial water is increased due to leaching of nutrients as a consequence of intensive donations of fertiliser. Catch crop as well as under sown crops would help to minimise risks from lacking soil coverage. The impact on the loss of soil organic matter can be quite high compared to the reference system. Harvesting of stalks and fruits results in depletion of soil organic carbon and has to be compensated.

There is an impact on biodiversity due to the application of fertiliser and weed control. In comparison to the reference system lower numbers of species in the plantations are expected.

Algae

/Haberl et al. 2012a/ are considering a biorefinery based on algae biomass as not very likely within the near future. It would require a continuous supply with high amounts of algae biomass. Although highly productive, an efficient production of micro-algae in continuous quantity is difficult due to seasonal and daily variations in light and temperature. However, a promising approach could be the incorporation in existing industrial production chains where carbon (e.g. CO_2 from flue gas) and nutrient rich streams (nitrogenous wastes from municipal or farming operations) can be processed especially if concentrating on high value products (e.g. EPA, DHA and β-glucan). Impacts on the environment could be minimised as sealing of additional soil could be minimised in existing plants. And a biorefinery concept including the production of high value compounds from algae and the conversion of waste products could add additional value.

5.4.2 Raw material conversion

The implementation of refineries is related to environmental impacts regarding

- Construction
- Buildings, infrastructure and installations
- Operation

The assessment of local environmental impacts in implementing and operating refineries reveals no fundamental differences between the different technologies investigated. Independently from the technology differences are not to be expected on a generic level during construction phases and related to buildings, infrastructure and installation.

Substantial differences arise from the location of a potential refinery. In a “Greenfield scenario” where the plant is to be built on unsealed areas, the potential impacts are by far higher than in a “Brownfield scenario” on e.g. former industrial zones. But this is independent from technologies applied and therefore not relevant for evaluation.

Differences in local impacts are expected during the operation compared to conventional refineries. Regarding the drain of water resources biorefineries likely exceed the demand of conventional refineries. This could cause negative impacts in regions with water scarcity especially during hot season.

<u>Drain of water resources</u>

Unfavourable for a biorefinery might be the drain of water in regions with water scarcity, as potential plants when built in the vicinity of irrigated feedstock would increase the risk of droughts especially in southern areas during dry seasons. Fossil-driven, conventional refineries need water as well but they usually are built along water reservoirs (sea, big rivers) for facilitation of cooling and transportation.

Nevertheless, on a generic level bio-based refineries seem to be environmentally more favourable than refineries based on fossil feedstock. This is basically linked to the following types of risks:

- Emissions of gases and fine dusts
- Traffic
- Disposal of waste / residues
- Risk of accidents

Emissions of gases and fine dust

Very little differences are expected on the issue of fine dust and gas emissions from chemical refineries and biorefineries, respectively. Crude oil processing and the production of synfuels from biomass (thermochemical plant) are considered slightly unfavourable as potential gases and odours might be more harmful. Coal plants are considered unfavourable due to particulate matter emissions from stock piling. Although only the local vicinity is affected, these particulate matter emissions due to handling of feedstock are considered more severe compared to emissions from biorefineries since parts of the particulates are radioactive /Jansen 2008/.

Traffic

Additional traffic causes additional emissions and increases the risk of accidents. Local traffic is expected to be increased in the area of biorefineries with feedstock provision from the vicinity, which in case of a Greenfield scenario will exceed the impacts from a Brownfield scenario. Considering urban traffic impacts from the latter scenario might even be negligible. However, local traffic is expected to increase with size of a central mature thermochemical plant (2025 scenario) compared to decentralised facilities spread over the country. In the BIOCORE project it could be highlighted that the available feedstock in European case study areas is limited due to competing use. Smaller units were suggested for the future /Doublet et al. 2012/ thus favouring a concept with decentralised plants to minimise impacts from traffic.

Disposal of waste / residues

Bio-based refineries have a clear advantage regarding the disposal of organic residues as it can be used for combustion (energy production), animal feed or fertiliser. Nuclear power plants are most unfavourable due to the uncertainties related to the final disposal of radioactive substances and to the danger (toxicity, radiation) of specific radionuclides.

Risk of accidents

The risk of accidents in fossil-driven, conventional refineries is considerably high due to hazardous production conditions (high temperature, high pressure, hazardous substances). Although bio-based refineries usually work with genetically modified organisms (GMO) the risk is considered comparably low.

5.4.3 Interpretation

Feedstock provision

In Europe arable land is limited. Due to a small scale structured landscape the availability as well as the provision possibility of uniform feedstock for a potential mature biorefinery is limited as well. And in regions with suitable feedstock in relevant quantities (e.g. wood in central Germany, cereal straw in northern France and northern Germany), competing uses are established. In case of wood residues the use of log wood for domestic heating might even increase.

Therefore the implementation of huge biorefineries as planed in the mature scenario for 2025 with a capacity of 400 kt DM/a bears risks. From an LC-EIA point of view it makes sense to reduce capacities and to decentralise the locations of potential plants. This offers the chance to take different types of feedstock into account in order to react to market demands.

Clear recommendations for a specific feedstock or feedstock crop are not possible. All types of feedstock investigated show advantages and disadvantages although perennial crops like SRC poplar seem to be slightly favourable from an LC-EIA point of view. An intensified use of bio-based feedstock however, seems to be limited. In Germany for instance, the area available for agricultural use decreased between 1995 and 2011 by 700.000 ha and fallow land decreased by about 1.000.000 ha /Statistisches Bundesamt 2012/ while the development of urban infrastructure increased. Nevertheless, the yields in agriculture increased as well, indicating a trend towards higher efficiency in production methods and the use of more efficient crop species.

This could be an option for the provision of bio-based feedstock besides the fact that additional land is necessary to increase the production. For the sustainability assessment, land use changes have to be taken into account. A shift in feedstock production to overseas regions is not sustainable from an LC-EIA point of view as the examples of oil palm cultivations or soy on the expense of tropical rain forest shows.

Conversion technology

From an LC-EIA point of view a clear preference for a specific type of conversion technology is not possible. Any refinery built has impacts on the environment. Differences might regard in quantitative issues but on a generic level qualitative impacts are comparable. The assessment of a specific plant has to be based on a case-by-case study.

6 Conclusions, limitations and recommendations

The objective of this chapter is to draw conclusions, identify limitations and make recommendations for the intended application and target audience of the environmental assessment.

6.1 Conclusions

In this chapter, conclusions from screening life cycle assessment and life cycle environmental impact assessment, respectively, are presented and subsequently merged.

6.1.1 Conclusions from screening life cycle assessment (LCA)

In the following, conclusions are drawn which are based on the results from screening life cycle assessment (LCA) presented in chapter 4. The focus here is on **environmental impacts at global / regional level**.

Significant issues of SUPRABIO systems

Environmental impacts at global / regional level occur at all stages of the life cycle, however, the extent to which each life cycle stage contributes to the overall balance varies both *between scenarios* and *between environmental impact categories*.

In general, **the core biorefinery processes (pre-treatment and main process) are responsible for the majority of the environmental impacts**. These are to a large extent under the direct management influence of the biorefinery, but future operators also need to take responsibility regarding upstream processes such as enzyme provision since optimisations are needed along the entire supply chain. This is especially the case within the biorefinery itself. This study showed that in the biochemical route, staged gasification of process residues followed by conversion of the obtained syngas into heat and power via a gas turbine has the potential to substantially improve environmental impacts. Furthermore, process modifications of the gasification unit in the thermochemical route (higher operating pressures and quenching temperatures) have very positive impacts.

In contrast to this group of processes, **transport processes are of minor importance** from an environmental point of view (both biomass transport and product transport).

In the case of SUPRABIO products, **biomass provision plays an intermediate role** and the **use phase is less important** – at least as far as the investigated environmental impact categories are concerned. Biomass provision features with an apparent, yet less significant contribution, mainly because lignocellulosic biomass residues and low-input lignocellulosic crops are considered in SUPRABIO. However, this only applies if **no direct or indirect land use changes** are associated with biomass provision. Regarding land use, only land occupation was quantified: the impact assessment of land use was done outside the LCA in the LC-EIA part (see below).

For the products assessed in this study, the use phases of bio-based and conventional life cycles are rather similar and thus only lead to minor differences in environmental impacts with two exceptions: First, only CO_2 emissions from biofuels and bio-based products are compensated by equal amounts of CO_2 uptake during plant growths. Second, organic acids produced within SUPRABIO may exhibit different functional properties than conventional propionic acid and thus lead to variations in replacement rates. There is no separate end-of-life treatment because all assessed use options are consumptive (e.g. combustion).

We conclude that the entire life cycle of a product should be considered and strongly discourage short-cut studies, e.g. so-called cradle-to-gate assessments, which end at the manufacture of the bio-based product. This is because bio-based products might only show their superiority during use phase and end-of-life treatment.

SUPRABIO vs. conventional systems

Apart from the expenditures / emissions associated with the bio-based product, the **expenditures / emissions associated with the substituted conventional reference product are decisive**. Since the environmental burden associated with the latter is avoided, the avoided expenditures / emissions are credited to the bio-based product. Depending on the nature of the product, this credit varies a lot: highest credits are obtained for complex molecules that would require substantial inputs if produced synthetically from petroleum.

The comparison of SUPRABIO products to conventional products leads to different results:

1. The investigated biofuels (ethanol, FT fuels and DME) typically lead to advantages in terms of non-renewable energy use and global warming potential. The latter only applies if no direct or indirect land use changes are associated with biomass provision. At the same time, disadvantages are incurred regarding eutrophication and ozone depletion. Other impact categories show indifferent results (acidification, photochemical ozone creation and particulate matter formation). This means that from an LCA point of view, the investigated **biofuels do not show a clear advantage** over conventional fuels.
2. The investigated **mixed organic acids lead to clear additional environmental burdens** (disadvantages) in all environmental impact categories.

The pattern mentioned under point 1 is well known for 1st generation biofuels. Disadvantages regarding eutrophication associated with the 2nd generation biofuels investigated in SUPRABIO are either due to nitrogen nutrient inputs to the biochemical biorefinery (fermentation processes) or to the agricultural system (fertiliser for the cultivation of dedicated crops or for the compensation of nutrients removed via straw). In terms of eutrophication, products from forest residues (only investigated for the thermochemical route) perform equal or better than conventional products, mainly because no compensation fertilisation of forest systems was assumed.

Due to the result patterns mentioned above **we conclude that it is not sufficient to restrict the analysis to life cycle non-renewable energy use and greenhouse gas emissions.** As stipulated by ISO 14044, the selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied.

Comparing the results presented above, it must not be concluded that biofuels *generally* are to be preferred over bio-based products (e.g. mixed organic acids). The fact that the biofuels investigated in SUPRABIO show less disadvantages than the investigated bio-based products cannot be generalised and only applies to the products that happened to be chosen in SUPRABIO. There are plenty of studies which show that bio-based products are on a par with biofuels: the net climate change mitigation per land used of bio-based products is in the same range as for biofuels, in some cases considerably higher /Dornburg et al. 2003/, /Reinhardt et al. 2007/, /Rettenmaier et al. 2010/. The challenge is “just” to identify these more promising pathways. The bio-based products investigated in SUPRABIO still require further R&D efforts and considerable breakthroughs are needed in the field of energy efficiency and product separation and purification.

From an environmental angle, there is thus no reason to prefer the use of biomass for energy over the use of biomass for bio-based products as it is the case in Europe due to the current political framework (especially due to the Renewable Energy Directive, RED /EP & CEU 2009b/). From a supply security point of view, it would make sense to divert more biomass towards material use since biomass is the most obvious renewable carbon sources for the chemical industry (apart from power-to-gas / power-to-liquid technology), whereas renewable energy can be provided from other sources such as wind and photovoltaics and the transport sector can be electrified to a large extent.

As regards the RED, FT fuels from forest residues investigated in SUPRABIO would safely achieve the minimum greenhouse gas emission savings of 60 % (as stipulated after 1 January 2018), provided that the thermochemical processes are further optimised, e.g. towards higher operating pressures. In case of the biochemical processes, the optimum of what was proposed in SUPRABIO has to be reached and external influences have to be optimised (e.g. higher enzyme performance). Otherwise, 2nd generation ethanol from straw would have difficulties to fulfil the 60 % requirement. However, since the greenhouse gas balances according to Annex V of the RED deliver *relative* savings achieved *per unit of product* instead of *net* (or *absolute*) greenhouse gas emission savings *per unit of limited resource* (i.e. biomass or land), the results obtained via these calculation rules should not be taken as a basis for political decisions, but only for the regulation of economic operators.

SUPRABIO vs. other biomass-based systems

The availability of biomass or land for its production is the main limiting factor for the production of bio-based products. Thus, all SUPRABIO scenarios have to be compared to other use options of the same biomass or land to be able to answer the question if and under which conditions these scenarios should be established on large scale.

Comparing the 2nd generation biofuels investigated in SUPRABIO to existing 1st generation biofuels on a land use basis, it could be shown that

- The results for 2nd generation ethanol from poplar are in the same range as many the results for different types of 1st generation ethanol. However, it is surpassed by 1st generation ethanol from European sugar beet. It cannot be directly compared to 1st generation ethanol from sugar cane since sugar cane is cultivated outside Europe[6].
- The results for FT fuels from poplar are considerably better than the results for other diesel-type biofuels such as FAME and HVO produced from rapeseed (which is the most relevant oil crop in Europe and thus relevant for a comparison on a land use basis)

6 One hectare of land in Europe cannot be directly compared to one hectare of land elsewhere due to significant differences between agro-environmental / pedo-climatic zones.

- The results for hydrogenated vegetable oil (HVO) are as poor as the results for 1st generation biodiesel (FAME) if produced from the same biomass feedstock (rapeseed being most relevant in Europe)

We conclude that 2nd generation technology does not show the potential to significantly improve the land use efficiency of ethanol. Thus, 2nd generation ethanol production from dedicated crops (even if perennial) does not live up to the high expectations connected to it in terms of environmental benefits. The thermochemical route towards FT fuels offers higher (relative) improvements over 1st generation biodiesel, however, **2nd generation ethanol shows higher potentials for climate change mitigation per unit area than FT fuels** from the same biomass feedstock. Yet, **FT fuels display advantages over lignocellulosic ethanol regarding environmental impacts other than climate change as well as greater biomass flexibility.** The latter is due to the relatively robust pyrolysis step which is able to convert virtually any biomass (especially biomass residues) into a relatively homogenous bio-oil to the subsequent more delicate gasification. Moreover, FT fuels do not face any blending restrictions (in contrast to ethanol) and might be more desirable since the demand for diesel-type and kerosene-type renewable fuels in Europe will increase in the future, whereas gasoline demand (and thus the demand for ethanol) is projected to decrease.

Regarding other biomass-based systems, which compete for the same biomass or land, the fiercest competitor for SUPRABIO is direct combustion of biomass for combined heat and power generation. **The stationary use of biomass usually outperforms the biofuel use of biomass by far – at least today**. However, the quantitative results of the stationary use of biomass for energy depend on the composition of the substituted conventional electricity mix: the higher its specific non-renewable energy demand and specific emissions are, the better the results if it is substituted. Today, the share of coal in the electricity mix is still high. In the long run, however, the transition of the energy system is likely to reduce the share of coal in the electricity mix and at the same time to decrease the environmental burdens avoided by new biomass-fired CHP plants. In view of the latter and considering increasing environmental burdens of petroleum-based fuels, **2nd generation biofuels might become more attractive in the future**.

Moreover, renewable heat and power can also be provided from sources other than biomass whereas airplanes, ships and heavy trucks are unlikely to be electrified in the near future and will most probably depend on liquid or (compressed) gaseous hydrocarbons. The latter can be produced renewably either from biomass or via power-to-gas / power-to-liquid technology (as discussed for material use, see above). In other words: the choice of the most environmentally friendly biomass use option varies over time.

6.1.2 Conclusions from life cycle environmental impact assessment (LC-EIA)

In the following, conclusions are drawn which are based on the results from life cycle environmental impact assessment (LC-EIA) presented in chapter 5. The focus here is on **environmental impacts at local level**.

Significant issues of SUPRABIO systems

Environmental impacts at local level occur at all stages of the life cycle, too. The extent to which each life cycle stage contributes to the overall balance varies *between scenarios* but not *between environmental impact categories at local level*.

Within this study, the use phase and end-of-life treatment were not considered, since the impacts associated with the earlier life cycle stages are by far higher and thus far more relevant. In general, **local environmental impacts of SUPRABIO systems are dominated by biomass provision**. However, the impacts' extent and magnitude is largely dependent on the type of biomass feedstock. Large areas of land are affected either by the extraction of agricultural or forest residues or by the cultivation of dedicated lignocellulosic crops, i.e. the *extent of impacts* is generally quite large, depending on the yield of biomass residues and dedicated crops, respectively. The potential impacts are mainly land-use related and affect water, soil and biodiversity. Provided that biomass residue extraction rates are sustainable and provided that no direct or direct land use changes are induced (=main precondition underlying this assessment), it can be stated that in terms of *magnitude of impacts* both the provision of biomass residues (wheat straw or forest residues) and the provision of dedicated lignocellulosic crops (e.g. perennial crops like SRC poplar) are associated with comparatively low risks. Higher risks are associated with imported biomass, especially oil crops. However, from an LC-EIA point of view, a clear preference for a specific type of biomass feedstock cannot be given since all investigated feedstock show advantages and disadvantages. Regarding biomass residues, the provision of wheat straw is a slightly better option than forest residues.

In contrast to that, **transport processes are of minor importance** from an environmental point of view (both biomass transport and product transport).

The core biorefinery processes (pre-treatment and main process) play an intermediate role. Local environmental impacts vary *between scenarios*. From an LC-EIA point of view, a clear preference for a specific type of conversion technology is not possible, since qualitative impacts on a generic level are comparable. Quantitative differences might occur especially in terms of water use which is expected to be higher in case of the biochemical route. Other quantitative differences which arise from the location of a potential biorefinery are independent of the scenario. In a Greenfield scenario where the plant is built on unsealed ground, the potential impacts are by far higher than in a Brownfield scenario where the plant is built in a former industrial area.

We conclude that **it is important to consider land use and water use** (resource depletion: water) **as part of the comprehensive set of environmental impact categories** when evaluating biorefineries and other biomass-based systems.

SUPRABIO vs. conventional systems

Apart from the local environmental impacts associated with the bio-based product, the **impacts associated with the substituted conventional reference product are decisive**.

Since the environmental burden associated with the latter is avoided, the avoided expenditures/emissions are credited to the bio-based product. Since the type of risks associated with the biomass-based systems and conventional (mostly petroleum-based) systems are completely different in quality and quantity, a direct comparison is not possible. However, a comparison of impacts at the level of environmental factors is feasible.

Regarding local environmental impacts, the comparison of SUPRABIO products to conventional products shows that the **land use impact of biomass provision is orders of magnitude higher than the land use impact of conventional (fossil) feedstock provision** – provided that crude oil extraction from conventional petroleum deposits is considered. The picture might change, though, if unconventional petroleum deposits such as oil sands were chosen as reference system. In general, the environmental impacts related to the provision of biomass feedstock are expected to be mostly reversible – as long as the main precondition underlying this assessment (no land use changes) is fulfilled. In contrast to that, most of the impacts from conventional (fossil) feedstock provision are expected to be long-term and non-reversible. **As regards raw material conversion, the land use impacts of SUPRABIO biorefineries and conventional refineries is comparable.**

In terms of water use, the drain of water resources by biorefineries likely exceeds the one by conventional refineries – at least in case of the biochemical route. This could cause negative impacts in water-scarce regions, especially during the hot season.

SUPRABIO vs. other biomass-based systems

In Europe, arable land is limited. Due to a small-scale agricultural landscape, the availability of large quantities of uniform feedstock (and thus the possibility of providing it to a future biorefinery) is limited as well. Moreover, in regions where suitable feedstock is available in relevant quantities (e.g. wood in central Germany, cereal straw in northern France and northern Germany), competing uses are being established. For example in case of forest residues, the use of log wood for domestic heating might even increase.

Therefore, the implementation of large biorefineries (capacity of 400 kt DM/a in 2025) bears risks. **From an LC-EIA point of view it makes sense to reduce plant capacities and to implement a configuration with distributed pre-treatment units.** This offers the chance to take different types of feedstock into account in order to react to market demands.

Comparing different land use options, it could be shown that

1. regarding feedstock provision, perennial lignocellulosic crops such as poplar short rotation coppice used for 2nd generation biofuels lead to fewer impacts on environmental factors than most annual crops used for 1st generation biofuels. Among the annual crops, particularly high impacts are associated with sugar beet cultivation. However, it has to be noted that sugar beet has a higher sugar yield per hectare than lignocellulosic crops. Moreover, it produces a feed co-product which reduces the net land use. In other words, there is a trade-off between magnitude and extent of impact.
2. regarding raw material conversion, differences between 1st and 2nd generation conversion technologies are very low from an LC-EIA point of view.

Regarding different use options of biomass residues, differences between conversion technologies e.g. a biorefinery and a CHP are very low from an LC-EIA point of view. Thus, a ranking of technologies is not possible.

6.1.3 Synopsis of conclusions from LCA and LC-EIA

LCA is a very versatile tool for the ex-ante evaluation of environmental impacts of products. Although methodological developments are under way, local environmental impacts are not yet covered in state-of-the-art LCA studies. Therefore a new methodology, termed life cycle environmental impact assessment (LC-EIA) methodology was developed and successfully applied in SUPRABIO, qualitatively capturing important impacts at local level which would have been omitted if only state-of-the-art LCA impact categories had been analysed. For example, LC-EIA underlines the importance of the biomass provision stage whereas LCA suggests that rather the core biorefinery processes (pre-treatment and main process) are responsible for the majority of the environmental impacts. **We conclude that – at least for the time being – LC-EIA is a useful supplement to LCA.**

Excursus for experts: LC-EIA as a supplement of the LCA

The life cycle environmental impact assessment (LC-EIA) has been successfully established as a supplement to LCA methodology. It allows capturing vital factors influencing local environmental impacts. In this context, LC-EIA provides robust answers on questions that currently cannot be given by LCA methods despite constant evolution. The main distinction stems from the fact that LC-EIA is able to include data in qualitative form that are not currently available for exact quantification, whereas quantitative data remains a requirement for LCAs. The purpose of LC-EIA is the identification of environmental risks and their subsequent evaluation for significance. Further, mitigation measures are recommended to inform pending decisions. This identification of relevant risks does not depend on the summing up of effects across the entire life cycle, the method applied in LCAs, which is superior in principal. However, this is not possible for qualitative differences between individual life cycle stages and their respective reference systems. Thus, a combination of LCA and LC-EIA may reveal additional insights relevant for decision makers. Supplemental LC-EIAs are particularly recommended for life cycle comparisons that include biomass utilisation as long as quantitative LCA methods remain immature, or the data the for rigorous application of these methods are unavailable. In addition, LC-EIAs provide a standard that may act as a gauge for the applicability and validity of novel quantitative methods.

To avoid confusion, please note carefully that LC-EIAs do not qualify as appropriate substitutes for formal environmental impact assessments (EIAs). The methodology may be similar; however, EIAs always address a specific project.

The main features of the LC-EIA approach can be summarised as follows:

- Intensity and resolution of the environmental effects can be arranged between the classical project-related EIA and the strategic environmental assessment (SEA).
- Outcomes of the LC-EIA are fully compatible to LCA. Results of the LC-EIA give a new quality to the environmental impact category "land use" within the standardised methodology of LCA, not only by balancing the area needed for the application of a new technology but additionally giving information on the quality of the land use change and its possible impacts on local environmental factors.
- LC-EIA is broadening the scope of EIA (as well as SEA) in terms of assessment of the whole life cycle. The local approach of classical EIAs usually prevents the inclusion of

local environmental effects outside of certain administrative boundaries and thus possibly neglects important environmental effects, e.g. on biodiversity.

- Due to the generic, technology-focussed approach, different scenarios can be assessed and compared more quickly and easily.
- Overall sustainability assessment of a new technology can be carried out more easily and the optimisation of technology-implementation by finding the best options or possible ways to remedy environmental effects can be done more effective.
- Within the framework of SUPRABIO and other related projects a comparable methodology for the analysis of biomass production and conversion is provided.

6.2 Limitations

Each study on potential future production systems, which will not only affect a singleproduct market but several sectors, is limited in its achievable accuracy. This chapter summarises those uncertainties and data gaps, which have been identified to have the biggest potential of changing the conclusions drawn from the results.

First of all, this study analyses plausible and consistent scenarios, which are based on modelled biorefineries, which themselves are based on extrapolations of experimental data on lab or pilot scale. This bears the risk of data inconsistencies when comparing these immature biomass-based systems to mature conventional reference systems operating at industrial scale. For example, hardly any information on emissions to air was available from the process flow sheets. We have therefore supplemented emission data based on our expertise. Data inconsistencies is also an issue regarding the evaluation of human und ecotoxicity which was not possible due to complete lack of (or at least questionable quality of) LCI data for 2025. These impact categories are potentially relevant in the case of bio-based products (especially during use phase), e.g. in the case of organic acids. This study does not intend to predict any probability whether these scenarios may be realised. Expected but not yet realised technological progress is part of the mature technology scenarios for 2025. Thus, these analyses are to be interpreted like “If X is reached and implemented until 2025, then impact Y results from it.”

The biggest uncertainty regarding environmental impacts of all scenarios involving land use is the extent and the consequences of indirect land use changes. Depending on many factors including global population growth and changing human diets due to economic development as well as agricultural productivity, effects can vary from negligible to dominant. This mainly influences the decision whether or how much cultivated biomass should be used for biofuel and bioenergy production. Unfortunately, methodological developments to quantify impacts of land use (and also water use) in LCA are still under way, i.e. these impact categories could not be covered quantitatively. At least, they were covered qualitatively by LC-EIA.

6.3 Recommendations

To industry

- The environmental performance of a biorefinery depends very much on the targeted product(s) and implemented processes. Of the assessed options, biofuels – both syngas-derived FT fuels and ethanol – should be preferred over the production of mixed acids for crop preservation. However, this result cannot be generalised. Bio-based materials often show higher potentials for environmental benefits than biofuels – always depending on technology and implementation conditions.
- Based on the scenarios assessed here, FT fuel production is more environmentally friendly than bioethanol production. It can be optimised to be similarly advantageous regarding climate change mitigation and savings of non-renewable energy but causes less disadvantages in terms of acidification or eutrophication.
- Optimisation of each process is crucial. Energy demand, consumption of nitrogen-containing inputs (for the biochemical route) and conversion efficiency are most important for the assessed processes. The highest energy demand is caused by product separation from the fermentation broth (ethanol production) or by water gas shift reaction and acid gas removal (FT fuel production). For bioethanol production, concrete optimisation potentials were identified regarding enzyme provision and performance as well as reduction of nitrogen inputs into the fermentation process. Nitrogen inputs should be limited to the amount necessary for sustaining microbial growth or by recycling microbial cell material. Moreover, other bases than N-containing ammonia should be used for pH adjustment. Furthermore, gasification of solid process residues prior to combustion is advantageous. For FT fuel production, high gasification pressures, high syngas input temperatures to the gas cleaning process, one central pyrolysis unit instead of five distributed ones, and provision of all steam via a combined heat and power plant are recommended.
- Choice of feedstock: Underutilised residues are to be preferred over cultivated biomass because these residues do not pose a risk of competition with food production and thus potential indirect land use changes. The potential of using lignocellulosic residues for fuel production is a genuine advantage of 2nd generation technologies. This advantage should be used especially in the context of rising public awareness (e.g. food vs. fuel debate). Otherwise, the choice of feedstock should be made according to local conditions and suitability for the used technology.
- HVO production shares environmental risks with biodiesel production because of the identical feedstock. From an environmental perspective, new biofuel processes should not be based on imported oil seeds that are currently on the market including palm oil, soybean oil or Jatropha oil because of a high risk of e.g. rainforest destruction for their production, be it direct or indirect. Fuel production from domestic seed oil is inefficient because of agricultural yields. Even process improvements in HVO production cannot overcome inherent problems of sustainable and efficient biomass provision for this process. Thus, decision makers should consider the risk that the development of new processes may result in a fuel that cannot be sold as environmentally friendly in the future.
- An integration of a 2nd generation biofuel plant with an algae production facility may result in yield challenges that are rather big compared to likely achievable gradual synergies

according to our qualitative analysis. Especially in the early implementation phase, such complex plants with potentially contrarious optimal operating conditions should be avoided.

To policy makers

Competition about biomass or land use between bio-based materials, chemicals, fuels and energy, as well as foodstuffs, fodder and nature conservation represents one of our most important societal challenges around biorefineries. New technologies such as 2nd generation biorefineries will increase the demand for biomass. This conflict must be actively managed with clear objectives. We specifically recommend the following measures:

- In the mid- to long-term, national and European **biomass allocation and land use plans** should be compiled. Because environmental burdens and social impacts of resource scarcity in particular do not possess an adequate price, market mechanisms cannot replace these plans.
- **Regional planning**, which comprises project planning guidelines, should be based on this premise. This framework should also rule out the cultivation of cultures that are unsuited to the local conditions. For example, the quantity of agricultural or forest residues that can be extracted without impairing soil fertility, depends on the location. Moreover, regional planning is also important because market participants with individual high biomass demand and large market power are created with the aid of public funding, and may be additionally created by establishing biorefineries. Distortions in the biomass market can and must be mitigated by appropriate planning.
- As long as this is not the case, binding area- and cultivation-specific **sustainability criteria** should be **uniformly defined** as preventive measures **for all applications**, that is for bio-based materials, chemicals, fuels and energy, as well as for food and feed.
- Following an initial phase necessary to establish the technology, **support for biorefineries** should be oriented around the reductions in environmental impacts actually achieved.
- Technologies that are flexible and less demanding regarding biomass input such as FT fuel production should be supported to reach industrial scale demonstration stage. That way, it can be tested whether the modelled performance can be reached in practise. If this is the case, FT fuel production from heterogeneous and long-term underutilised feedstocks such as biomass from landscape management could be an environmentally friendly option of fuel production.

Independent of biomass and land use competition, we recommend the following:

- Before mature industrial scale biorefineries are established on a large scale, a sustainability analysis for each specifically planned large facility should be mandatory. It cannot be replaced by generalised studies such as the one presented here. Because it is anticipated that lignocellulosic biofuel facilities will attract large investment volumes, the expense for such a sustainability analysis is justifiable in relation (estimated < 0.5 %). Certification towards the current European Renewable Energy Directive (RED) is not sufficient to cover all relevant environmental aspects such as whether the limiting resources biomass and agricultural land are efficiently utilised. For example, a biofuel from underutilised residues may be more sustainable than a biofuel from dedicated crops even if greenhouse gas emission savings according to RED should indicate the contrary.

- A project to provide a greenhouse gas calculation tool according to the RED should be initiated for 2nd generation biofuels (‘BioGrace III’). This is urgently needed to clarify ambiguities and create a safe investment climate. For example, greenhouse gas emissions calculated for 2nd generation ethanol within the KACELLE project cannot be compared to results given here as long as detailed background information on the calculations is not published /Persson 2014/.
- There is no need for new specific environmental regulations for early lignocellulosic fuel plants. They are of course to a certain degree less efficient than later implementations will be. Nevertheless, environmental effects are qualitatively the same and no substantially higher risks could be found.
- In the view of increasing demand for diesel-type and jet fuels especially for heavy transportation and aviation in the future, a strategy should be implemented to develop renewable fuel(s) of that type to market readiness. Unless more promising technologies can be developed to a similar stage as FT fuels in the coming years, an industrial scale demonstration plant for FT fuels would be the next step to take – as it has been done for 2nd generation ethanol e.g. by Biochemtex in Crescentino, Italy.

To research

One original aim of SUPRABIO was to combine the production of high volume / low value products such as fuels with low volume / high value products. This aim continues to promise environmental advantages although the approaches in SUPRABIO were no immediate success. The following lessons could be learned from this project for further research in this direction:

- A competition of high volume / low value and low volume / high value products for the same feedstock fraction, as it is the case for ethanol production and the production of mixed acids, should be avoided.
- Complex integration of two largely independent and both very innovative units such as a lignocellulose-based biochemical biorefinery with algae production may cause more disadvantages through incompatibilities than advantages due to cascading use of nutrients, water and heat. As the evaluation of this combination could only be based on a qualitative environmental analysis of preliminary results, a later quantitative analysis is recommended if new research results instead suggest substantial potential synergies.
- Synergies should be aimed at through production of high value products from complex molecules that are present in the feedstock. These products have a high potential to replace conventional products that would require complex and energy-intensive syntheses otherwise, which can create high environmental advantages. In the case of lignocellulosic biomass, this mainly applies to lignin-based products, which could replace phenol derivatives. Although this could be successfully demonstrated for lignin originating from the Organosolv pre-treatment /Rettenmaier et al. 2013/, SUPRABIO lignin from steam explosion turned out not to be suitable for material use as without further processing. Nevertheless, any promising option towards this direction should be investigated further because a combination of energy-efficient steam explosion with

material use of lignin would be a big achievement – as long as lignin purification or modification does not require extraordinarily high energy or material inputs. In contrast, the thermochemical approach is less suitable for the integration with low volume / high value products because all potentially valuable compounds within the biomass are broken down into small and rather simple molecules in the initial pyrolysis step.

7 Abbreviations

Abbreviation	Explanation
1G	First generation
2G	Second generation
ASP	Activated sludge process
CHP	Combined heat and power (plant)
DHA	docosahexaenoic acid , an omega-3 fatty acid
DM	Dry matter, further specification for mass units; often used as tonne DM (→t)
DME	Dimethyl ether
EDBM	electrodialysis using bipolar membranes
EIA	Environmental impact assessment
EPA	eicosapentaenoic acid, an omega-3 fatty acid
eq.	equivalent
FT (diesel)	Fischer-Tropsch (diesel)
GHG	Greenhouse gas(es)
GMO	Genetically modified organism
ha	Hectare (10^4 m^2)
HVO	Hydrogenated Vegetable Oil; liquid biofuel made by hydrotreatment of vegetable oil
IE	Inhabitant Equivalent, yearly environmental impact of an average European (EU27)
ILCD	International Reference Life Cycle Data System
iLUC	Indirect land use change
ISO	International Organization for Standardization
kt	Kilotonne, 1000 tonnes (10^6 kg)
LCA	Life Cycle Assessment
LC-EIA	Life Cycle Environmental Impact Assessment
LCI	Life cycle inventory (phase 2 of LCA)
LCIA	Life cycle impact assessment (phase 3 of LCA)
odt	oven dry tonne
ReCiPe	A method for life cycle impact assessment (→LCIA)
RED	Renewable Energy Directive, EU directive 2009/28/EC
REED	reversed electro-enhanced dialysis
RO	Reverse osmosis
SEA	Strategic environmental assessment
SHcF	Separate hydrolysis and co-fermentation
SOC/SOM	Soil organic carbon / soil organic matter
SRC	Short rotation coppice
SSF	Simultaneous saccharification and fermentation
t	(Metric) tonne (10^3 kg)
UF	Ultrafiltration
VFA	Volatile fatty acid
WP	Work package
WWT	Waste water treatment
yr	Year

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9 Annex

This annex contains additional descriptions of alternative biomass and land use options (chapter 9.1), a summary of important input data for the screening LCA (chapter 9.2) and additional results from screening LCA and LC-EIA (chapters 9.3 and 9.4, respectively).

9.1 Details on alternative biomass-based systems

The following systems are assessed as alternatives to SUPRABIO (see also chapter 3.2.2):

Direct combustion

Biomass is dried if necessary and chipped / crushed. Then it is burned for heat generation using conventional technology (no prior gasification). The bandwidth of scenarios includes direct combustion of lignocellulosic biomass in existing biomass power plants without heat use, existing combined heat and power (CHP) and more efficient state of the art CHP plants. The following efficiencies were set for the scenarios:

Table 9-1 Efficiencies for direct combustion scenarios

Efficiency	Power plant	CHP plant	State of the art CHP
Electric	26 %	17 %	28 %
Thermal	-	54 %	61 %
Total	26 %	71 %	89 %

Scenarios are based on the setting that heat and power from a marginal mix of conventional (fossil fuel based) plants are replaced.

Sugar beet, wheat grains and maize grains

These agricultural biomass feedstocks are converted into first generation bioethanol via alcoholic fermentation. To this end, sugar or starch are extracted form beets and grains, respectively. Starch is hydrolysed into sugars while the extracted sugar is directly used for fermentation. The produced bioethanol replaces gasoline. Co-products of the bioethanol production are used as feed. For wheat bioethanol, the additional co-product gluten is used in food production and straw remains on the field. All co-product uses result in credits of avoided burdens from the production of replaced conventional products.

Maize (whole plant)

Whole maize plants are harvested, ensiled and used as feedstock for biogas production. The biogas can be used in various ways. In the scenario assessed here, it is used to produce heat and power in a small combined heat and power (CHP) unit. This bioenergy replaces heat and power from a mix of conventional sources. Fermentation residues are used as fertiliser and replace mineral fertiliser.

Triticale (whole plant)

Triticale is a hybrid of wheat and rye, which can be used for bioenergy generation via direct combustion in a combined heat and power (CHP) unit. For this purpose, the whole plant is harvested including straw. The produced bioenergy replaces heat and power from a mix of conventional sources.

Rapeseed (biodiesel)

Rapeseed is the main feedstock for biodiesel in Europe. Rapeseed oil is converted into fatty acid methyl esters by transesterification and then used instead of conventional diesel. Co-products are used as feed (rapeseed meal) and in cosmetics (glycerol), respectively.

Rapeseed (HVO)

Alternative to biodiesel production, rapeseed oil can be converted into hydrogenated vegetable oil (HVO), which is used as transportation fuel instead of conventional diesel, too. In this process, hydrogen is used to reduce the plant oil to saturated paraffinic oils and propane. Co-products are used as feed (rapeseed meal) and as substitute for petroleum based naphtha (short chain paraffinic oils), respectively.

Palm oil (HVO)

Palm oil is an alternative imported feedstock for European HVO plants. The conversion process of oil to HVO is largely identical to that for rapeseed oil. Main differences arise from cultivation and the oil mill process in palm oil producing countries such as Malaysia and Indonesia. Co-products are used for production of detergents (palm kernel oil) and as feed (press cake). In many places, rain forests are cleared for establishing oil palm plantations. Depending on the region, some of these cleared rainforests grow on peat land, which leads to additional emissions because the exposed peat degrades over time. Therefore, three scenarios are analysed: without LUC, with LUC: rainforest, with LUC: rainforest on peat land

Soy oil (HVO)

Another imported feedstock for HVO production is soy oil. Like for palm oil, cultivation and the oil mill processes are specific for the feedstock but the conversion process to HVO is identical. The main co-product is soybean meal, which is a valuable feed product. Also for soybean cultivation, natural ecosystems with high carbon stocks accumulated in the vegetation are cleared in some places. As an example, a scenario depicting clearing of rainforests is analysed additionally to the scenario without LUC.

9.2 Summary of quantitative input data for screening LCA

Selected quantitative input data for the LCA calculations that are not documented elsewhere (see chapter 4.1.4) are summarised in this chapter.

9.2.1 Biomass provision

In the LCA part of this study, the biogenic feedstocks of the main scenarios are assessed in the following ways:

- Agricultural residues: wheat straw
  The main expenses for cultivating wheat are completely attributed to the harvested grains because straw is a co-product, which currently is unused to a significant degree. Only the additional environmental impacts compared to the reference systems described below are attributed to the harvested straw.
  The reference system is ploughing in. If straw is not ploughed in but harvested, an additional demand for mineral fertiliser in the next cropping period is created. The environmental burdens of the production of the fertiliser and of the straw harvesting and baling are counted as expenses for the straw.
- Forest residues:
  This residue is extracted from forests during thinning or harvest operations as a co-product of stem wood extraction. Compensatory fertilisation after residue extraction is not part of the scenarios as this is not required in many forests. However, in some forests this may become necessary depending on soils, nutrient deposition and extraction rates. The reference system is leaving the residues in the forest to decompose.
- Agricultural biomass: Poplar short rotation coppice (SRC)
  Poplar is a perennial plant that is cultivated as SRC mainly on agricultural land, which would be suitable for many other crops, too. The default reference system is non-rotational fallow land. The rotational set-aside land does not accumulate significant amounts of carbon stocks. The temporary carbon stocks, which build up during the cultivation of poplar are considered negligible.

Provision of agricultural feedstocks is modelled according to /Müller-Lindenlauf et al. 2014/.

Table 9-1 Background data on agricultural processes for 2025

	Units (per ha · a)	Wheat straw	Forest residues	Poplar SRC
Seedlings	kg	(none: co-product)	(none: co-product)	25
Fertiliser				
N	kg	14	none	17
P_2O_5	kg	7	none	27
K_2O	kg	33	none	55
CaO	kg	11	none	81
Crop protection	kg	(none: co-product)	none	0.1
Diesel fieldwork	l	5	8	36
Yields				
Biomass	t (dry matter)	2*	1**	12
Water content	% of fresh matter	14%	20%	50%

*: The yield for wheat straw represents the average annual harvest based on one harvest every third year. On average, wheat straw can be harvested only every third year to preserve the soil organic carbon content depending on local soil quality. See chapter 5.2.1.1 for details.

**: The yield varies strongly depending on local conditions and previous management practise. Therefore, expenditures are exemplarily given per tonne of dry wood.

9.2.2 Process-specific data on biomass conversion

All processes that are assessed quantitatively in this report have been modelled and described in detail in previous confidential deliverables /Nygård et al. 2013/, /Ljunggren et al. 2013/, /Ochoa-Fernández et al. 2013/. Here, product outputs of main scenarios are summarised as most important process specific data. For confidentiality reasons, more details cannot be disclosed.

Table 9-2 Product and co-product outputs of main scenarios

Scenario	(Co-) Products	Amount per t of biomass (dry matter)
Straw to Ethanol (2015)	Ethanol	310 kg
	Electricity	250 kWh
Straw to Ethanol (2025)	Ethanol	340 kg
	Electricity	350 kWh
Poplar to Ethanol (2025)	Ethanol	250 kg
	Electricity	650 kWh
Straw to Propionic acid (2025)	Propionic acid	330 kg
	Butyric acid	0 kg
Straw to Butyric acid (2025)	Propionic acid	290 kg
	Butyric acid	230 kg
Forest residues to FT fuels (2015)	FT diesel	34 kg
	FT gasoline	37 kg
	Electricity	110 kWh
Forest residues to FT fuels (2025)	FT diesel	52 kg
	FT gasoline	42 kg
	Electricity	100 kWh
Forest residues to DME (2025)	DME	186 kg
	Electricity	30 kWh
Straw to FT fuels (2025)	FT diesel	41 kg
	FT gasoline	33 kg
	Electricity	70 kWh
Poplar to FT fuels (2025)	FT diesel	43 kg
	FT gasoline	35 kg
	Electricity	80 kWh

Energy content of fuels: Ethanol 27 MJ/kg, FT diesel 44 MJ/kg. FT gasoline 44 MJ/kg, DME 28 MJ/kg

9.2.3 Background process data

Most background process data stems from the ecoinvent database /ecoinvent 2010/ as agreed in the harmonisation process between the projects SUPRABIO, EUROBIOREF and BIOCORE.

Energy consumption and production were assessed in the following way:

Net consumed electricity was assessed using an average European power mix equivalent to those, which are part of the background data on other processes like provision of input chemicals. In almost all scenarios, biorefineries do not show electricity consumption but substantial net electricity production. This output was assessed according to the marginal concept (see also chapter 3.1.5.2). A marginal power mix for 2025 was used based on 50 % natural gas and 50 % hard coal with a share of 25 % cogeneration and efficiency gains of 5 % from 2010 to 2025.

9.3 Additional results from screening LCA

Life cycle assessment results regarding all assessed environmental impact categories for the main scenarios , which had to be omitted in the results chapter 4.2 for space reasons, can be found in this chapter. Please see chapter 4.2 for examples how to read these graphs and an interpretation of the results.

Results of individual life cycle steps are shown as wide coloured bars and net results are shown as thin white bars. An overview of all scenario names can be found in chapter 3.1.6.

9.3.1 Biochemical route

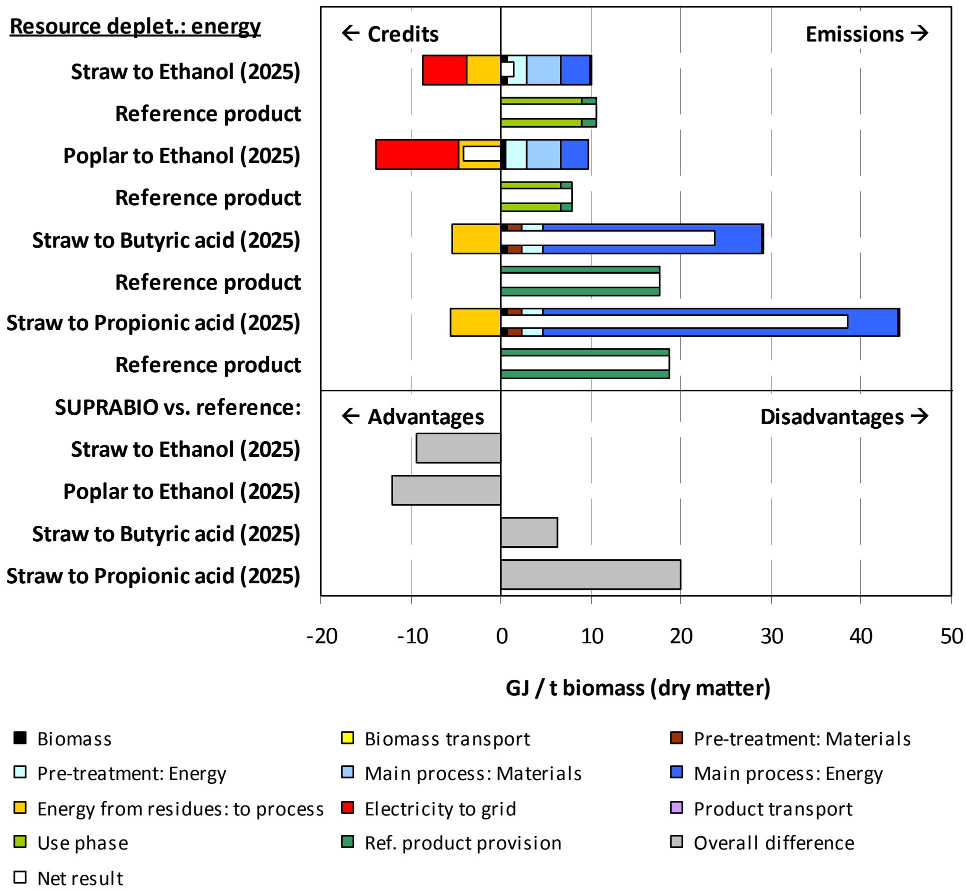
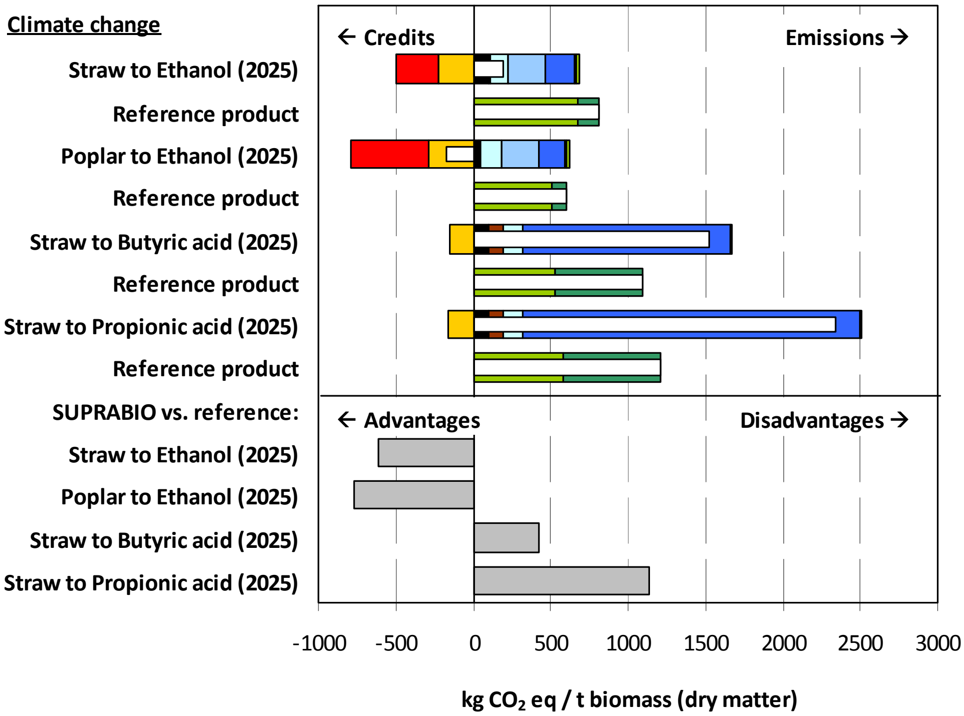


Fig. 9-1 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenarios “Straw to ethanol (2025)”, “Poplar to ethanol (2025), “Straw to butyric acid (2025)” and “Straw to propionic acid (2025)” (scenarios II, III, IVa and IVb, respectively) and their reference products for all investigated environmental impact categories. Pairs of life cycles are compared in form of an overall difference.



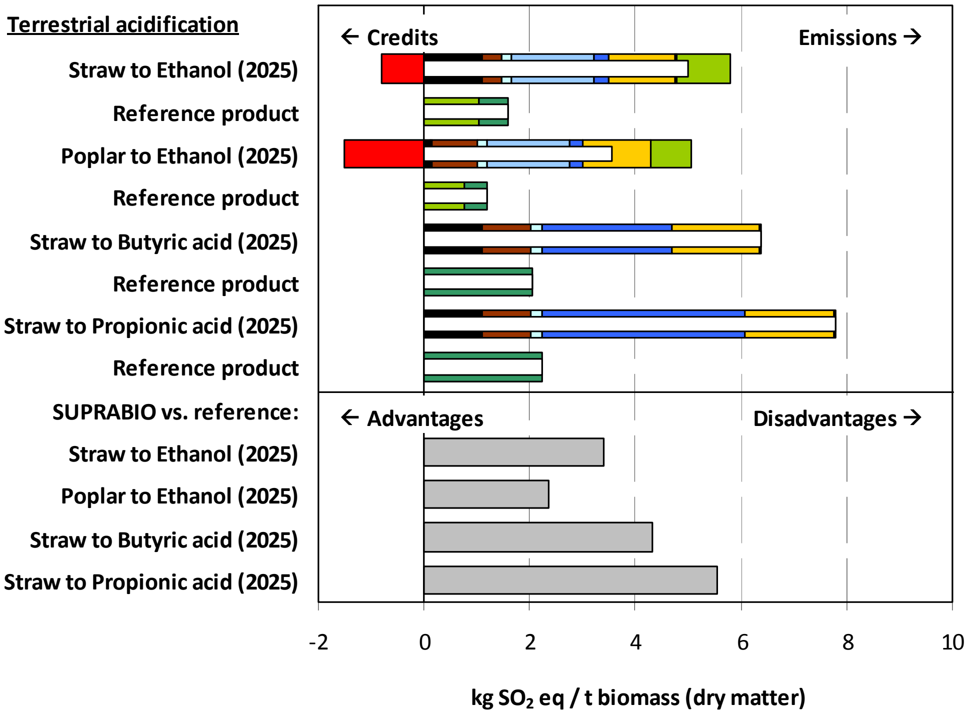
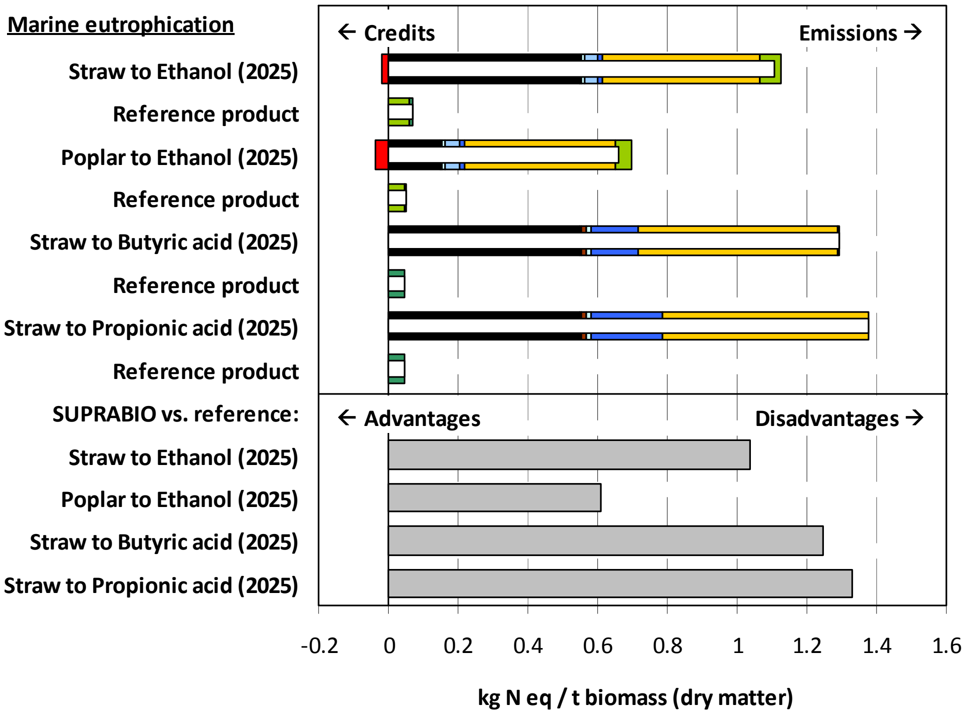


Fig. 9-1 (continued)



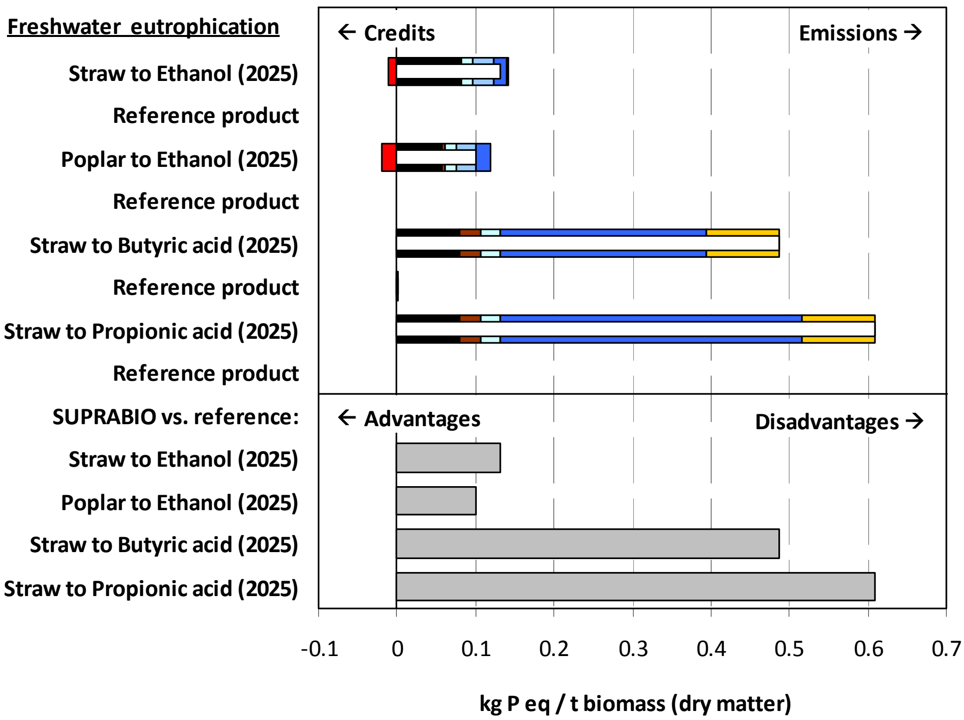
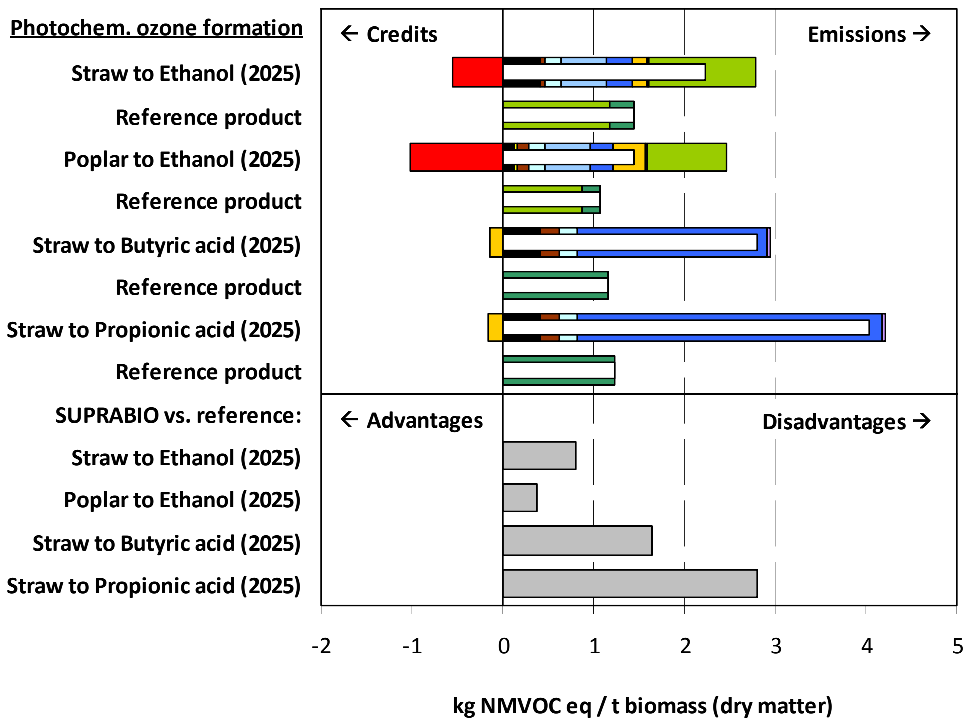


Fig. 9-1 (continued)



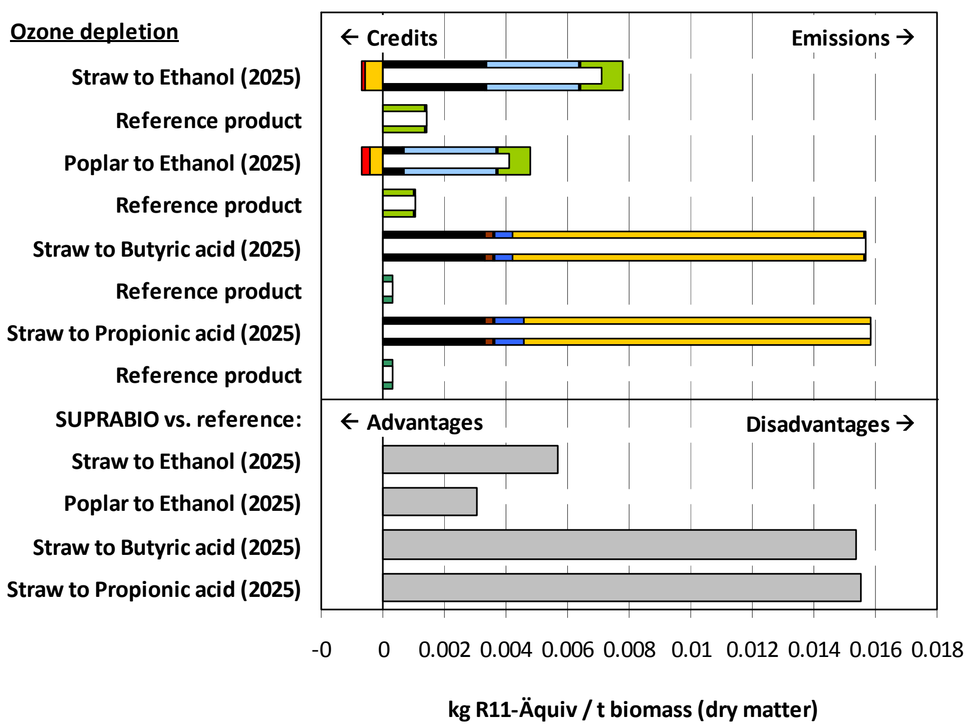


Fig. 9-1 (continued)

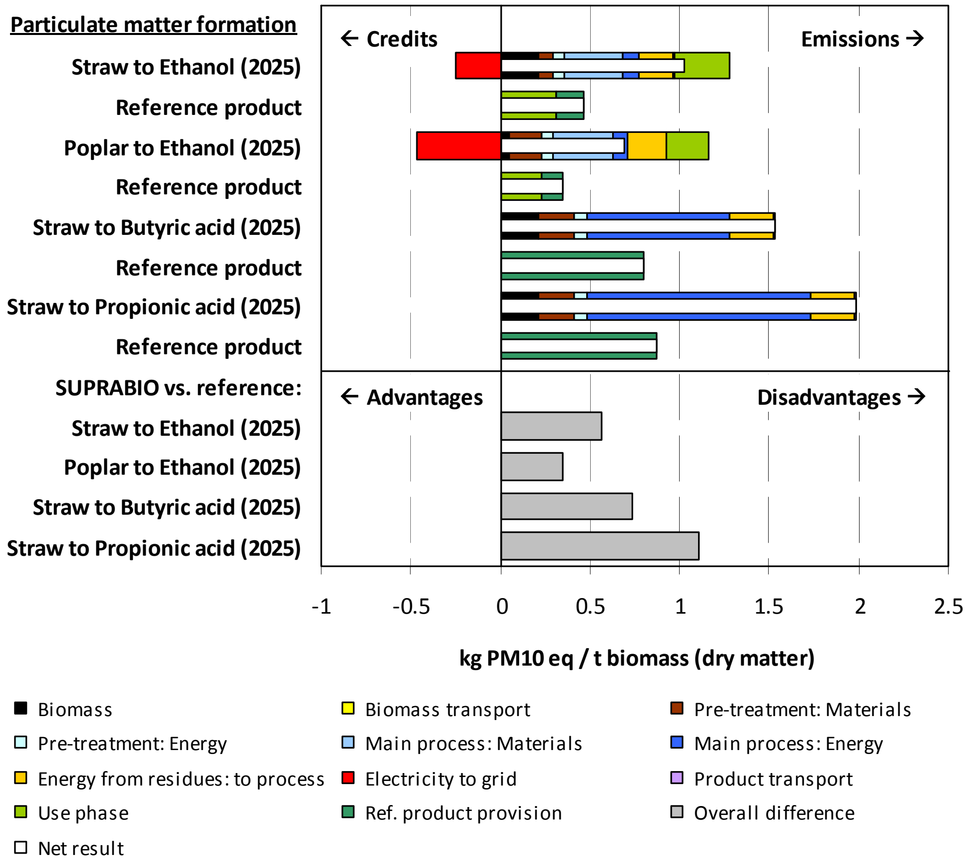


Fig. 9-1 (continued)

9.3.2 Thermochemical route

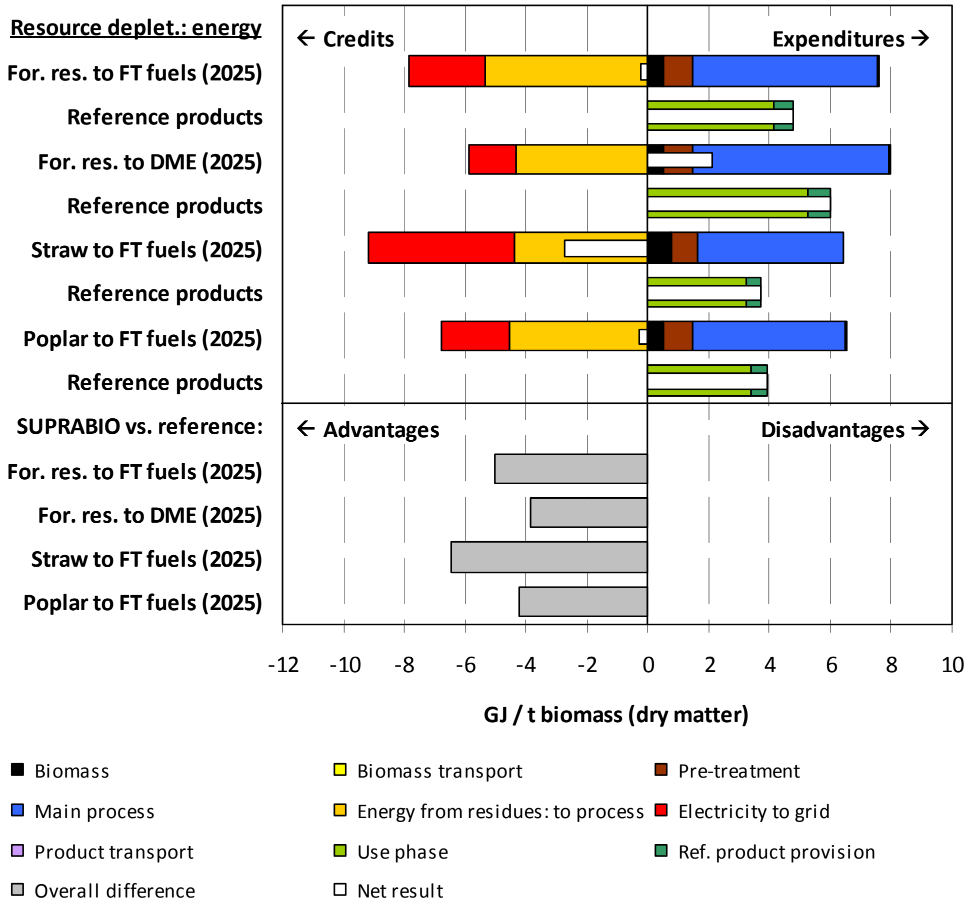
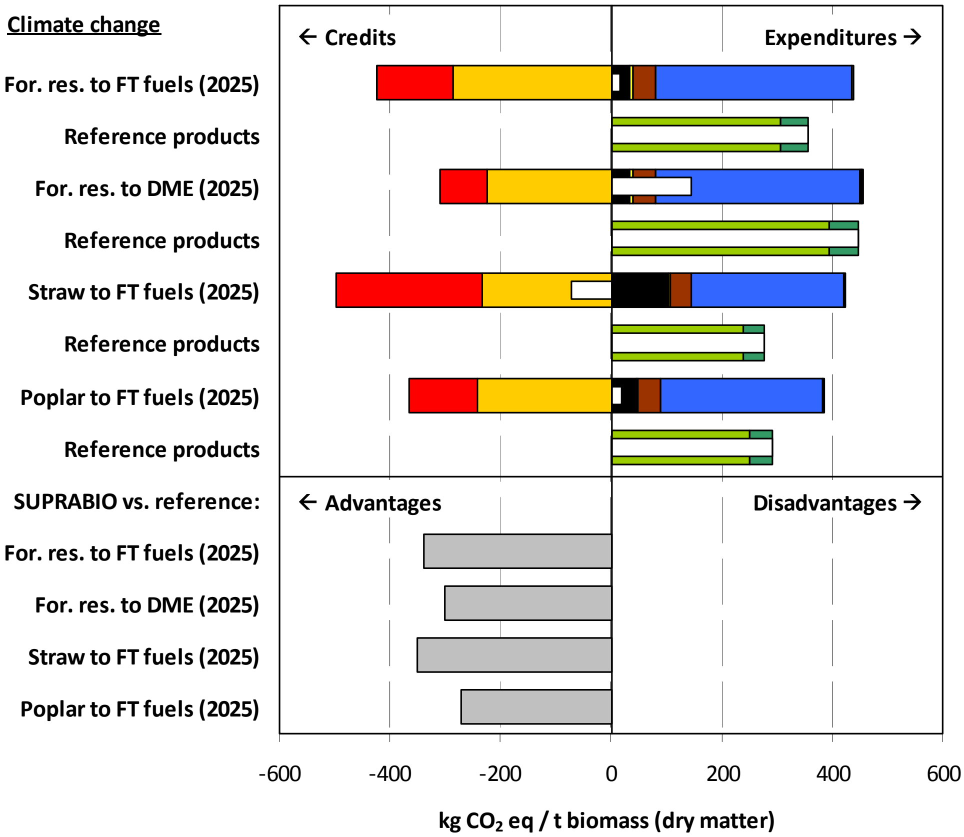


Fig. 9-2 Contributions of individual life cycle steps to the overall net results of the SUPRABIO scenarios “Forest residues to FT fuels (2025)”, “Forest residues to DME (2025)”, “Straw to FT fuels (2025)” and “Poplar to FT fuels (2025)” (scenarios II, III, IV and V, respectively) and their reference products for all investigated environmental impact categories. Pairs of life cycles are compared in form of an overall difference.



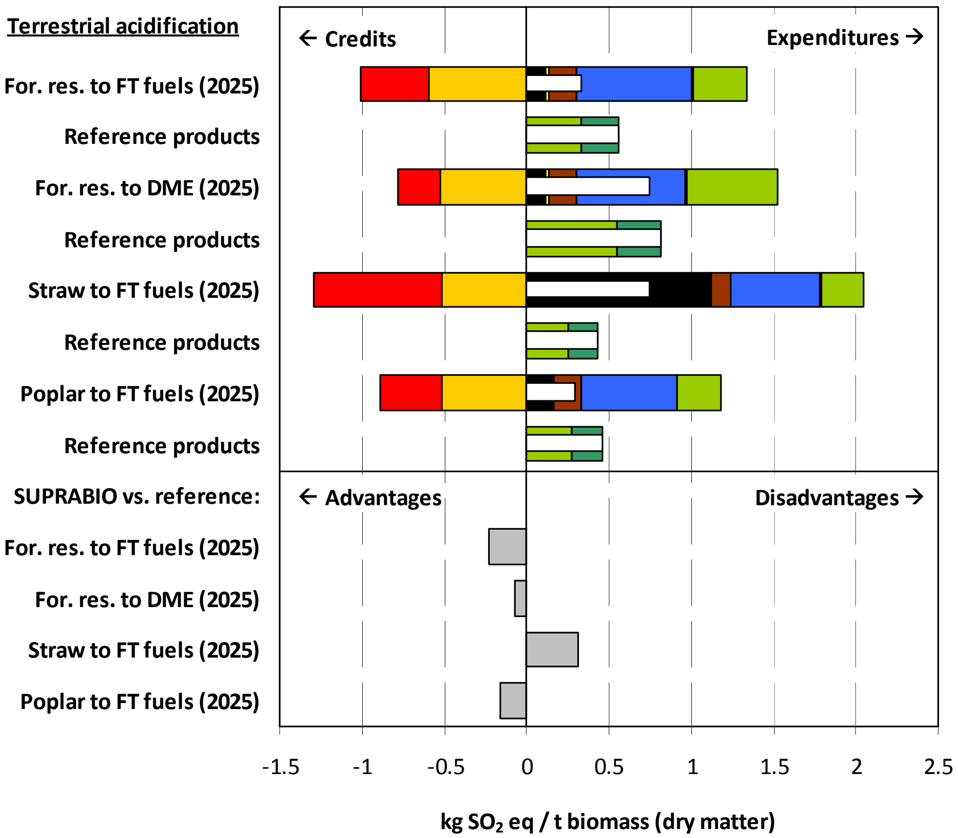
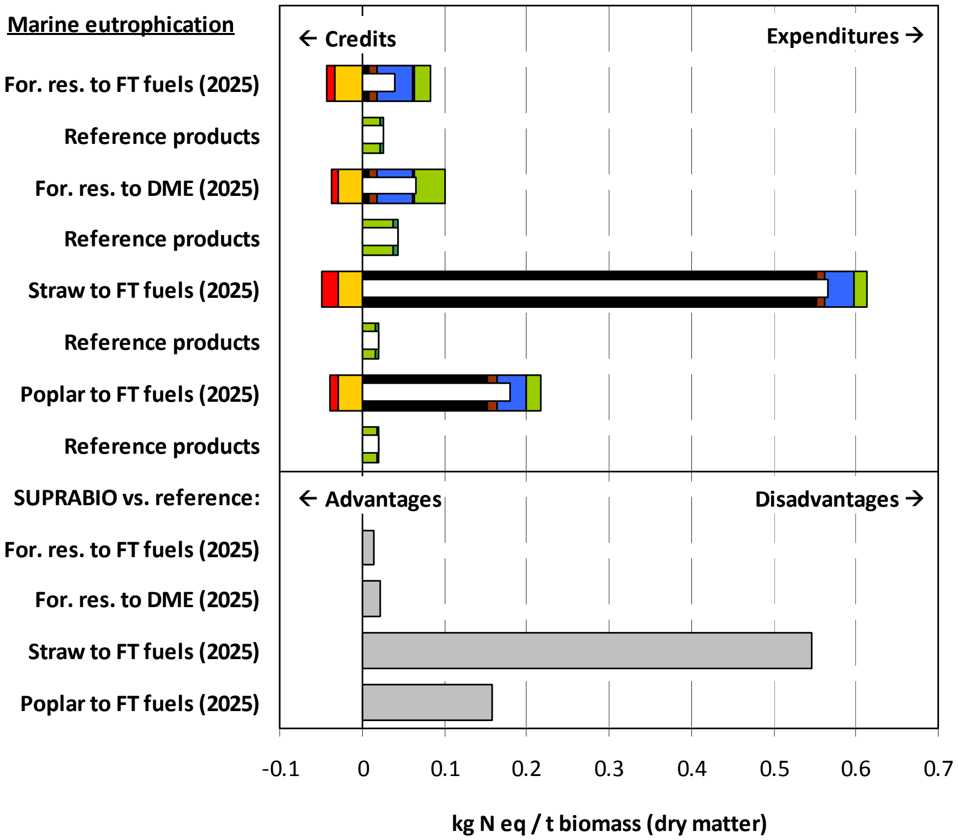


Fig. 9-2 (continued)



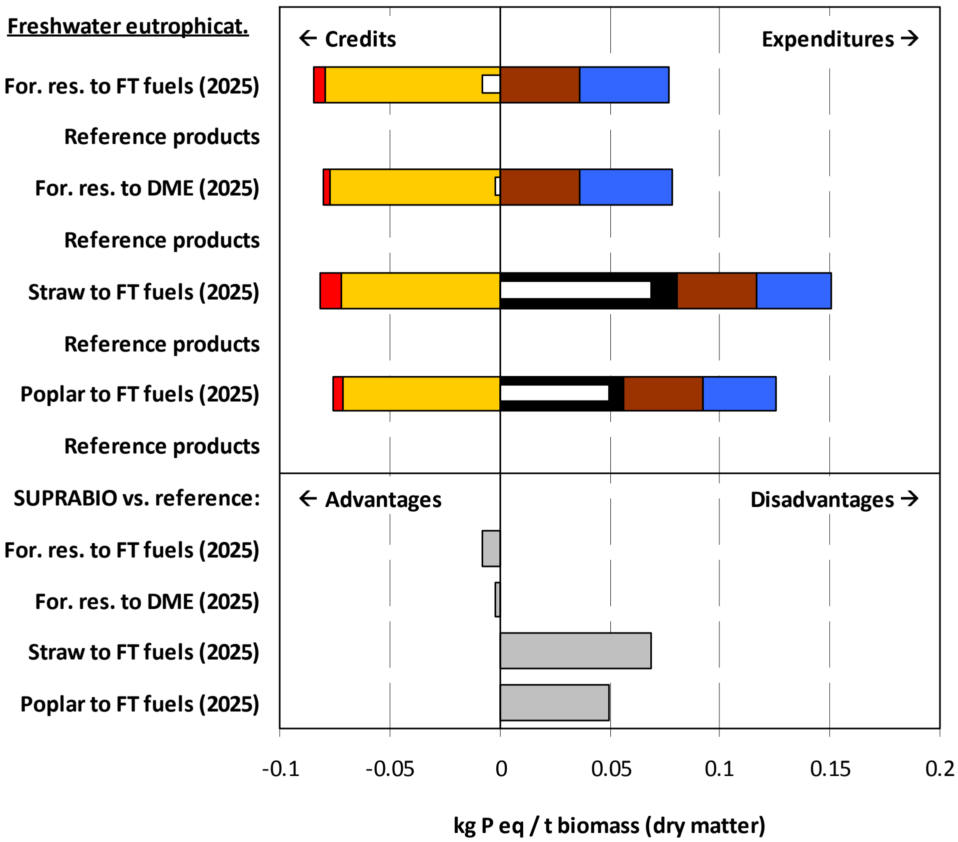
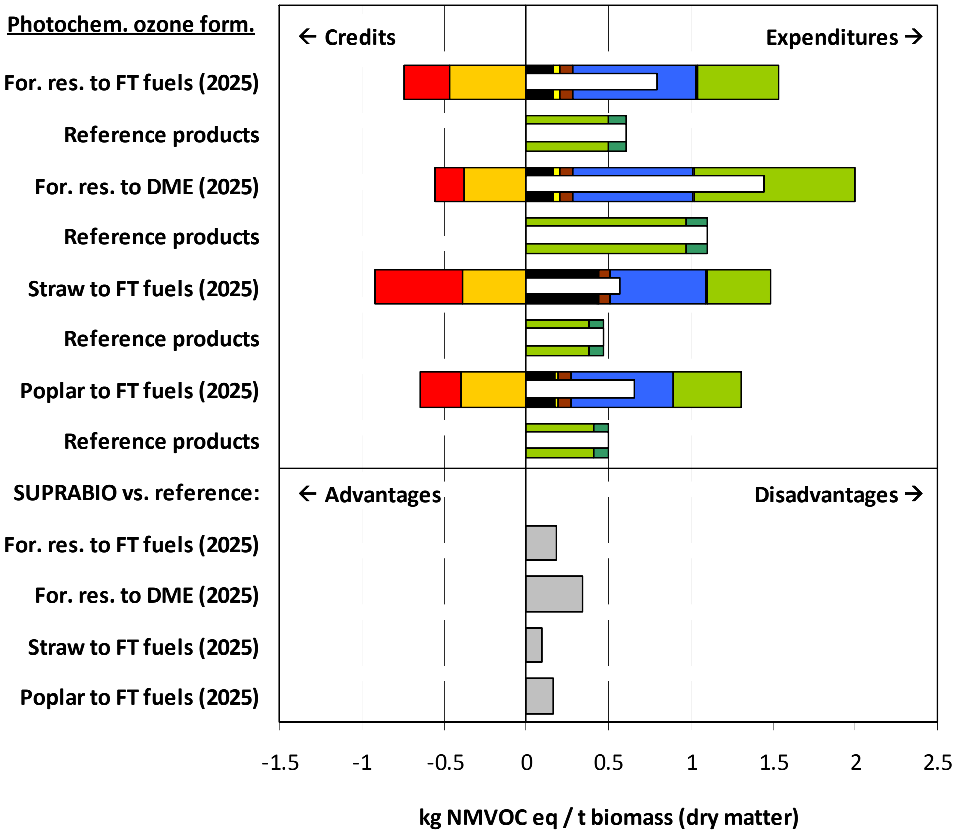


Fig. 9-2 (continued)



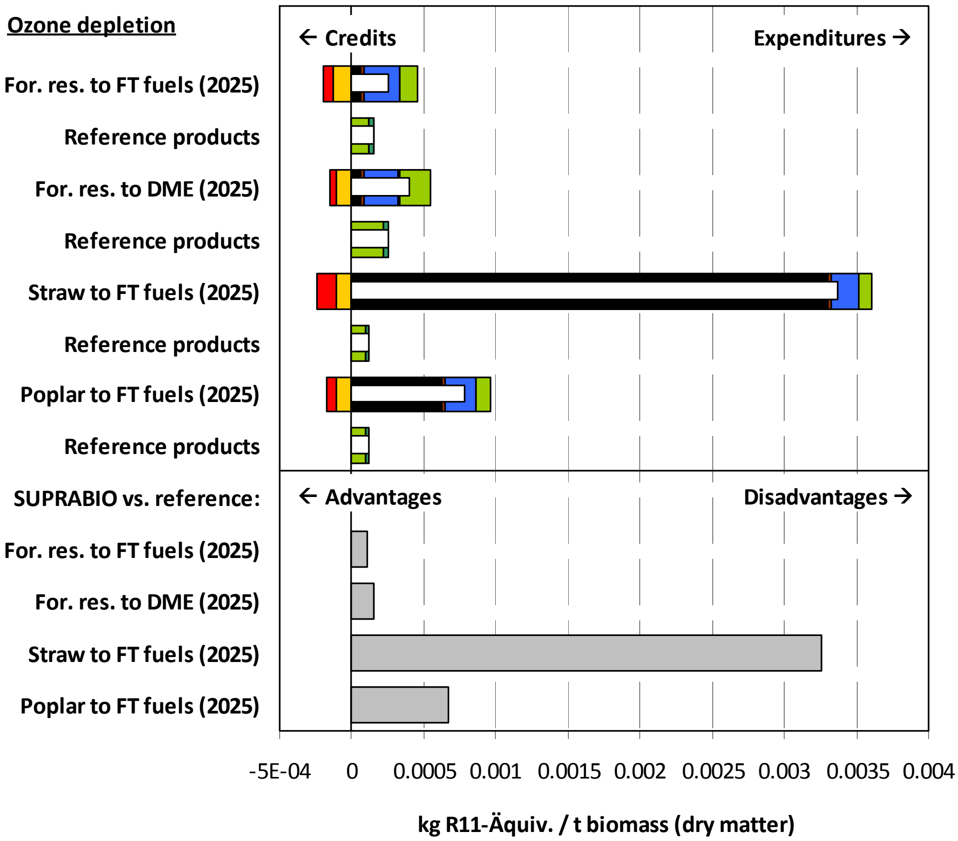


Fig. 9-2 (continued)

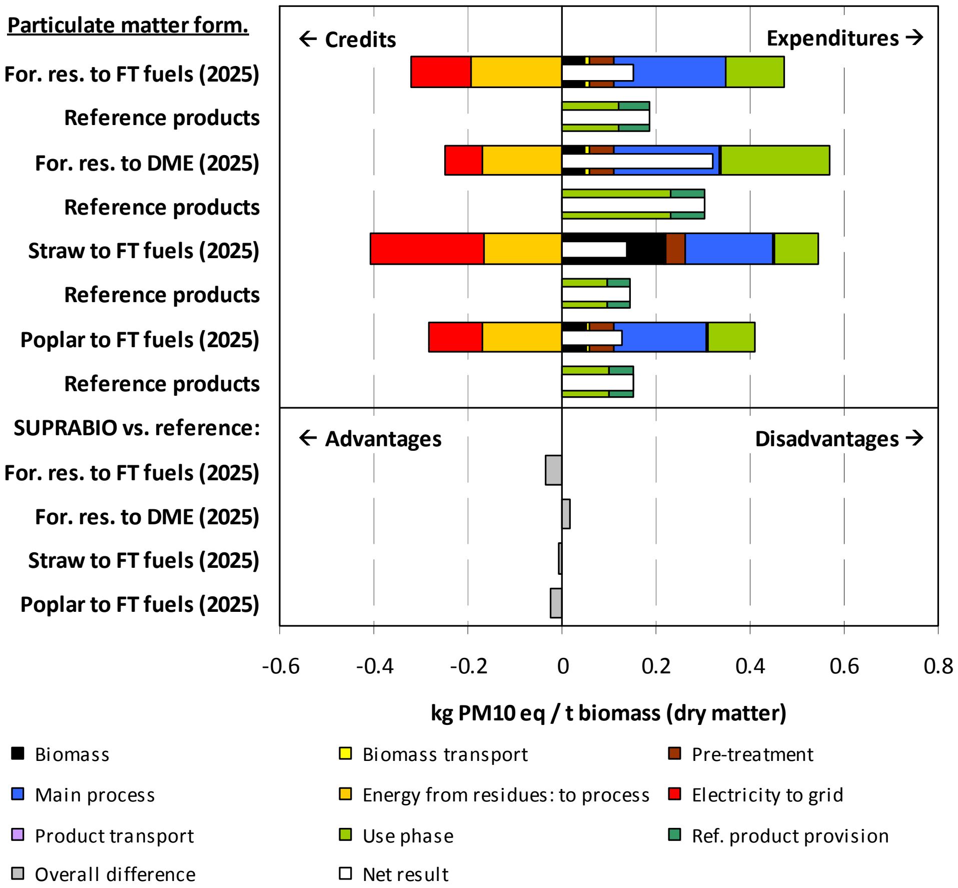


Fig. 9-2 (continued)

9.4 Local environmental impacts of alternative crops

In the following chapter, detailed information and impact matrices on the alternative feedstock crops can be found. Due to limited space, they were not presented in chapter 5.3.2, but only summarised in a table.

9.4.1 Sugar beet

The cultivation of sugar beet e.g. for bioethanol production requires a high soil quality. Highest yields are achieved on deep soils with homogenous structure. As the young plants are endangered by overgrowth from the surrounding arable flora an intensive weed control is required. Due to a high number maintenance cycles and heavy vehicles (e.g. high applications of fertiliser [120-160 kg N / ha], need of weed and pest controls) there is a high risk of soil compaction. A consequence is an increased risk of nutrient leaching, affecting both groundwater and superficial water, especially by runoff during heavy precipitations. Ploughing of leaves after harvesting in fall will not compensate the loss of nutrients in total (fruit : leave ratio ≈ 1,2 : 0,8 /Schlegel et al. 2005/), so additional supply of organic fertiliser is necessary for soil balance. Intensive processing, use of heavy machines for the application of fertiliser and weed control in combination with the risk of erosion due to late soil coverage can affect plant and animal diversity. Thus succeeding crops (e.g. legumes, winter wheat) are recommended and help to minimise erosion. Potential impacts on landscape are comparable to the reference system of non-rotational fallow land.

Loss of habitat types and species might cause impacts if there is a change in habitat quality e.g. woodland is converted to arable land. The cultivation of sugar beet on arable land is not expected to cause a loss of habitats. Table 9-3 summarises the risks associated with cultivation of sugar beet on the environmental factors.

Table 9-3 Risks associated with the cultivation of sugar beet (ploughing of leaves) compared to the reference system of non-cropping (rotational fallow land)

Type of risk	**Affected environmental factors**								
	Soil	**Ground water**	**Surface water**	**Plants / Biotopes**	**Animals**	**Climate / Air**	**Land-scape**	**Human health and recreation**	**Bio-diversity**
Soil erosion	negative[1]		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of soil organic matter	**neutral / negative**[1,2]			**neutral / negative**[1,2]	**neutral / negative**[1,2]				**neutral / negative**[1]
Soil chemistry/ fertiliser	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Nutrient leaching		negative	negative						
Water demand		negative		negative	negative				neutral
Weed control / pesticides'		negative	negative	negative	negative				negative
Loss of landscape elements				neutral	neutral	neutral	neutral	neutral	neutral
Loss of habitat types				**neutral / negative**[1]	**neutral / negative**[1]				**neutral / negative**[1]
Loss of species				**neutral / negative**[1]	**neutral / negative**[1]				**neutral / negative**[1]

1: Negative impact can be minimised in case of crop rotation (succeeding crop), e.g. winter wheat;
2: Ploughing of leaves is usually not enough to compensate loss of nutrients)

9.4.2 Wheat grains

Wheat besides maize is used for 1st generation ethanol production and thus an important feedstock for the production of biofuels. In Canada, 15 % of the ethanol produced by fermentation comes from wheat. In Europe and Australia, wheat is the primary feedstock considered for expansion of the starch-based ethanol industry /Drapcho et al. 2008/. Due to intensive maintenance cycles the cultivation of wheat is basically linked with negative impacts on the environment if compared to fallow land as a reference system. Intensive cultivation and maintenance is responsible for soil compaction and as a consequence impacts on plants / biotopes and animals are expected. For bioethanol production winter grain is favoured as biomass yields are higher due to a longer vegetation periods. The impact on soil in case of winter grain is less in comparison with sugar beet and maize, as soil coverage during winter minimises the risk of erosion /Schlegel et al. 2005/. Succeeding crops like Sorghum or maize can help to minimise erosion effects due to uncovered soil. Soil and groundwater will additionally be affected due to intensive maintenance, use of fertiliser as well as weed and pest control. Especially the need of fungicides is relatively high in case of grain production An additional issue might be the regional scarcity of groundwater for irrigation at least part time of the year, as it is for example in Punjab / India (see e.g. /Doublet et al. 2012/). Table 9-4 summarises the risks on the environmental factors associated with cultivation of wheat compared to rotational fallow land as reference system.

Table 9-4 Risks associated with the cultivation of wheat (straw left on the field (ploughing)) compared to the reference system of "non-cropping" (rotational fallow land)

Type of risk	**Affected environmental factors**								
	Soil	**Ground water**	**Surface water**	**Plants / Biotopes**	**Animals**	**Climate / Air**	**Land-scape**	**Human health and recreation**	**Bio-diversity**
Soil erosion	**neutral / negative**[2]		negative						
Soil com-paction	negative	negative		negative	negative				negative
Loss of SOM	**neutral / negative**[2]			**neutral / negative**[2]	**neutral / negative**[2]				negative
Soil chemistry / fertiliser	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Nutrient leaching		negative							
Water demand		negative		negative	negative				neutral
Weed control / pesticides		**neutral / negative**[1,2]	**neutral / negative**[1,2]	**neutral / negative**[1,2]	**neutral / negative**[12]				**neutral / negative**[1,2]
Loss of landscape elements				neutral	neutral	neutral	neutral	neutral	neutral
Loss of habitat types				**neutral / negative**[1,2]	**neutral / negative**[1,2]				**neutral / negative**[1,2]
Loss of species				**neutral / negative**[1,2]	**neutral / negative**[1,2]				**neutral / negative**[1,2]

1: Negative in case of short-stalked varieties; long-stalked varieties afford less weed control
2: Negative impact can be minimised by crop rotation;
e.g. winter wheat and / or double cropping

9.4.3 Maize grain

Techniques and production conditions for maize grains e.g. for production of bioethanol do not differ from maize cultivation for feed or food production. As an essential difference to harvesting the total plant it is assumed, that maize straw is left on the field for green manuring thus reducing the amount of fertiliser (corn : straw ratio ≈ 1 : 1,3 /Kaltschmitt et al. 2009/). Due to high needs of nitrogen especially for the young plants the use of artificial fertiliser is still necessary on most soil types.

The chance of genetic engineering on maize (GMO) to optimise the output of grains might exist. As a market for GMO feedstock in Europe is relatively low it is not expected that GMO maize is grown in a considerable amounts. Nevertheless the risk exists although it is considered relatively low.

Risks of impacts on the environmental factors soil (erosion, compaction due to maintenance cycles), water (nutrient leaching and eutrophication) plants, animals and biodiversity (weed and pest control, monoculture) are effective as well. Table 9-5 summarises the risks of maize cultivation with use of grains.

Table 9-5 Risks associated with the cultivation of maize (ploughing of straw) compared to the reference system rotational fallow land

Type of risk	Affected environmental factors								
	Soil	**Ground water**	**Surface water**	**Plants / Biotopes**	**Animals**	**Climate / Air**	**Land-scape**	**Human health and recreation**	**Bio-diversity**
Soil erosion	negative		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of SOM	**neutral / negative**[1,2]			**neutral / negative**[1,2]	**neutral / negative**[1,2]				**neutral / negative**[1]
Soil chemistry / fertiliser	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Nutrient leaching		negative	negative						
Water demand		negative		negative	negative				neutral
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landscape elements				neutral	neutral	neutral	neutral	neutral	neutral
Loss of habitat types				**neutral / negative**[1]	**neutral / negative**[1]				**neutral / negative**[1]
Loss of species				**neutral / negative**[1]	**neutral / negative**[1]				**neutral / negative**[1]

1: Negative impact can be minimised in case of crop rotation (succeeding crop), e.g. winter wheat;
2: Ploughing of straw is usually not enough for a total compensation of nutrient loss

9.4.4 Maize (use of whole plant)

Due to high yields maize (C4-plant) is considered a valuable energy crop suitable both for bio-gasification and combustion. Requirements for soil quality are quite low although high yields are achieved on middle and heavy soils. As cultivation leaves the soil uncovered for quite a long time erosion effects are quite significant. In addition maize is known as a humus consumer thus affecting soil quality. Huge efforts have to be taken to balance humus quality e.g. the use of fertiliser, catch crops, crop rotation and return of fermentation residues. Additionally nitrogen fertiliser is necessary to provide sufficient yields with potential impacts on ground water (nutrient leaching) and superficial water (eutrophication during run of during heavy rain falls). Thus intensive maintenance cycles increase the risk of soil compaction.

Young plants are very sensitive towards competing weeds which affords weed control especially on the beginning of the cultivation. Due to intensive use of herbicides accompanying arable flora is scarce thus affecting flora, animals and biodiversity. Monocultures increase the risk on biodiversity as well as the risk for pest infestation (e.g. European corn borer *Ostrinia nubilalis* and Western corn root worm *Diabrotica virgifera*) with needs of additional pest control. Table 9-6 summarises risks associated with the cultivation and use of maize (whole plant) versus rotational fallow land.

Table 9-6 Risks associated with the cultivation of Maize (total plant harvested) compared to the reference system rotational fallow land

Type of risk	**Affected environmental factors**								
	Soil	**Ground water**	**Surface water**	**Plants / Biotopes**	**Animals**	**Climate / Air**	**Land-scape**	**Human health and recreation**	**Bio-diversity**
Soil erosion	negative		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of SOM	negative			negative[1]	negative[1]				negative
Soil chemistry / fertiliser	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Nutrient leaching		negative							
Water demand		negative		negative	negative				neutral
Weed control / pesticides		negative[1]	negative[1]	negative[1]	negative[1]				negative[1]
Loss of landscape elements				neutral	neutral	neutral	neutral	neutral	neutral
Loss of habitat types				**neutral / negative[1]**	**neutral / negative[1]**				**neutral / negative[1]**
Loss of species				**neutral / negative[1]**	**neutral / negative[1]**				**neutral / negative[1]**

1: Negative impact can be minimised by crop rotation e.g. winter wheat

9.4.5 Triticale (use of whole plant)

An intensive cultivation of cereal like triticale is linked with negative impacts on the environment compared to fallow land as a reference system. Harvesting and use of the whole plant (grain and straw) as in biogas plants will definitely affect soil quality as soil organic matter will decrease. It has to be compensated by organic fertiliser. In case of bio gasification (anaerobic digestion) the residues could balance the soil organic matter to a certain extent. Erosion effects due to lacking soil coverage are low and can be minimised after harvesting with succeeding crops (e.g. Sorghum). Soil and groundwater will additionally be affected due to intensive maintenance, use of fertiliser as well as weed and pest control. An additional issue might be the regional scarcity of groundwater for irrigation at least part time of the year, as it is for example in Punjab / India (see e.g. Doublet et al. 2012/). Intensive cultivation and maintenance is responsible for soil compaction and as a consequence there will be impacts on plants / biotopes and biodiversity. Table 9-7 summarises risks associated with the cultivation and use of triticale (whole plant) versus rotational fallow land.

Table 9-7 Risks associated with the cultivation of Triticale (total plant harvested) compared to the reference system rotational fallow land

Type of risk	**Affected environmental factors**								
	Soil	**Ground water**	**Surface water**	**Plants / Biotopes**	**Animals**	**Climate / Air**	**Land-scape**	**Human health and recreation**	**Bio-diversity**
Soil erosion	**neutral / negative**[2]		negative						
Soil compaction	**neutral / negative**	negative		negative	negative				negative
Loss of SOM	negative			negative[2]	negative[2]				negative
Soil chemistry / fertiliser	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Nutrient leaching		negative							
Water demand		negative		negative	negative				neutral
Weed control / pesticides		**neutral / negative**[1,2]	**neutral / negative**[1,2]	**neutral / negative**[1,2]	**neutral / negative**[12]				**neutral / negative**[1,2]
Loss of landscape elements				neutral	neutral	neutral	neutral	neutral	neutral
Loss of habitat types				**neutral / negative**[1,2]	**neutral / negative**[1,2]				**neutral / negative**[1,2]
Loss of species				**neutral / negative**[1,2]	**neutral / negative**[1,2]				**neutral / negative**[1,2]

1: Negative in case of short stemmed varieties;
long-stalked varieties afford less weed control
2: Negative impact can be minimised by crop rotation (succeeding crops, e.g. Sorghum)

9.4.6 Rapeseed (ploughing of straw)

Rapeseed is generally grown on deep loamy grounds and requires adequate lime content and constant water supply. On heavy soils the production requires good nutrient supply with homogeneous precipitation. Both shallow and sandy soils lead to minor yields as rapeseed needs a high rooting depth. High efforts in weed / pest control is necessary as rapeseed is sensitive against diseases (e.g. fungi) and certain vermin beetles (e.g. cabbage stem flea beetle *Psylliodes chrysocephala* and cabbage stem weevil *Ceutorhynchus napi*). Furthermore rapeseed needs high doses of nitrogen (110-220 kg / ha) with an increased danger of nutrient leaching and eutrophication especially on groundwater. With a fruit : straw ratio of about 1 : 2,9 /Kaltschmitt et al. 2009/ ploughing of straw after harvesting e.g. in case of biodiesel production can contribute to soil balance although the residues provide high nitrogen doses in the soil thus enhancing the risk of nutrient leaching.

Potential impacts on soil fertility can be minimised with rotational cropping e.g. using rapeseed as a winter crop. Due to its intensive rooting and a dense coverage it is often used as a starter crop for early wheat seeds. Although rapeseed is cultivated in monocultures thus affecting the biodiversity of epigeous fauna the blossoms attract flower-visiting insects with a promoting effect on animals and biodiversity (Table 9-8).

Table 9-8 Risks associated with the cultivation of rapeseed compared to the reference system of rotational fallow land

Type of risk	Affected environmental factors								
	Soil	Ground water	Surface water	Plants / Biotopes	Animals	Climate / Air	Land-scape	Human health and recreation	Bio-diversity
Soil erosion	neutral / negative[1]		negative						
Soil compaction	negative	negative		negative	negative				negative
Loss of SOM	neutral / negative[1,2]			neutral / negative[1,2]	neutral / negative[1,2]				neutral / negative[1]
Soil chem. / fertiliser	negative	negative							
Eutrophi-cation	negative	negative	negative	negative	negative				negative
Nutrient leaching		negative	negative						
Water demand		negative		negative	negative				neutral
Weed control / pesticides		negative	negative	negative	negative				negative
Loss of landsc. el.				neutral	neutral	neutral	neutral	neutral	neutral
Loss of hab. types				neutral / negative	negative / positive[2]				negative / positive[2]
Loss of species				neutral / negative	negative / positive[2]				negative / positive[2]

1: Negative impact can be minimised in case of double cropping, if used as a starter crop
2: Negative because of low biodiversity due to monoculture but increased number of blossom visiting insects during flowering period

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Suggested citation:

Keller, H. *et al.*, Environmental assessment of SUPRABIO biorefineries, IFEU and IUS, Heidelberg, 2014